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16. Abstract
The purpose of the National Highway Traffic Safety Administration project titled "An Exploration of Vehicle-Based Monitoring of Novice Teenage Drivers" was to systematically identify and structure the range of alternatives that might use vehicle-based sensing to mitigate the novice teen driver safety problem. The project sought to identify a range of promising approaches, ascertain user needs and preferences, indicate the research required to evaluate and compare alternatives, and provide recommendations for carrying this work forward. This report describes the activities and findings of the project. A series of literature searches was conducted to identify key research and reports related to teen driver behavior and monitoring devices. Focus groups of teen drivers and their parents were conducted to explore issues of motivation, preference, and usability of teen monitoring systems and concepts. A workshop on in-vehicle monitoring of novice teen drivers was held to share the project's initial findings and ideas with a diverse group of outside experts and stakeholders, and collaborate to identify opportunities and needed steps to take full advantage of driver monitoring capabilities. A research study was conducted to collect new data on teen driving under naturalistic conditions. Researchers instrumented the personal vehicles driven by novice teen drivers and recorded extensive detail on their behavior in the course of naturally occurring travel. Results suggest that teens classified as high risk based on early driving behaviors and crash records engaged in secondary tasks, high risk secondary tasks, and speeding behaviors significantly more frequently than did the low risk drivers. Results also suggested that the high risk teens performed extreme levels of longitudinal deceleration during "normal," baseline driving significantly more frequently than did the low risk drivers. Based on the findings of these tasks, a set of high priority research needs was developed, and a research plan was devised to propose research to address these needs.

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Executive Summary

Novice teen drivers have exceptionally high rates of crash involvement. Despite efforts in driver training, graduated licensing, enforcement, and safety education, novice teen drivers still have per-mile crash rates several times higher than mature drivers. Recent advances in technology now make feasible another means of addressing this problem – the use of in-vehicle technology to sense and respond to driver behavior. Sensing and communications technology permit real time feedback to drivers, alerts to parents, summary reports on performance, coaching to correct driving errors, real time vehicle adaptation to current conditions, and the integration of driver actions into programs that provide positive or negative consequences.

Since these technologies have only recently become feasible for consumer use, there is little research or real-world experience that suggests how effective they are or what features are most effective. Some of the earliest implementations of driver monitoring devices were in vehicle fleets, where fuel efficiency and vehicle location tracking were often the primary purposes of monitoring. Fleet monitoring devices, however, have been used to monitor behaviors that are direct or indirect measures of safety, and studies have shown dramatic improvements in a range of safety-relevant behaviors.

There are now a number of ongoing studies to evaluate driver monitoring strategies for teen drivers. Although there have been few published reports with rigorous experimental designs and analyses, it appears that monitoring can significantly reduce the occurrence of risky behaviors, especially among the most risk-prone teens. While initial findings show promise, there is currently little evidence to help guide the development and implementation of teen driver monitoring systems and programs. Furthermore, there has been little advantage taken of vehicle adaptation possibilities. Teen monitoring is a complex application that requires careful consideration of required functions, technologies, interfaces, implementation strategies, and stakeholder concerns.

This report summarizes the findings of a project titled “An Exploration of Vehicle-Based Monitoring of Novice Teenage Drivers,” which was initiated by NHTSA to assess the state of the art and the state of practice in teen driver monitoring. Furthermore, a series of new research projects were conducted to provide data on the effects of monitoring on teen drivers, assess teens’ and parents’ opinions and preferences for monitoring, and assemble an expert workshop on teen driver monitoring to establish priorities for future efforts in the field. Finally, based on the results of these tasks, a research plan was created to address high priority research required to advance the field of teen driver monitoring, culminating in a major field evaluation of monitoring systems.

The project began with a thorough literature review to identify key research, reports, and statistics related to teen driver behavior and monitoring devices. This provided important background on teen behaviors, characteristics, and situations that are associated with risk, and therefore important to consider in a monitoring system. The initial stage of the project also included a review of current and emerging technologies that could be used in monitoring systems.

In parallel with the information search and analytic activities of this project, a research study was conducted to collect new data on teen driving under naturalistic conditions. The study was sponsored by the National Institute for Child Health and Human Development with additional

funding from NHTSA. The purpose of the study was to fill in the research gaps in teen driving research related to 1) assessing the prevalence of teen driver engagement in risky driving behaviors and 2) understanding which behaviors are associated with an increase in a teen driver's crash/near-crash risk. Researchers instrumented the personal vehicles driven by 42 novice teen drivers and unobtrusively recorded extensive detail on their behavior in the course of naturally occurring travel over 18 months. Participants were grouped into high risk and low risk groups based upon their involvement in crashes and near-crashes during the first six months of driving. A crash was operationally defined as any physical contact with an object where kinetic energy is measurably transferred. A near-crash was operationally defined as any circumstance that required a rapid, evasive maneuver by the subject vehicle or other vehicle, to avoid a crash. Results suggested that the high risk teen drivers engaged in secondary tasks, high risk secondary tasks, and speeding behaviors significantly more frequently than did the low risk drivers. Results also suggested that the high risk teens performed extreme levels of longitudinal deceleration during "normal," baseline driving significantly more frequently than did the low risk drivers. It is not evident to what extent the relationship of these behaviors to the driver risk categories is a causal one. That is, are the "high risk" drivers at greater risk *because* they engage in these behaviors or are the behaviors merely correlates that suggest who the at-risk drivers might be? In either case, the finding may be useful for the design of teen monitoring systems. To the extent that the relationship is causal, effective feedback to teen drivers may decrease the prevalence of these behaviors, so their involvement in crashes may also be reduced. To the extent that the behaviors identify at-risk teen drivers, the information could be used to adapt warning and feedback algorithms to adjust for the greater risk.

A series of focus groups were conducted with teens and parents to explore issues of motivation, preference, and usability of alternatives. Three focus groups were conducted with teens and three were conducted with parents. All groups followed a similar discussion path that addressed the role of parents in controlling teens' driving, reactions to in-vehicle technology options and feeling about monitoring, and preferences among hypothetical monitoring systems and programs.

The project also included a workshop that brought together experts in a wide variety of professional fields related to teen safety and monitoring. The workshop objective was to share the project's initial findings and ideas with a diverse group of outside experts and collaborate to identify best opportunities and needed steps to take full advantage of driver monitoring capabilities. The workshop emphasized the functional monitoring needs and programmatic strategies rather than focusing on the sensor and communications technologies themselves. The intent was to provide insights on promising approaches and strategies, issues related to successful implementation, short-term and long-term research needs, and suggested next steps.

Finally, based on the results of the other tasks in this project, a set of high priority research needs and a recommended research plan were devised. Forty-two research needs were identified, and were organized under three major topic areas: evaluating systems and programs, system design, and use and acceptance. The research plan, which was designed to address the research needs, includes six component studies. Four of these are areas of fundamental research that will inform any program of teen driver monitoring. Another component of the recommended research approach is to foster the coordination and integration of research activities and findings by diverse entities. A final component of the proposed plan is a large scale field evaluation of the actual benefit of novice teen driver monitoring.

Table of Contents

List of Figures

List of Tables

1 Introduction

This report presents the methods, findings, and recommendations of the National Highway Traffic Safety Administration project titled "An Exploration of Vehicle-Based Monitoring of Novice Teenage Drivers." The project involved a combination of information search, analytic activity, new research, and expert/stakeholder input in order to identify issues, options, and research needs for advancing the development, use, and evaluation of teen driver monitoring technologies. As used in this report, the term "driver monitoring" refers not only to the detection and recording of driving behaviors, but also encompasses the way in which data are provided to users (e.g., real-time feedback to drivers, reports of driving performance to parents, and so forth).

1.1 Novice teen driver crash problem and driver monitoring technology

Inexperienced teen drivers have exceptionally high rates of crash involvement. In 2006, 5,658 young drivers between the ages of 16 and 20 were killed in traffic crashes, and an additional 410,000 were injured (NHTSA, 2007). Teen drivers in general have much higher per-mile crash rates than more mature drivers. For example, Kweon and Kockelman (2003) found that drivers under the age of 20 have a crash rate about 3.5 times the rate of mature drivers. But this enhanced risk for teenage drivers in general is small relative to the risk for those least mature and least experienced teen drivers. Crash rates are highest at age 16. Per-mile crash rates (for crashes of all types) for 16 year olds are about double those of 18-19 year olds. While the difference is not as extreme for fatal crashes, 16 and 17 year old drivers also have the highest crash rates for these most severe crashes (Insurance Institute for Highway Safety, n.d.). Under some driving conditions, this already extreme crash rate becomes even greater, such as when there are multiple teen passengers or during night driving.

Driver training, graduated licensing, enforcement, and safety education all have been directed at the effort to reduce novice teen driver crashes. While safety benefits have been demonstrated, in particular for graduated licensing, the benefits have yet been modest. Another approach, only explored in recent years, is to use in-vehicle technology to sense and respond to teen driver behavior. If key behaviors can be sensed, technology provides the opportunity for real time feedback to the driver, alerts to parents, summary reports of incidents, evaluations of performance, coaching to correct errors, or provision of rewards or sanctions. There are many options in terms of sensing technologies, behaviors and situations to monitor, communications strategies, information to convey, and program implementation. The effectiveness, practicality, parental and public acceptance, and social desirability of various approaches are not well understood, but some recent research studies show that monitoring technologies have the potential to be effective tools to improve driver safety.

Driver monitoring, feedback, vehicle adaptation, and reporting have been used effectively for some time in various sorts of fleet management. Controlled studies have established that driver monitoring can improve a range of safety-related behaviors in mature driver populations. One striking example comes from a study of an ambulance fleet in metropolitan Little Rock, Arkansas, where there were concerns regarding the ambulance fleet safety experience and driver performance (Levick & Swanson, 2005). Data were collected over 18 months from 26 ambulances equipped with monitoring and feedback devices. More than 250 drivers used the vehicles during the study period. The system monitored speed, acceleration, braking, cornering velocity, seat belt use, turn signal use, lights and siren use, use of parking brake, and use of backup spotters. The system provided warnings when drivers approached predetermined violation levels and then alerted drivers when a violation was recorded. There were rapid, dramatic, and sustained drops in a variety of undesirable behaviors after implementation of the system. Compared to baseline performance, driver “penalty count” rates (instances of speeding, hard acceleration or deceleration, etc.) dropped from 0.018 miles per violation to 15.8 miles per violation, seat belt violations dropped from 13,500 to 4, and vehicle maintenance costs were reduced by 20 percent.

Another study investigated the effects of monitoring and feedback on 103 drivers from the fleets of six different organizations in Israel that provided vehicles to their employees as part of their benefits program (Musicant, Lotan, & Toledo, 2007). An in-vehicle data recording system was installed to provide driving feedback to drivers concerning episodes of hard braking, swerving, high vehicle speed, and GPS location data. Drivers could receive feedback through text messages and on a dashboard display that used colored lights to indicate driving performance (green is moderate, yellow is intermediate, red is aggressive). Drivers were also provided with monthly reports that indicated their overall performance for each drive, as well as detailed feedback about particular types of vehicle maneuvers, comparisons with performance in previous months, and comparisons with other fleet drivers. From these data, risk indices were calculated based upon previous crash records as well as the driving parameters collected by the system (e.g., trip time, vehicle location, number of hard braking maneuvers, etc.). After baseline data were collected for a period of eight weeks, feedback regarding braking patterns, speed selection, acceleration around corners, and other unsafe driving maneuvers was stored on a website that the drivers could access. Results indicated a 38 percent reduction in crashes per 1,000 miles traveled within the first two months of receiving feedback. No recurring increase in crash rate was reported through the first seven months of driving with feedback, thus indicating that the reduction in crash risk remained stable over time. In another study using the same system, Toledo, Musicant, and Lotan (2008) examined a different group of 191 drivers. The results showed a significant reduction of 38 percent in overall crash rates, but not in at-fault crash rates. However, the remainder of the fleet (which was neither monitored nor exposed to feedback) showed a 19 percent reduction from the period before exposure to feedback to the period after exposure. There was also a significant correlation between crash rate and the calculated risk index for the monitored drivers. Fleet studies such as these show that driver monitoring and reporting systems can have dramatic effects in improving safety-related behaviors.

Another technology widely used in large commercial vehicles is speed governors, which limit trucks’ speeds to some predetermined limit. Most vehicle fleets use speed governors, and they are present in more than three quarters of large commercial trucks (McDonald & Brewster, 2008). The Insurance Institute for Highway Safety recommends the use of truck speed governors to reduce crashes, and Johnson and Pawar (2005) also found speed governor benefits with regard to reducing fuel consumption, emissions, and vehicle maintenance costs. The Federal Motor Carrier Safety Administration is also pursuing the development of on-board monitoring and reporting systems for large trucks (Misener et al., 2007).

Truck fleets, however, include experienced professional drivers, not teen novices, and the instrumented vehicles essentially constitute a workplace environment with no personal ownership of the vehicle. Therefore there is a question of how effective monitoring might be for novice teen drivers in their personal travel. There are only limited published data on this, but results appear promising. Various reports from manufacturers of monitoring systems or insurance companies implementing programs have lacked detail or been anecdotal. A number of more systematic evaluations of teen driver monitoring are currently ongoing, including studies in Minnesota, the greater Washington, DC, area, and Israel. The two most detailed analyses at this time come from teen driver research conducted in rural Iowa. McGehee, Raby, Carney, Lee, and Reyes (2007) provided the DriveCam™ system to families with teen drivers. In this study, an in-vehicle feedback system consisting of accelerometers and cameras provided both real-time driving performance feedback to the teen drivers and post hoc feedback to both the teens and their parents. When teens performed hard decelerations or hard swerve maneuvers past a set *g*-force level, a light on the data collection system would illuminate and a segment of video and driving performance data would be saved in a file. Data were automatically downloaded at the teen's high school parking lot. These segments of video were consolidated on a CD-ROM and mailed weekly to the parents and teens for them to review. The results from this study indicated that teens who frequently engaged in these risky driving performance maneuvers reduced the frequency of such maneuvers by 72 percent in the first 9 weeks that the feedback device was installed in their vehicles. By the second 9-week period, the risky teens were performing at comparable levels to the teens with low frequency of risky behaviors (McGehee, Raby et al., 2007). These levels were then maintained throughout 36 weeks of feedback. The low-frequency teen drivers did not exhibit any reduction, likely due to a floor effect. Teens were only compared to themselves – there was not a control group.

A follow-up report by McGehee, Carney, Raby, Lee, and Reyes (2007) with the same group of drivers found that the benefits of teen driver monitoring were maintained for 8 weeks after the feedback and reporting period had ended. Except for one high-frequency driver, the results showed that the high-risk drivers maintained a lower frequency of risky events during the second baseline period. This indicates that driving habits were successfully changed during the feedback period, and that the changes were durable. It is important to note that for this particular monitoring and feedback system, the downloaded files required significant post-processing before the parents could receive feedback (to weed out false alarms and categorize the events). Such a system could be difficult to implement on a widespread basis due to the significant resources required to perform this post-processing. It should be noted that some teens in this study had been driving for quite a while before the study began, due in large part to the laws in Iowa that allow a teen to receive a school driving license at age 14.5 (solely to drive to and from school events).

In summary, fleet studies and teen driver studies suggest that at least some forms of driver monitoring and feedback are technically feasible and apparently effective. However, there is little indication of what devices and strategies will work best with teen drivers and how effective such systems will ultimately prove to be. Furthermore, most studies have used more than one feedback strategy (e.g., immediate alert and monthly report), which complicates the interpretation of the effectiveness of any individual strategy.

NHTSA recognized the emergence of feasible teen driver monitoring technologies and also raised questions about the effectiveness of some of the early consumer products in this area. In 2004, NHTSA organized a "Workshop on Vehicle Technologies to Aid Teen Drivers" (NHTSA, 2006). This workshop was an important precursor to the present project. It established that an expert community from a range of stakeholder groups viewed monitoring technologies as feasible and as having potential to reduce the teen driver problem. It also identified a range of important issues and potential barriers to effective implementation. The participants also identified a variety of roles the Federal government, and NHTSA in particular, might play in promoting progress in this area.

The focus of the 2004 workshop was to explore ways to reduce teenage driver fatalities and injuries by using vehicle-based technologies to detect and report unsafe driving behaviors. Participants were invited to attend the workshop based on their expertise, interest, and previous work in areas related to teenage driver safety. Among the participants were experts on teen behavior, vehicle technologies, law enforcement, insurance programs, driver education, crash statistics, and research methods. There was general consensus that teen monitoring systems were technically feasible, but products on the market at that time must be improved. Given such improvements, participants agreed that teen monitoring systems could potentially be valuable and that a teen driver monitoring initiative would be worth implementing. Teen monitoring systems have the potential to reduce the crash rate for young drivers, although the size of the safety benefit was not yet known. Research needs included determining which behaviors to monitor and which implementation models are most feasible and likely to succeed. Implementation of teen monitoring programs requires more research, which could be done in parallel to basic research on behavior and technology. The federal government could have a role in funding research to collect naturalistic driving data on the appropriate age group, developing improved monitoring systems, evaluating existing systems, developing minimum standards for devices, creating a list of “approved devices”, promoting enabling technologies, supporting standards for commonality of vehicle data and connectivity, informing legislators of the value of these systems (if proven), providing possible model legislation, and accelerating development of the concept through research and by working with stakeholders.

1.2 Project objectives

The purpose of the National Highway Traffic Safety Administration project titled “An Exploration of Vehicle-Based Monitoring of Novice Teenage Drivers” was to systematically identify and structure the range of alternatives that might use vehicle-based sensing to mitigate the novice teen driver safety problem. Based on the results of these activities, the final goal was to identify the associated research activity that will be required to successfully advance the application of driver monitoring to teen crash reduction. The specific project objectives indicated for the project were the following:

- Collect data on real world teen driver behaviors to identify behavioral indicators to use in a teen driver monitoring system.
- Identify stakeholders, including representatives of vehicle and supplier companies, insurance, driver education, and licensing, to determine their needs, roles, and interests in participating in the development and evaluation of a teen driver monitoring system.
- Identify preliminary options for system design and deployment.
- Develop research plans for next steps needed to develop and evaluate in-vehicle teen driver monitoring concepts.

The project sought to identify a range of promising approaches, ascertain user needs and preferences, indicate the research required to evaluate and compare alternatives, and provide recommendations for carrying this work forward. It included a broad review of literature and technology, focus groups with teens and their parents, new data collection from a naturalistic driving study, and input from the broader community of experts and stakeholders. A "Workshop on Novice Teen Driver Monitoring" provided the opportunity for expert perspectives from a wide range of stakeholders and disciplines. The ultimate purpose of this project was to define the key research questions that must be answered to advance the field of teen driver monitoring, and to create a structured plan for conducting the highest-priority research studies.

1.3 Organization of this report

This report describes the activities and findings of the project. Section 2 describes the information search related to driver behavior, monitoring-related technology, and implementation strategies. Section 3 presents the findings of focus groups of teen drivers and the parents of teen drivers, regarding their attitudes, preferences, and motivations related to alternative strategies for driver monitoring. Section 4 describes a major workshop on teen driver monitoring which brought together leading experts and stakeholder groups to discuss strategies and research needs. Section 5 presents findings from a naturalistic driving study in which the behavior of 42 teen drivers was recorded during the course of their normal driving. Finally, Section 6 incorporates the project findings into a set of key research needs and puts forth a recommended program of research.

2 Information search for novice teen driver monitoring system requirements

2.1 Overview of search activities

A series of literature searches was conducted to identify key research and reports related to teen driver behavior and monitoring devices. Search activities included keyword searches of major publication databases (e.g., TRIS, Google, FirstSearch, SafetyLit) and scans of relevant websites. The searches identified more than 300 relevant documents, which were obtained and classified according to topic (e.g., monitoring technology, risk taking, visual scanning) and assigned keywords for indexing. Documents were then reviewed and relevant information was extracted and summarized in tables, described below. Additional searches were conducted to identify driver safety programs that currently use monitoring technology or that suggest key teen driver factors to consider for such systems.

2.2 Behaviors, situations, and characteristics to monitor

Crashes and near-crashes are rare events, and a goal of monitoring systems should be to identify and help correct, or compensate for, risky behaviors, situations, and characteristics before a crash occurs. It is therefore critical to identify risk factors that may lead to a crash or increase the severity of a crash.

An extensive literature search was conducted to identify the behaviors and situations associated with teen driver risk. Many related behaviors and situations were identified, although the empirical evidence for the relationship to crash risk was well established for some and tenuous for others. In order to organize and summarize this literature, a categorization was devised, which is reflected in Appendix A. The findings are grouped under four major headings in Appendix A: teen driver behaviors (Section A1); driving situations (Section A2); problem driver characteristics (Section A3); and a reference citation section for the Appendix A review (Section A4).

The array of potential behaviors and situations that might reasonably be measured is expansive. Factors such as vehicle speed and acceleration/deceleration rate are relatively easy to measure and appear to be frequent choices, but it is not known whether other measures may be better alternatives or useful supplements. Furthermore, the most appropriate factors to measure might depend on the way in which a teen monitoring program is implemented. For example, the optimal behaviors to monitor for a system that provides real-time feedback to teen drivers might not be the same as the optimal behaviors to monitor for a system that provides weekly reports to parents.

The behaviors, situations, and characteristics in this section and in Appendix A are described without regard to the feasibility of actually monitoring them. Feasibility of monitoring approaches is considered in Section 2.3 of this report, which addresses enabling technologies. The prioritization of factors to measure must consider the relevance to safety and improving driver skills, as well as the cost, practicality, and acceptability of various monitoring approaches.

The major categories of *driver behavior*, reflected in Appendix A1, are the following:

- vehicle control;

- risky/aggressive acts;
- in-vehicle activity;
- hazard recognition/risk perception/situation awareness; and
- driver status.

Vehicle control measures include such aspects as lane keeping, curve negotiation, speed choice, turning, car following, gap acceptance, error recovery, passing/overtaking, and backing. Risky or aggressive driving acts include such things as high speed, non-compliance with right-of-way, hard braking, tailgating, dangerous overtaking, failure to obey traffic control devices, and intentional risk taking and showing off. In-vehicle activity includes such behaviors as use of communication and entertainment devices while driving, using vehicle displays/controls, interaction with other vehicle occupants, reading, eating/drinking, smoking, dancing/singing, and personal hygiene. The category of hazard perception and situation awareness includes the timely recognition of hazards and potential hazards, proper visual search, mirror use, and the appreciation of the degree of risk in a given situation. Driver status includes conditions of drowsiness, impairment (drugs and alcohol), workload, and physiological arousal.

There are also particular situations that increase teen driver risk. Although these are not "behaviors," it may still be useful to monitor them, since they may be incorporated into decision algorithms or driver feedback. For example, warnings or feedback about vehicle speed or tailgating might be different on wet road surfaces. Or tolerance for vehicle control measures might be tightened if multiple passengers are detected in the vehicle. Key teen *driving situations* for potential monitoring were categorized under the topics of:

- passenger presence;
- environmental conditions;
- trip characteristics;
- roadway characteristics; and
- specific problem scenarios.

Passenger presence includes the age, gender, and number of passengers and also their relationship to the driver. Environmental conditions include weather and light conditions. Trip characteristics include trip purpose, time of day, and vehicle attributes. Roadway characteristics encompass features of road geometry, road surface, road type, intersection features, and highway-rail grade crossings. There are also specific scenarios (combinations of features) that may be particularly related to crash risk.

Finally, some teens have personal characteristics that are generally associated with risky driving. While these may be known to be correlates of crash risk, individual differences are not a primary focus of this project. However, it is still useful to consider some of the major factors and whether they may be potentially incorporated into a monitoring system. Teen *driver characteristics* were categorized under the topics of:

- personality;
- gender; and
- experience.

Personal characteristics include driver age, gender, and experience; risk taking propensity and sensation seeking; aggressiveness; and mental disorders such as ADHD. Gender is itself a relevant primary factor but also interacts with various other factors. Driver experience includes the amount of driving, unsupervised driving, and exposure to various driving situations.

Appendix A summarizes relevant findings from the literature for all of these various behaviors, situations, and to a more limited degree, driver traits. There are certain other potential measures, not included in Appendix A, which might also prove useful in modifying driver behavior to improve safety. It is possible that some factors not directly related to safety might nonetheless act indirectly. For example, feedback and reporting related to fuel efficiency, driving costs, or vehicle emissions ("green driving") might modify teen driver behavior in a way that results in safer driving. If the behavioral outcome results in improved teen driver safety, behaviors related to fuel use or direct measures of fuel consumption might also be monitored and incorporated into safety-oriented teen driver monitoring systems.

Although the literature suggests a wide range of teen behaviors that are associated with driving risk, there is currently an inadequate empirical basis for selecting a specific set of behaviors for use in monitoring systems. Decisions need to be made regarding both the behaviors that are directly sensed by the system and the descriptive or summary information that is provided as feedback to the driver, parent, or other involved party. Despite the limited guidance from the literature, some behaviors stand out as most promising for further investigation because they have been cited frequently as major contributors to teen occupant crashes and injuries. Although feasibility and cost of technologies are not of primary interest here, all of the recommended measures can be acquired using extant technology.

- Vehicle speed relative to the speed limit
- Hard acceleration/deceleration
- Seat belt use in all occupied seating positions
- Number of passengers (ideally, system would identify peer-age passengers)
- Forward headway and time-to-collision
- Engagement in distracting activities (e.g., use of electronic devices, eyes-off-road)

2.3 Enabling technologies

The information search for this project also included consideration of the technologies that will be used to support teen driver monitoring systems. A technology review was conducted that included literature review, review of current and planned products, identification of current and emerging sensor and communications technologies, and contacts with technical experts, the automotive industry, and device manufacturers. The review represents a snapshot of the state of technology; because of the dynamic nature of technology, it is expected that new technologies will be available in a few years, and current technologies may improve in quality or decrease in price.

Technology has two roles in the development of a teen driver monitoring system. First, technology is required to achieve the system functions ("component technology"). For example, a function to provide feedback about speed limit changes requires technology components to detect vehicle location and speed within a geographical database that records speed limits. Second, technology may also be required to enable specific methods of system operation ("enabling technology"). For example, biometric technology may be needed to record the identity of a driver so that certain system functions are enabled or modified to the needs of that individual.

The technology required to enable the functions of a teen driver monitoring system can be divided into five categories: (1) measurement technology and sensors; (2) communication technology; (3) interlocks and limiters; (4) driver feedback; and (5) driver identification. Specific technologies that can be used to enable system functions are described in the following sections.

2.3.1 Measurement technology and sensors (including interlocks)

Measurement technology and sensors present the system with the ability to collect relevant safety data that allow the system to monitor some aspects of driving performance or the occurrence of unsafe driving behavior.

GPS: GPS allows the system to monitor the specific location of the vehicle in real time. GPS data combined with a geospatial database allows the system to monitor roads the vehicle has been driven on or even specific addresses where the vehicle has been parked. GPS can also be used to calculate the speed of a vehicle, which offers a low cost solution to sense and warn the driver of a speed limit violation. While accurate at moderate to high speeds, commercially available GPS cannot resolve vehicle location with sufficient resolution to be used for any application that requires low-speed precision.

OBD-II (Second generation on board diagnostics): Every vehicle sold in the United States since 1996 has an OBD-II port. Unfortunately, a communication standard does not exist and there are five different communication protocols. The OBD-II port is primarily used in the automotive industry for assisting mechanics in diagnosing vehicles. However, useful safety data such as vehicle speed, engine rpm, and throttle position can be monitored through the OBD-II port. Devices are available that convert the OBD-II signals to serial communication. Also available are wireless Bluetooth OBD-II communication tools that wirelessly port OBD-II data to a PC, PDA, or smartphone. Beginning in 2008, every vehicle sold in the United States must be equipped with the ISO 15765 CAN communication protocol which should help standardize transmitted information and how it is coded.

Accelerometer: Accelerometer data can be used to determine if a crash or reckless driving has taken place. Some current driver monitoring systems use an accelerometer to detect sudden changes in vehicle acceleration that correspond to possible crash occurrences. Acceleration thresholds can be selected as triggers for the system.

Video recording: Digital video camera technology has enabled the development of small, unobtrusive recording devices and storage media, as well as easy transfer to personal computers via portable memory cards or wireless data connections. Some driver monitoring systems continuously record video footage of the environment in front and inside of the vehicle. Recording devices can be linked to sensors to allow for event-based recording, which reduces video storage requirements and allows reviewers to focus on events of interest. The video footage can be saved and uploaded to a server where a parent or coach can log on and review driving performance and behavior. Some systems also include “panic buttons” that allow the driver to manually activate video recording.

Passenger occupancy sensor: Studies have shown that teens are at much greater risk when one or more peers are present in the vehicle. Thus, it would be helpful to know if a teen is driving with passengers. This is possible with piezoelectric occupant seat sensors that accurately measure passenger weight. Similar sensors are currently used in vehicles to characterize passenger weight for safe airbag deployment and enhanced belt reminders for passengers. These same sensors could be used to determine if passengers are present while a teen is driving. It would also be advantageous to be able to determine the ages and genders of drivers and passengers, as these group composition factors can significantly influence the likelihood of risky behaviors and crashes, though technology to achieve this does not currently exist in any feasible form.

In-vehicle audio recording: Stereo systems and boisterous behavior should not compete for driver attention. Monitoring in-vehicle sound levels could prove to be an effective way to mitigate distractions from these sources. A microphone can be placed inside the vehicle and connected to a data acquisition board where the audio signals can be processed. If the decibel level reaches an unacceptable limit the system is invoked. Similar technologies are employed in high-end vehicles to ensure the radio is at a constant volume regardless of speed. In newer versions of this technology the driver can be warned, and if the situation persists, parents could be notified or the sound system could be muted.

Cellular phone detector: A number of commercially available devices exist to detect the presence or use of a cell phone. Typical systems detect the RF signals emitted by cell phones while they are turned on, even when they are not currently in use. Although capable of detecting signals for distances up to 100 feet, they often allow a user to set the sensitivity down to detect phones within a radius of as little as 6 feet. Basic devices are inexpensive, but to be useful in a teen monitoring system, a cell phone detector should be able to recognize individual cell phones (to identify whether it is the driver or a passenger using a phone) and respond by blocking cell phone use, issuing an alert to the driver, or providing a report to a parent or authority. Technologies to detect and identify individual cell phones are not currently available for consumer applications.

Cellular phone blocker: About half of teen drivers report using a cell phone while driving (Children's Hospital of Philadelphia and State Farm, 2007), and this distracting behavior inhibits driving performance and contributes to crashes (Greenberg et al., 2003; Mayhew, Simpson, & Pak, 2003). Cell phone blockers or jammers can disable cell phones so that teens are not able to use the cell phones while driving. Although some technologies that jam cell phone signals are illegal for civilian use, certain technologies that prohibit use of a single phone may be legal. For instance, the Key2SafeDriving device developed by researchers at the University of Utah uses a smart key to transmit a disabling signal to a selected cell phone using Bluetooth or RFID signals, though it does not prohibit 911 calls (www.key2safedriving.net). The system sends all incoming calls directly to voice mail. Cell phone blocking systems must consider methods to allow passengers to use cell phones and to allow drivers to use cell phones while parked or in emergencies.

Infrastructure Information Databases: Road characteristics such as speed limits, curves, construction sites, or road hazards can be stored in geospatial databases. GPS sensor information can be used to query data in real-time. The data allows the system to tell the driver what the speed limit is or if there are any road hazards present such as upcoming construction sites or poor weather conditions.

Smart Wheel: Research at Northeastern University has led to the development of the Smart Wheel prototype system. The Smart Wheel has embedded sensors that continuously monitor the driver's skin conductance, pulse, skin temperature, respiration rate, and grip force. These physiological parameters can estimate the driver's current cognitive/emotional state to infer driver fatigue or alertness.

Road friction measurement sensor: Novice teen drivers do not possess the necessary experience to effectively handle degraded road conditions. Tire-road friction measurement sensors can actively measure the coefficient of friction between tires and the road. This information can be used to warn drivers of slippery conditions and to provide overspeed warnings.

2.3.2 Communication technology

Communication-enabling technologies allow a particular sensor or device to transfer its data to an onboard or offboard computer, smartphone, or PDA where the data can be processed to monitor driving behavior.

Bluetooth communication: Bluetooth communication offers a wireless solution for sensors to communicate with a teen driver monitoring system computer, or mobile phone, or other portable electronic device. Bluetooth is a low power communication protocol that interfaces with many mobile phones and computers wirelessly. The maximum communication distance is about 30 feet, which limits the risk of hacking. Serial to Bluetooth converters can be purchased for about 70 dollars, which means that almost any sensor could conceivably be modified to communicate via Bluetooth.

ZigBee communication: ZigBee is a relatively new high-level communication protocol that uses a low-power digital radio signal to provide low bandwidth wireless communication over a small area. ZigBee is a cheaper alternative to Bluetooth communication and uses less electricity.

802.11 wireless communication: Wireless communication enables a vehicle to automatically upload data recorded in one trip to a central server. This technology could enable the uploading of acquired driving data to a PC where the parent can easily access and review driving performance. This eliminates the need to swap data from memory cards or USB flash drives.

Cellular modems: Cellular modems allow real-time updates to appropriate parties (e.g., parents or authorities). This allows the system to automatically send out text messages or emails to parents if the teen is driving in a particular area at a particular time of day or speeding. It also allows the system to communicate with authorities if an accident has taken place.

2.3.3 Interlocks and limiters

Interlocks prevent drivers from moving the vehicle or prevent access to particular vehicle features unless certain conditions are met. Interlocks could prevent or limit access to virtually any vehicle feature based on any conditions that can be sensed. A few of the most promising interlock options are described below.

Seatbelt interlock: At least 58 percent of 16 to 20 year-olds killed in traffic crashes were unbuckled at the time of the crash (NHTSA, 2007). Therefore, ensuring that teenagers use seatbelts is an important part of any teen driver monitoring system. A seatbelt interlock could forbid teen drivers from starting the car without the seatbelt fastened. Systems may also require all passengers to buckle if seat belt and occupant sensing are present in all seat positions.

Entertainment system interlock: Unlike the systems described above, an entertainment system interlock would not disable the vehicle, but would disable some or all features of the vehicle’s entertainment system until particular criteria are met (e.g., seat belts buckled, speed reduced to acceptable level).

Speed limiter: Technologies are currently implemented to limit vehicle speed capabilities. For instance, the vehicle's speed could be limited to a criterion speed through the use of a governor or the engine's horsepower could be limited to prevent racing and reckless acceleration.

2.3.4 Driver feedback technology

Feedback enabling technologies facilitate the communication of the system with a driver, parents, or other authority figures. Feedback may occur in real-time or near-real-time. Alert timing and modality must be chosen with careful consideration of the abilities and limitations of novice drivers. For instance, in-vehicle displays may draw drivers' attention away from the road, and therefore should not be used at a time when the driver must identify and respond to an on-road hazard.

In-vehicle display: In-vehicle displays can be utilized to provide the driver with visual cues or warnings. They also can be used to display what a camera sees so the driver can see in places he or she normally couldn't. Many vehicles have this technology implemented to provide assistance while backing. In-vehicle displays can be represented by various technologies that can include LCD panels and plasma screens that can display information (e.g., camera view), or simple LED's that flash to provide drivers with a warning.

Head-up display (HUD): HUDs allow drivers to simultaneously keep their eyes on the road while monitoring vehicle parameters such as speed and fuel level. HUDs can also provide supplementary safety features such as night vision, and enhance the view of lane markings, street signs, pedestrians, or other vehicles in low visibility conditions.

Speech recognition: In-vehicle systems that use speech recognition minimize drivers' need to look away from the road and perform manual tasks, potentially reducing visual distraction (Ranney, Mazzae, Garrott, & Goodman, 2000). This may be especially valuable for teens, because research indicates that they take long glances away from the road more often than adults (e.g., Donmez, Boyle, Lee, & Scott, 2005; Olsen, Lee, & Simons-Morton, 2006) However, it is also important to keep these systems simple to facilitate learning the voice commands. Many vehicles are already equipped with such speech recognition to interact with on-board systems. The Ford SYNC system allows drivers to bring nearly any mobile phone or digital media player into their vehicle and operate them using voice commands, the vehicle's steering wheel, or radio controls. Software has also been developed to implement speech recognition on smartphones or PDAs.

Audio and voice alerts: Voice-generated auditory alerts can be given through the vehicles' stereo systems or independent speakers. Many navigation systems use this technology to issue directional prompts to drivers.

Haptic feedback: Often, the most effective way to convey messages to drivers is via tactile communication. This is especially true for emergency situations where immediate corrective action is needed. Vibration actuators can be placed in the seat or steering wheel to notify the driver of an imminent hazard. For example, vibrating actuators can be placed in the left and right side of the driver seat. If the system detects the car is leaving the lane on the left side, the left part of the seat is vibrated. Likewise, the right side of the seat is vibrated if the system detects the car leaving the right side of the lane.

2.3.5 Driver identification technology

Novice teen drivers often share a vehicle with parents or siblings. In this situation, it is important that the teen driver monitoring system "knows" who is driving and engages teen-specific monitoring features only when a teen is driving. A simple on-off switch could be used, but this would allow teens to easily disable the system. A password could be used to prevent unauthorized disabling of the system, but passwords could be guessed by teens or forgotten by parents. For truly reliable driver identification, more robust technologies must be explored.

Smart keys: A smart key contains a computer chip that links a specific key to a specified driver, to the vehicle monitoring system. Smart keys have been used in vehicles for many years to identify drivers for purposes such as automatically adjusting the driver's seat to the keyholder's preferred position. Teens may be issued keys that identify the driver as a teen and therefore engage the teen monitoring system. Monitoring would be limited to specific keys, therefore not impose limits on other persons using the vehicle. Ford announced that it plans to release a smart key system intended specifically for teen drivers on some 2010 models. If a teen is driving, the MyKey system would limit vehicle speed to 80 mph, engage a more assertive enhanced seat belt reminder system, limit stereo volume, and engage other features intended to improve teen safety. Smart keys are typically provided by manufacturers, but the smart chips may also be attached to existing keys. The main limitation of smart keys is that the vehicle identifies the key, not the driver, so there is the possibility that teens may switch keys with another driver to bypass monitoring features.

Biometric fingerprint identification: To best increase accountability, a teen monitoring system should be able to identify a driver. Biometric fingerprint identification is a reliable way to ensure the identification of a teen driver. Before driving, the driver would place one of their fingertips on the sensor. The system would then compare the fingerprint reading with readings stored in a fingerprint database. Once the system matches the drivers fingerprint to one stored in the database, the driver is identified. Readers can be connected to a computer via a serial or USB connection. They can also communicate with a smartphone or PDA via Bluetooth communication. Fingerprint identification has been used for advanced security practices for many years, and has recently become available for consumer devices such as laptop computers.

Voice recognition: Drivers can also be identified through a voice recognition system. Such a system utilizes an in-vehicle microphone or a built in microphone on a smartphone or PDA is another possible identification solution. Biometric speech identification software has been developed that is able to confirm a person's identity over the phone. Such a system could be used to identify novice drivers in a vehicle. Upon vehicle startup, the system could ask the driver to speak into a microphone. The software would then match the driver's response to a voice stored in a database to verify the identity of the driver.

Facial recognition: Recent technology has led to the development of software that has the ability analyze a picture of a face and match the face to one that is stored in a database to identify the person in the picture. A similar system could be used inside a vehicle to identify the driver. A camera mounted to the rear view mirror could identify drivers and passengers. These systems require a substantial amount of processing power, which considerably increases the ease of integration and cost.

Passwords: A system that requires a driver to enter a password is another possible solution for identifying a driver. Passwords could be entered into a keypad or touchscreen. The password entered by a driver would then be compared against a database with passwords for all drivers. Passwords are easy and inexpensive to implement, but could be easily bypassed.

Eye scan: There are two basic types of eye scans: iris scanning and retinal scanning. Every human has a unique iris pattern and a unique pattern of blood vessels within the retina. Both techniques are highly accurate and difficult to deceive. To be scanned, an individual must look into the scanner for a few seconds. Eye scanning is most often used in security applications and current technology costs may be prohibitive for motor vehicle applications. Drivers may need to remove eyewear and scans may not work with people with cataract or glaucoma.

2.3.6 Current system functions

A number of existing systems incorporate functions that can be applied to a teen monitoring system. These examples demonstrate the feasibility of integrating types of enabling technology and the viability of specific support functions.

Emergency detection and communication: Many serious crashes occur where nobody is present to notify the authorities. The driver is often physically unable to call for help after a crash has taken place. Therefore, teen monitoring systems can help to increase crash survivability by detecting potential crashes by monitoring accelerometer data or airbag deployment. If a crash is detected, an operator can attempt to communicate with the driver through a wireless connection. If the driver does not respond, the system can contact emergency responders. A GPS device is essential to identify vehicle location in the event of a serious crash. Emergency detection systems may also include a “panic button” for the driver to alert an operator about an emergency in the case that the situation was not automatically detected.

Geofencing: Geofencing allows a parent or guardian to be alerted if the teen driver travels into or out of a particular zone. Parents can define areas where they want their teen driver to travel or not travel. If the teen travels into a restricted area, the system automatically notifies the parent.

Night vision: In 2006, 44 percent of all teen crash fatalities occurred between 9 pm and 6 am (Insurance Institute for Highway Safety, n.d.), and, per million miles driven, teen males are 6 times more likely to have a have a fatal crash at night than adult males (NHTSA, 2007). Although many factors contribute to teens’ elevated nighttime crash risk, a night vision system could aid teens by improving visibility in the difficult nighttime driving environment. A night vision system uses a high resolution infrared sensor located on the vehicle grille that detects thermal radiation from the surrounding environment. The system constantly monitors the vehicle’s surroundings and displays thermal images in a HUD or an in-vehicle monitor. Warm objects appear bright while cool objects are dark. The system enables the driver to see 150 meters away in a dark environment. While night vision can improve nighttime visibility, it is important to ensure that teens are instructed on proper use and distribute their attention properly.

Adaptive cruise control: Teen drivers have a propensity to tailgate and put themselves at risk on the highway. Adaptive cruise control (ACC) systems can teach novice drivers how safe following distances change with speed. An adaptive cruise control system measures the distance to a lead vehicle on a freeway or highway. If the system detects the vehicle is too close, then the vehicle will automatically slow down until a safe following distance is reached. Likewise, the vehicle will speed up (but not exceed the set cruise speed) if a lead vehicle speeds up.

Driver attention system: Novice drivers are nearly three times more likely to be injured in a crash crash when they are fatigued (Lam, 2003), and more than half of teens report driving drowsy at least once in the past year (National Sleep Foundation, 2006). Driver attention systems could help to prevent these crashes. Typical systems for commercial drivers who drive long hours use infrared cameras (to function in low light conditions) and visible light camera sensors to continuously monitor the driver's face. The video is transmitted to an onboard computer where it is processed to measure the driver's drowsiness using head position and/or by detecting closed eyes. Alternative systems may monitor vehicle lane position or other metrics to detect symptoms of driver inattention. Volvo's driver alert control system is one of few such systems currently available in passenger vehicles. For teen drivers who appear to be drowsy, driver attention systems could attempt to keep the driver awake through intense alerts, encourage the driver to stop the car, and/or alert a parent or coach. In a worst-case scenario in which the driver appears to be completely unalert, the system could disengage the drive gear and/or brake the vehicle to a stop. Though driver attention systems could potentially benefit teen drivers, they are not commercially available and there is insufficient evidence from field operational tests to determine their effectiveness.

Blind spot detection system: Blind spots can be very problematic for teen drivers. Blind spot detection systems can consist of cameras or other sensors that detect if a vehicle is present in the driver's blind spot. The system gives a visual notification if a vehicle is located in the blind spot. If the system detects that a driver is attempting a lane change that would interfere with a vehicle located in the blind spot, tactile, auditory, or visual alerts could be provided.

Road sign recognition: Novice drivers often have difficulty multitasking and distributing attention effectively in complex environments (Crundall & Underwood, 1998, in Lee, 2007). A road sign recognition system can help teens by providing relevant road sign information. aRoad sign recognition systems are not currently completely accurate and may not correctly detect signs in complex urban environments or in inclement weather. A geospatial database with speed limit information is an alternative to road sign recognition that does not rely on real-time detection, though databases must be accurate and kept up to date.

Lane departure warning system: Novice drivers often have difficulty negotiating curves and staying within the roadway edgelines (Clarke, Ward, Bartle, & Truman, 2006; Lerner, Tornow, Freedman, Llaneras, Rabinovich, & Steinberg, 1999). Novice drivers are also particularly poor at correcting their steering following a lane departure, sometimes resulting in serious crashes and rollovers (Ulmer, Williams, & Preusser, 1997). Lane departures can also result from driver inattention or drowsiness, and teens are particularly prone to these conditions (Lam, 2003). A lane departure warning system can alert drivers in the case of inadvertent lane departures. Lane departure warning systems must alert the driver quickly enough that they can correct their steering before departing the roadway, which is far more likely to require emergency maneuvers and result in a crash. One currently available system is Volvo's Driver Alert Control, which monitors the car's movements and assesses whether the vehicle is being driven in a controlled or uncontrolled way. Driver Alert Control consists of a camera, a number of sensors, and a control unit. The camera, which is installed between the windscreen and the interior rear-view mirror, continuously measures the distance between the car and the road lane markings. The sensors register the car's movements. The control unit stores the information and calculates whether the driver risks losing control of the vehicle. If the risk is assessed as high, the driver is alerted via an audible signal. In addition, a text message appears in the car's information display, alerting him or her with a coffee cup symbol to take a break.

2.3.7 Enabling technologies status

Table 1 summarizes the status of key enabling technologies related to various categories of driver behavior (drawn from the set of behaviors in Appendix A). For each behavior, the table indicates the empirical data required, the likely sensors involved, and the availability and feasibility/cost of these sensor systems. Because new technologies are continually emerging, the costs dropping, and the usability improving, this table should be viewed as a "snapshot" at a particular moment. Judgments of status and practicality also have a somewhat subjective aspect. This table was assembled by the University of Minnesota project team as part of the technology assessment conducted early in this project, and reflects the status in late 2006. It remains useful for providing a general sense of where things stand, but the shelf life of any such technology status review will be limited regarding specific entries.

Table 1. Status of enabling technologies

Category Driving behavior, condition, or characteristic that contributes to crash risk	**Measures** Empirical data relevant to the driving category	**Sensors** Device or system that measures the driving behavior, condition, or characteristic	**Availability** A=mass produced B=niche market C=prototype	**Feasibility** A=easy/inexpensive* B=moderate C=difficult/expensive
Lane keeping	1. Lane deviation	GPS with road map database	C	C
		Vision lane detection system camera	B	B
Curve negotiation	1. Curve detection	GPS sensor with curve database/map	C	A
	2. Lane deviation	Vision curve detection system camera	B	A
Speeding	1. Speed relative to preset limit	GPS	A	A
		OBDII	A	A
	2. Speed relative to speed limit	Speed limit database	C	C
		Traffic sign detection	B	B
Turning	1. Steering angle	Potentiometer/ encoder	A	B
	2. Yaw rate	Accelerometer	A	B
Car following	1. Headway	Lidar unit	B	C
		Radar unit	A	C
		Vision system camera	B	B
		Adaptive cruise control	B	A
	2. Following distance	Lidar unit	B	C
		Radar unit	A	B
		Vision system camera	B	B
		Adaptive cruise control	B	A
Emergency maneuver/error recovery	1.G-force measure	Accelerometer	A	B
	2.Roll probability	Rollover prevention system	A	B
	3. Yaw stability	Yaw stability control system	A	A

* Cost is roughly categorized as follows: Inexpensive = under $1,000; Moderate = under $5,000; Expensive = more than $5,000

Category Driving behavior, condition, or characteristic that contributes to crash risk	**Measures** Empirical data relevant to the driving category	**Sensors** Device or system that measures the driving behavior, condition, or characteristic	**Availability** A=mass produced B=niche market C=prototype	**Feasibility** A=easy/inexpensive* B=moderate C=difficult/expensive
Passing and overtaking	1.Detect if vehicle is in blind spot	Blind spot detection system	B	A
Backing/parking	1.Rear view camera scene	Camera located on the back of vehicle	A	A
Seatbelt use	1. Detect if driver and passengers are fastened	Seatbelt interlock	B	A
		Passenger seat sensor	B	B
Driving while impaired	1.BAC	Breathalyzer	A	A
		Transdermal	A	C
Driver drowsiness	1. Eye opening	Driver attention vision system	B	C
Obeying traffic law	1.Stop sign detection	Traffic sign database	C	C
		Traffic sign recognition	B	B
Hard braking	1.G-force measure	Accelerometer	A	A
	2.Brake pedal activity	Potentiometer/load cell	C	B
Tailgating	1. Headway	Lidar unit	B	C
		Radar unit	A	C
		Vision system camera	B	B
		Adaptive cruise control	B	A
	2. Following distance	Lidar unit	A	C
		Radar unit	A	C
		Vision system camera	B	A
		Adaptive cruise control	B	A
Dangerous overtaking	1.Detect if vehicle is in blind spot	Blind spot detection system	B	A
Use of communication/ entertainment devices	1. Block cell phone signals	Cell phone jammer	B	B
	2. Record audio in-vehicle audio level	Audio recorder	A	B
	3. Mobile phone call management	Mobile phone manager	B	B
Using vehicle displays/controls	1. Video recording	Video recorder	A	A
	2. Eye /head orientation	Driver attention vision system	B	B
Passenger interaction	1.Audio recording	Microphone	A	A
Eating/drinking/ hygiene/searching/etc	1.Video recording	Video recorder	A	A
Visual search	1. Video recording	Video recorder	A	A
	2. Eye /head orientation	Driver attention vision system	B	C
Gauge/mirror use	1. Video recording	Video recorder	A	A
	2. Eye /head orientation	Driver attention vision system	B	C
Driver workload/ drowsiness	1.Driving time	Data log	A	A
	2. Driver drowsiness	Driver attention system	B	B
Weather	1.Weather station communication	GPS with cellular modem/smartphone/ PDA	A	A
Lighting	1.Infrared radiation	Night vision system	A	A

Category Driving behavior, condition, or characteristic that contributes to crash risk	**Measures** Empirical data relevant to the driving category	**Sensors** Device or system that measures the driving behavior, condition, or characteristic	**Availability** A=mass produced B=niche market C=prototype	**Feasibility** A=easy/inexpensive* B=moderate C=difficult/expensive
Trip time	1.Driving time	Data log of driving time	A	A
Road geometry	1. Curve detection	GPS sensor with curve database	C	A
	2. Lane deviation	Vision curve detection system camera	B	A
Road surface	1.Real-time weather data	GPS with cellular modem/smartphone/PDA	A	A
Locale	1. Geofencing	GPS with map fencing software and communication	A	A
Intersection	1. Intersection detection	Traffic sign recognition	B	B
		Intersection database	C	C
Highway railroad crossing	1. Intersection detection	Rail road sign recognition	B	A
		Railroad track database	C	C
Attention span/ ADHD	1. Video recording	Video recorder	A	A
	2. Eye opening/ head orientation	Driver attention vision system	B	B
Aggression	1. Acceleration/ deceleration	Accelerometer	A	B
		Potentiometer/load cell	A	B
		ODBII throttle and RPM	A	A

2.4 Implementation strategies

Central to teen driver monitoring system development is the question of what to do with the information about the monitored behavior. The two most basic strategies of monitoring are (1) to deter or prevent dangerous actions and (2) to improve novice driver knowledge and skills through education and experience. A teen driver monitoring program may adopt one or both of these strategies. While the target outcome of the program is the modification of teen driver behavior, this does not mean that the teen drivers themselves are the sole, or even primary, direct recipients of the feedback. Depending on how the program is conceptualized, feedback about driving safety could go to the individual teen, some group of teen drivers, parents, licensing authorities (GDL), enforcement and adjudication agencies, insurers, schools, driver educators, or other involved parties. For each potential user of the feedback, there area questions about user acceptance, general public acceptance, practicality, cost, barriers to implementation, cooperative needs, legal considerations, and ultimately, safety effectiveness. It is also important that information is provided in such a way that it instills safe driving practices in teen drivers and does not distract them or increase stress or workload to the point where driving performance suffers.

A search of current programs using monitoring technology, other teen oriented programs, and suggestions raised in the 2004 workshop (NHTSA, 2006) and elsewhere in the literature, indicated that the concept of “teen driver monitoring” is extremely broad. There are many alternatives in terms of the technologies employed, the behaviors monitored, the parties involved in the process, the incentive structure, and the type of program employed. In order to provide some framework for subsequent analysis, the approaches were categorized into five broad strategies. These implementation strategy categories are not mutually exclusive and an effective program might include multiple aspects. However, the framework provides a convenient means for considering alternatives and it was used as an organizational scheme for the workshop on novice teen driver monitoring, discussed in Section 4.

The five categories of implementation strategies are:

- Driver feedback
- Vehicle adaptation
- Reporting
- Coaching
- External motivation

Each of these is further defined below.

2.4.1 Driver feedback

Teen drivers could receive real-time feedback about errors or risks. Feedback might also be delayed somewhat, so that it is presented at a safe time. The key point is that the driver is made aware of errors or poor driving judgment at about the time the behavior occurs. The specific purpose of driver feedback is to make an error explicit and provide an opportunity to correct it. For example, a signal might sound when the vehicle exceeds the posted speed by a criterion amount. A voice display might inform the driver if an eyes-off-road time exceeds some duration (e.g., 2 seconds). A visual message might be presented if the vehicle enters a prohibited (“geofenced”) location.

Many current vehicles provide examples of driver safety feedback, although not specifically teen-oriented. These include enhanced seat belt reminder systems, backup collision warning systems, lane support systems, and more. Current aftermarket products for teen monitoring provide feedback to drivers when driving in excess of a predetermined speed, driving too fast on a curve, accelerating or braking rapidly, or other aggressive or dangerous acts.

2.4.2 Vehicle adaptation

Based on what the driver is doing or the situation the driver is in, some aspect of vehicle functioning can be altered. The specific purpose of vehicle adaptation is to prevent, terminate, or discourage certain behavior. For example, if the vehicle is speeding, the infotainment system could be locked out. If the system senses that the driver is distracted, the criteria for issuing warnings could be modified (e.g., longer time-to-collision criterion). If some potentially hazardous condition is sensed (e.g., the driver is not wearing a seat belt, road is wet, excessive driver-passenger interaction), the maximum vehicle speed may be limited. This latter example reflects a particular type of vehicle adaptation that has been termed a “forcing function,” where the technology prevents drivers from engaging in an unsafe behavior.

Adaptations need not be limited to actual vehicle functions; some adaptations may limit access to peripheral devices such as cell phones and aftermarket navigation systems. In the case of nomadic and aftermarket devices, however, the cooperation of device manufacturers may be required to allow for safety-related adaptation or lockouts.

There are few examples of the use of driver-monitoring based vehicle adaptation systems in current U.S. vehicles and products. One example is a speed limiter for trucks. An online survey of motor carriers found that 63 percent of fleets use speed governing devices, accounting for 77 percent of all large trucks (McDonald & Brewster, 2008). Another example is the use of alcohol ignition interlocks for DUI offenders. However, at least one major auto manufacturer has announced plans to implement a teen-oriented adaptive system that can limit vehicle speed, limit stereo volume, and disable the stereo if seat belts are not used, among other features (Ford press release, 2008). The SAVE-IT research program administered by NHTSA has specifically investigated ways to integrate vehicle adaptation and distraction mitigation in response to driver state and driver workload and provides an example of a prototype system, although the project has not been teen-oriented.

2.4.3 Reporting

Reporting refers to recording, and perhaps summarizing, behaviors for review at a later time. The report might be intended for the teen, parents, or other parties such as insurers, driver educators, or licensing authorities. The specific purpose of reporting is to characterize past performance in order to inform and to provide deterrence for negative behaviors or promote positive behaviors. Various technologies might be used to download and transmit the information. The report could include summary statistics, listings of events, details of incidents, evaluative ratings, or other information. For example, a report might provide a detailed log of speeding events, showing dates, times, locations, speed limits, and travel speeds. A report might compile a weekly index of driver performance and show the driver's score relative to a comparison group. A report might include video clips of the scene immediately before and after hard braking events.

The teen monitoring system used in McGehee, Carney et al.'s (2007) study of teen drivers in rural Iowa provides an example of an extensive reporting system. Weekly "report cards" were received by the participating families, which showed weekly and cumulative performance regarding unsafe behaviors and which showed performance relative to the group of teens participating in the study. Results show that risky behaviors were significantly reduced, particularly among the most at-risk teens. Another study, currently in progress and being conducted by the Insurance Institute for Highway Safety, is using a secure web site as the medium for providing parents with summary reports.

2.4.4 Coaching

An intermediary might process and interpret the monitored information and provide the teen driver with explanations of errors and advice for improved performance. The key aspect of coaching is that events are *interpreted* by someone with the relevant skills, so that the feedback to the driver is guidance and not just descriptive. The specific purpose of coaching is to provide the teen driver with critical feedback that makes errors explicit and more appropriate actions evident. For example, video recordings triggered by hard braking events could be transmitted to a service that interprets the scenes and determines what the driver could have done differently. Event data or video might be directly provided to a teen's driving instructor, who in turn uses the information to coach their students during training sessions. Teen peer groups might share event reports and discuss their suggestions of how to handle the situation better.

Some vendors of video-based teen driver monitoring systems offer "coaching" in which video clips triggered by criterion events (e.g., hard braking) are evaluated by company analysts and the teen driver receives explicit feedback about appropriate actions. While various types of "coaches" might be conceived of, it is interesting to note that research is being conducted on an intelligent vehicle-based system, called CarCoach, that automatically assesses driving errors and generates informative feedback (Arroyo, Sullivan, & Selker, 2006). Although it may be possible to provide coaching based on vehicle metric data, the most effective coaching is likely to come from video recordings that show the vehicle’s forward view and, preferably, additional views such as the vehicle interior and rear or side views.

2.4.5 External motivation

This category highlights how formal positive or negative incentives could be incorporated into a monitoring program. Generally teen monitoring systems have provided information for the teen driver or parent. The use of that information is a family matter. However, there may be incentives, such as lowered insurance premiums, simply for using a monitoring system. Benefits or disincentives might further be made contingent on performance as well. The specific purpose of external motivation is to motivate improved behavior. For example, pay-as-you-go insurance programs might adjust teen drivers’ insurance costs based on the amount of high-risk driving they are involved in. Schools might reward students with privileged parking spaces based on safe performance scores from summary reports. A GDL system might extend a provisional period if there is a high incidence of aggressive or risky events.

2.5 Summary of information search

Although initial findings suggest that monitoring of novice teen drivers may produce important safety benefits, the real extent of those benefits is not known and the most effective methods for using vehicle-based monitoring are also not known. Many possibilities in terms of driver behaviors and driving situations were identified. While some of these currently may be difficult to monitor, clearly the technologies for sensing, driver identification, in-vehicle feedback, and transmission of reports is adequately mature to support sophisticated programs involving a variety of implementation strategies. Recent and on-going driver monitoring projects amply demonstrate the practicality of the approach. A notable limitation in the literature was in the area of consumer acceptance and use of monitoring systems. There was little formal evaluation of what parents and teens desire in terms of products and programs, how they would use such systems, or their ability to make effective use of the potentially available information. Thus while technology status and initial findings regarding monitoring appear promising, there remains a need for objective empirical research regarding the formal evaluation of net benefits, comparative evaluations of alternative strategies, and public use and acceptance of products and programs.

3 Teen and parent focus groups

One key aspect that relates to the success of a teen driver monitoring strategy is the manner in which the family actually uses the system. Focus groups of teen drivers and their parents were conducted to explore issues of motivation, preference, and usability of alternatives. Three focus groups with parents and three focus groups with teenage drivers were conducted between March and June, 2008. The focus groups were organized so that a parent and their teenager participated on the same evening. A focus group of parents and a separate focus group of teen drivers were conducted simultaneously. Focus group moderators followed similar question paths for teens and for parents.

All focus group participants resided in Montgomery County, Maryland. They were recruited through newspaper advertisements and through contacts with local schools' Parent Teacher Associations (PTAs). Each participant was paid $75. Eight parent and teen pairs participated in the Group 1, ten pairs participated in the Group 2, and six pairs participated in Group 3. Families selected to participate in the first group were families where the teen driver was (or would be) the first of the parent's children to get a driver's license. Families selected to participate in the second group were families where the teenage drivers had older siblings who had already obtained a driver's license. Families in Group 3 were recruited because the teenage driver had been involved in one or more crashes or had received one or more citations for moving violations. The teenage drivers who participated in Group 1 and Group 2 had to be less than 18 years old and possess a valid driver's license or a learner's permit. All teens in Group 3 had their driver's license. Teens in Group 3 seemed much more confident about their driving abilities as compared to teens in Group 1 or Group 2. In general they were slightly older and had more driving experience.

The focus group discussion path is provided as Appendix B.

3.1 Summary of key findings

3.1.1 Parents' concerns

Although parents clearly appreciated the importance of wearing a seat belt, they were not concerned about monitoring seat belt use of their teen drivers because they believe that their teens always wear seatbelts when driving. Parents seemed more concerned about seatbelt use by passengers rather than the driver.

Parents had diverse opinions about how monitoring technology could affect their teen's privacy, trust in their relationship with their teen, data could be used by insurance companies, law enforcement.

3.1.2 Best and worst things about teenagers being able to drive independently

Teenage drivers indicated that advantages of independent driving include the freedom and the ability to drive to social events and to their jobs without relying on anyone else. The disadvantages of being a licensed driver were the added responsibilities including taking care of a vehicle, providing transportation to siblings and friends, and parental expectations for more assistance running errands and helping out. The high costs of gasoline and vehicle maintenance trouble many of the young drivers. Tickets were another disadvantage of independent driving. A number of the teens said that they share a vehicle with parents or siblings.

As new drivers, teens in Groups 1 and Group 2 indicated that they often have difficulty changing lanes, judging distances for turns, and recognizing which travel lane to follow in advance of turns, complex intersections, etc. Some teens mentioned the difficulty in using a different vehicle than the one that is most familiar to them.

Unlike the teens in Group 1 and Group 2, teen drivers in Group 3 said that the worst thing about driving was sharing the road with other drivers who are incompetent. They complained about incompetent elderly drivers and incompetent newly licensed drivers. One participant indicated that middle age drivers were also sometimes poor drivers. He cited "soccer moms" as the worst drivers because they are constantly talking on their cell phones while driving and do not care about anyone else on the road. The teens complained about other drivers who drive too slow and other drivers who "tailgate" them. One participant said that he responds to tailgaters by purposely slamming on his brakes, "If they hit me they will have to pay." A second male participant agreed, "I would applaud him [for slamming on his brakes]. I don't like people who drive stupid." The teen drivers in Group 3 cited their own crashes and crashes or near-crash experiences of friends and family members as evidence that there are too many poor drivers. One teen said, "Some people are not meant to be on the road."

Parents indicated that it is helpful that the teens can transport themselves and help with the driving tasks. Independent driving is seen as a rite of passage and many of the parents in Group 1 were quick to indicate that they are proud of their teens who are responsible and good drivers. In addition parents mentioned that it is a relief to have their teen drive independently rather than with another teen driver. There are a number of issues, however, that worry them about their children's independent driving. The negative factors include unsafe driving practices, congestion, and bad weather. Parents were particularly concerned about teens' inability to handle emergency maneuvers because these cannot be practiced. Many parents worried about teens' overconfidence behind the wheel, their sense of entitlement to drive, impulsiveness, and risk-taking tendencies. Some parents also felt that it is too easy for teens to get driver's licenses.

> *"I consider it a blessing and a curse."*
> *(Female, Parent Group 2)*

3.1.3 Regarding parental concerns and control

Teens said that their parents or their friends' parents worry about (and impose rules about) playing loud music, transporting friends, using a cell phone, and text messaging. Teens also said that parents are very worried about safety, speeding, poor weather, and vehicle maintenance. Some teens said that their parents require them to call often, especially when they reach their destination; all of the teenage participants said that they have cell phones which enable such calls. Many teens said that their parents impose curfews, and some said that their parents would take away their driver's license or driving privileges if they were caught drinking and driving, or using their cell phone to send text messages while driving. Another teen said that his parents sometimes got reports from their friends and neighbors about his driving.

A few teens mentioned that their parents had expressed financial concerns about costs associated with the teen's driving such as paying for traffic tickets. One teen said that his father monitored his gas mileage as a way to see if he had been driving too aggressively.

> *"Whenever I leave the house, they [parents] say drive safe, don't speed and stuff like that…don't floor it."*
> *(Male, Teen Group 2)*

Parents indicated that their major concerns were: distractions on the roadway and in the vehicle; driver inexperience and poor judgment; the ease with which teens are able to get a license; driver instructors and teens hurry to drive on faster roads and in more dangerous conditions; pedestrians, deer, and other hazards on the roadway. Some parents specifically referred to their teens' dangerous driving habits including speeding, maintaining short sight distances, driving with only one hand on the wheel, transporting too many passengers, and driving aggressively.

> *"They're overconfident about their ability, once they get their license they think that it's an entitlement – 'I have a license so I know how to drive.'" (Female, Parent Group 2)*

Teens indicated that when they drive with their parents their behavior is different.

> *"[I] definitely [drive differently]… [I] go probably about what the speed limit says when my parents are in the car, the radio is normally off, two hands on the wheel, always looking around but when I'm on my own I've got the radio on just relaxing."*
> *(Male, Teen Group 1)*

Among the licensed teen drivers in the first group most admitted to "texting" behind the wheel, some respondents hedged their initial statements and indicated they only send text messages at a red light. In the second group the participants noted that texting was too difficult to do while the car is in motion; but talking on a cell phone is similar to speaking to a passenger and is not dangerous.

> *"Talking on the cell phone, my mom's really strict about that-texting, driving, and talking … she'll say, 'the next time I see you I'll take your keys away and you can't drive.'"*
> *(Female, Teen Group 2)*

Many of the parents' rules relate directly to the GDL restrictions. Teens mentioned most frequently the use of curfews. Many parents place a curfew that replicates the required hour of return under GDL. However, some teens mentioned that they or their friends have earlier curfews. One parent noted that she set her teen's curfew earlier than the GDL curfew so that her teen would be less likely to speed to get home before curfew. In addition to curfews some parents have rules about driving with passengers or using a cell phone. After the initial licensing phase more freedoms are allowed, however curfews are in place for many participants.

Parents indicated that some of them delayed registration for the learner's permit or required a lengthy learner's permit phase with many hours of parental supervised driving. Parents mentioned a variety of interventions utilized once teens begin independent driving. These include the requirement for frequent phone calls, prohibition of cell phone use in the vehicle, and asking friends to keep their eyes open for any dangerous driving practices. There is a feeling that none of these restrictions necessarily mean that they are in control of their teen's behavior.

> *"I think he's a safe driver but do I know what he's doing behind that wheel when he's going to work?"*
> *(Female, Parent Group 1)*

3.1.4 In-vehicle technology

Focus group participants were introduced to the concept of technological tools that could be used to monitor or regulate teens' driving behavior. Not surprisingly, the teen participants' initial reactions were generally that they did not like the idea of monitoring devices installed in their vehicles. Most teens did not see why video of the driver would be useful, and technology that tracks and notifies parents about the vehicle location was not favored by the teen participants.

> *(The system knows where the vehicle is located.) "Like a GPS?" (Right.)… "That's Ridiculous!"*
> *(Female, Teen Group 1)*

However, many teens admitted that their parents might appreciate a system that allows them to know where the teen driver is located.

> *"If it was cheap they'd buy it." (Male, Teen Group 1)*

Parents indicated that they want to protect their children but also respect their privacy; they don't want to spy on their children. Some parents were more adamant that during the probationary licensing phase all bets are off and parents can supervise as much as they desire. Parents were not sure that the technologies could compensate for other types of parental intervention.

> *"I'm not sure that all the technology can help us as much as spending time in the car driving with them."*
> *(Female, Parent Group 1)*

One of the parents already uses a cell phone application that allows him to check the location of the teen, pinpointed via GPS signal from the teen's phone. Many of the parents were interested to learn about this application because they too worry about keeping track of teens. In addition, parents saw the monitoring devices as a learning tool to modify and improve driver behavior.

In the event of a crash, teens felt that a GPS based system was less distasteful. Teen participants indicated that they might be interested in having the system notify their parents if they are involved in a crash. Some teens want to be able to notify their parents on their own; others thought an automated notification system might be useful.

Speeding was seen as the most favored behavior to monitor. Teens indicated that their parents would be interested in this information. However many participants indicated that five mph above the speed limit is not excessive enough to warrant an alert and too much information would be annoying for parents.

> *"I don't think it really matters about five [mph] over, I think most people do five over anyway, that would be really annoying if it beeped just for going five over because there are some places where its really annoying to go the actual speed limit." (Female, Teen Group 1)*

Several parents were interested in monitoring drinking and driving, maybe using a breathalyzer and alcohol interlock. This issue seems to be top priority for parents in group 1, but not group 2. Parents were interested in seat belt use, but felt that their teens had grown up using seatbelts all of their lives and were more aware of seat belts than they are. Speeding is important, but they felt that five mph above the speed limit was still pretty low. Finally, any way to limit the use of cell phones in vehicles was considered positive by many parents.

Teens thought that a system that intervenes and controls speed automatically would be unsafe because of the exceptional emergency situation. A suggestion for a device that notified the teen of the current speed limit on roadways was popular. Additional information about the location of automated speed enforcement cameras (which are used throughout much of Montgomery County) was popular as well. In general teens seemed to feel that the speed cameras were a type of trap. Teens indicated that they do speed; for instance to reach home in time for a curfew. A reminder or tone to encourage them to travel home in time would not be helpful because they will still run late. Some teens did not feel that speeding was a problem at all.

> *"If someone's speeding out of control… its bad…. As long as you're in control it should be fine and slower people should move to the right." (Male, Teen Group 2)*

Teen participants considered hard braking and sharp turns and maneuvers unimportant. They did not believe that their parents would be interested in this information. Teens mentioned that parents drive in the same way and that this does not make someone a bad driver.

Teens prefer that driving reports do not go to parents and a number of the teen participants raised the issue of trust.

> *"I don't think that any of those machines you mentioned help build trust between a parent and kid, which is why it would be bad to have them sending all those reports, but if [program implementers] controlled what it sends to [parents], then I think that would be OK." (Female, Teen Group 1)*

Teens felt that reports that are provided to parents should represent what the teens see as "real" safety issues – speeding five mph above the limit does not qualify. Reports should not be so frequent as to be annoying. They believe their parents would be interested in information on seat belt use, speeding, and generally unsafe driving such as inability to control the vehicle. The reports might also offer opportunities to discuss what really took place and explain the circumstances; sometimes speeding might be acceptable.

Some teen participants indicated that any system that would require use of the Internet or email might prove difficult as their parents are not computer-savvy. Also, the effort required to log in to a website and review all of the data would be cumbersome for their parents. Finally, teens thought that the cost for some of the systems would be prohibitive and therefore the parents would not be interested.

Parents were interested in either paper reports or reports available by downloading from the device using a USB drive. Parents anticipated reviewing reports often at first and then slowly tapering off as the teen's driving abilities improve. Some of the parents were wary about any Internet based interventions in case the information relayed on a web site might be used by unauthorized individuals or agencies, and whether this information might be used punitively.

One parent worried about insurance companies trying to force monitoring systems on families. Many parents were concerned that information on the Internet could be hacked or stolen. Some parents were concerned that recorded information could be used against them or their teens in court if a crash were to occur.

Teens were asked about their parents' probable reactions to information provided via the reports. Some of the potential reactions included: discussions, nagging, questions, no gas money, suspension of driving privileges, and requirement of additional driving practice. Some of the teens indicated that the reaction would depend on which parent receives the reports.

> *"If they ever caught me drinking and driving… they would take away my license." (Male, Teen Group 2)*

However, one teen indicated that his parents enjoyed the fact that he could get to destinations independently too much to suspend driving privileges for more than a short period of time.

Teens were familiar with GPS (navigation) systems, backup cameras, and parking assist technologies. They were aware of the positive capabilities of the various technologies and some had positive experiences with these devices. Participants were wary of depending on electronic devices rather than driving experience. In addition, some teens indicated that it was not worth any extra cost to have an electronic device in the vehicle.

Teen participants mentioned a few additional potential favorable devices: a device that warns of theft or vagrancy near the vehicle, a panic button to contact 911, and finally, some teens brought up the idea of connecting such a system to a breathalyzer in order to prevent drunk driving. All of the teens in the second focus group indicated that while this was risky behavior most of them admitted to drinking and driving at least once in the past.

3.1.5 Four hypothetical monitoring systems and features

Four hypothetical monitoring systems were described to parent and teen focus groups to stimulate discussion. These systems were intended to represent a range of possibilities for monitoring, but did not specifically emulate existing systems. The systems are described below:

- System 1 is an event-based video recorder that records video clips of the driver's face and the view in front of the vehicle. Video and audio recording is triggered by unsafe events, including hard braking, hard turns, and hard acceleration. Speeding events are not recorded. The device does not intelligently detect who the driver is, so it records anyone who drives the vehicle and triggers events. The recordings are saved on the device, and parents must download the data from the device via a USB port. Families are also given the option to have recordings sent directly to a professional driving coach, who reviews the videos and provides feedback and tips for improvement. Families would then receive a DVD each month with videos and narration from the coach.

- System 2 is an in-vehicle driver feedback system that provides feedback (sounds) to the driver whenever an unsafe event occurs. The system monitors seat belt use, speeding over the posted speed limit, hard turns, and hard braking. Parents may download a list of recorded events from the device via a wireless connection to a home computer. The primary purpose of this system, however, is to provide direct, real-time feedback to the teen driver.

- System 3 is a real-time vehicle tracking system that monitors vehicle location, speed, and unsafe maneuvers. Parents can see the vehicle's current location and speed on a website map. The website also shows where unsafe events have occurred. Recorded events include speeding, hard turns, hard accelerations, hard braking, and seat belt nonuse. The device can contact a parent (via automated phone message, text message, or email) when an unsafe event occurs. Parent may also set location boundaries (geofencing) and be alerted if the teen's vehicle crosses a boundary. This system would include smart keys so that only the key used by the teen would activate monitoring and reporting features.
- System 4 is a driving summary reporting system that uses an in-vehicle "black box" to record speeding over the posted limit, hard acceleration, hard braking, hard turns, and seat belt use. The driver is identified by a fingerprint recognition device, and the system's monitoring and reporting features are only activated if a teen is driving. Summary reports of driving activity and events are sent to the family each week by email or postal mail. The family can also download reports from a website. The reports do not include a map view of event locations, but vehicle location information for events is given by the street name and nearest cross street.

Focus group participants discussed what they liked and disliked about each system individually, then compared them against one another. Participants also discussed the types of programmatic efforts that they thought these systems could be used in, as well as the incentives that could be offered to encourage use.

Video recordings were not attractive to teens but some of them admitted that their parents may be interested in this type of report. However, they believed if there was too much footage for their parents to watch it would prove to be tiresome. Teens considered audio recordings an even greater infringement on privacy and felt that they would serve no purpose. Some parents agreed that audio was unnecessarily invasive. The teens did not see a connection between unsafe driving and loud sounds and conversation in the vehicle. Commentary by a professional driving coach was not seen as a big attraction since the general consensus was that the results are interpretable by any licensed driver.

Some parents did not show much interest in video recordings, primarily due to the worry that it would further distract their teen driver. Some parents thought that video showing the driver was unnecessary while others thought that it would add context to the other recorded information and deter bad behaviors. Other parents believed that this is appropriate in the provisional phase and would encourage teens to develop safer driving behavior. Most parents did not like the idea of a professional driving coach reviewing the clips. Some of the parents indicated they would be willing to try such a system for free, but would not be interested in paying for the device or coaching service.

Teens and some parents considered real time driver feedback in the format of beeps or buzzers problematic. Teens made conflicting statements to the effect that the sounds may be both startling and ignored (similar to vehicles' seat belt reminder systems). One teen participant indicated that it is important to leave decisions to the driver. Parents were worried that the sounds would serve as further distraction in a difficult driving environment.

> *"I think beeping for hard braking would be more of a distraction.… You've got beeping going on; it's like a cell phone." (Male, Parent Group 1)*

However, other parents considered the driver feedback system most attractive. Parents said that this system is instructional, encourages correct behavior, and is good for any driver. They liked the idea of immediate feedback possibly combined with status reports to check on improvement in driving practices over time.

A system which allows for real time location of the teen driver and geo-fencing (parents establish geographic boundaries on where teens may or may not drive) was considered to be extremely undesirable by the teen participants.

> *"A stalking system." (Female, Teen Group 1)*

Some teens pointed again to the issue of trust. Although the teens generally provided their parents with information on their whereabouts, the general consensus was that parents shouldn't have the ability to know everything about them all the time.

> *"I feel like all of these things are extreme, like your parents really must not trust you if they want to put any of this in [your car]…" (Male, Teen Group 2)*

One participant mentioned that she doesn't believe her parents would impose such a system. In addition, teens believed that the real-time information is not useful since the parents do not have time to constantly monitor their teens. Teens only considered this type of system to be beneficial for tracking a stolen vehicle.

Parents had varying opinions about real-time tracking systems. Some parents agreed with the teens that this type of system is too intrusive and does not teach correct behavior.

> *"This is a problem as far as trust, this is more about parental control than safe driving to me." (Female, Parent Group 2)*
>
> *"This is an 'I gotcha' system." (Female, Parent Group 2)*

Other parents, however, did express an interest in this type of system because it allows for customization, mapping of problematic locations, and monitoring of teens in real time as needed. The parents believed that this system would serve as the starting point for specific discussion with their teen driver.

> *"I think what's good about this is if there is a particular road that is a [safety] problem… you can bring it to the attention of the police." (Male, Parent Group 1)*

One mother was nervous that her worrying would drive her to continually track her son's driving. She stated that her own behavior would need to be modified if she were to use this type of system. Another mother acknowledged that she didn't want to know everything her teen does and everywhere he goes, even if she would not approve of some activities. Another parent noted that this system might be more acceptable if teens were given the opportunity to correct bad behaviors before they are reported to parents.

Parents generally supported the use of summary reports, especially if they present change in driving performance over time. This option also allows for discussions with teen drivers and review of problem locations. This might allow for evaluation of need for further parental supervision in the vehicle. Another positive aspect of this system is the potential to avoid the Internet which is a source of concern for some of the participants.

3.1.6 Use of in-vehicle monitoring device in various programs

Teens believed that during the GDL phase there are already enough restrictions without the monitoring device. Some teens felt that use of monitoring technology is just an extension of the learner's permit and that there is no need for a further delay of independent driving.

> *"It's just like a learner's permit but with a camera instead of a parent." (Male, Teen Group 2)*

One suggestion was that a device should only be installed for teen drivers who have already proven to be untrustworthy; for example after a third moving violation. Another option was if an incentive were offered by the insurance company or another entity it might be worthwhile to use a monitoring system.

> *"If I were paying for my own insurance I wouldn't mind obeying the rules making sure that the system didn't go off to be able to get lower insurance rates." (Male, Teen Group 2)*

Most parents believed that the provisional phase of licensing is the best time to have any type of monitoring system, and that monitoring is not necessarily an appropriate tool once the teen is a fully licensed driver without restrictions.

> *"It's good for provisional period, [but] after that it crosses over to an invasion of privacy." (Male, Parent Group 2)*

A number of parents suggested that monitoring devices should be required by law during the GDL licensing phase. This would reduce negative reactions from teens and minimize conflict with parents since all teens would have to go through the same process.

"If everybody had it, it would be a lot more acceptable." (Male, Parent Group 1)

Finally, one parent suggested awarding merit points towards college applications for using the system. Parents believed that even among parents who are not disciplinarians there would not be protests since the goal is to increase safety.

3.1.7 Interest in utilizing an in-vehicle monitoring device

The teen participants felt that teens are already under enough restrictions. Some completely rejected the monitoring concept while others acknowledged that monitoring technologies could be useful tools for parents. One participant indicated that he would want to protect his child and that a monitoring device could help by building safer driving patterns. However, the teens indicated that it is important for parents to trust them and to monitor their behaviors only under certain conditions.

> *"If you feel the need to have your kids on a "baby monitor" all the time… if you don't trust them enough and you feel like you need to watch them then you shouldn't be letting them drive in the first place." (Male, Teen Group 2)*

Parents felt that these monitoring systems show great promise in reducing injuries and fatalities among teens. They see the monitoring devices as learning tools to help teens become better drivers. A few indicated that if they faced a problem of trust with their teen or there were too many examples of poor driving behavior (tickets) then the device would be a useful tool.

A couple of parents indicated that teens might not accept such devices willingly. However, other participants stated that if use of the device is required by law or even if a parent chooses to use such a device voluntarily the teens will accept the device. Acceptability was thought to be related to the degree of discipline that the teen is used to, as well as the sense of security that parental intervention provides.

> *"Some teens will rebel against it, but a lot of teens will understand that they don't have the experience and this can be used to increase their safety." (Male, Parent Group 1)*

Parents also felt that they could offer tradeoffs to their teens that might make them more willing to accept monitoring devices. One parent mentioned that they could offer their teen the choice between a nice new car with a monitoring system or an old, less desirable car without a monitoring system. More simply, teens could be offered to choice to drive with a monitoring device or not drive at all.

Some parents preferred the idea of renting a device rather than purchasing because they felt that monitoring devices should only be used for a limited time while teens are still learning good driving behaviors. Some parents also preferred to rent because they were unsure whether they would like using a monitoring device and wanted the freedom to discontinue use if they felt that it was not a good fit for them and their teens.

4 Workshop on novice teen driver monitoring

A workshop on in-vehicle monitoring of novice teen drivers was held on May 15, 2008 at the U.S. Department of Transportation headquarters in Washington, DC. The workshop objective was to share the project's initial findings and ideas with a diverse group of outside experts and collaborate to identify best opportunities and needed steps to take full advantage of driver monitoring capabilities. The workshop emphasized the functional monitoring needs and programmatic strategies rather than focusing on the sensor and communications technologies themselves, although remaining cognizant of the opportunities and constraints afforded by current and anticipated technologies. The intent was to provide insights on promising approaches and strategies, issues related to successful implementation, short-term and long-term research needs, and suggested next steps.

The workshop was attended by 35 invited experts, as well as NHTSA staff and the project team (total of approximately 50 participants). The full list of participants is presented in Appendix C. The attendees represented a range of stakeholder groups, disciplines, and areas of expertise, including:

- Federal agencies (U.S. and Canada)
- States and state-related organizations
- Safety advocacy organizations
- Automotive industry
- Commercial monitoring technology
- Insurance industry
- Driver education and training
- Enforcement, licensing
- Research: driving safety, adolescence, technology

4.1 Workshop activities

The morning portion of the workshop was devoted primarily to the presentation of background information, with some opportunity for group discussion. The afternoon portion of the workshop was devoted to group collaborative activities, first in the form of breakout working groups, followed by a full group discussion. Specifically, the morning and lunchtime presentations consisted of:

- NHTSA Welcome and Problem Background
- Problem Framework and Workshop Objectives
- Overview of Candidate Behaviors and Situations for Potential Monitoring
- Associated Technologies
- Parent and Teen Focus Group Findings
- 40-Teen Naturalistic Driving Study

With these presentations as background, the attendees then broke into five separate breakout groups, each dealing with a different approach to teen driver monitoring. Section 4.3 describes the breakout groups and their procedures. The breakout groups had two hours to deliberate, after which the full group reassembled. Each breakout group provided an overview report on its findings and suggestions. The final portion of the workshop was then devoted to full group discussion of the day's presentations and reports.

4.2 Summary of presentations

Six presentations were provided as background for the attendees. Copies of the Powerpoint slides for each presentation are provided as Appendix D. A capsule description of each follows:

NHTSA welcome and problem background (Stephanie Binder, NHTSA):

This presentation briefly described the novice teen driver crash problem, explained the motivation behind this NHTSA project, and indicated the program objectives, which are to (a) identify unsafe behaviors and situations to monitor and the criteria needed to do so, (b) identify and compare the alternative requirements for key components tailored to deployment options, and (c) identify research needs to further develop/implement monitoring technologies. The project component tasks and their status were described.

Workshop objectives (Neil Lerner, Westat):

The context and structure of the teen driver monitoring approach were described and major questions were indicated. The workshop was then described in terms of specific objectives, makeup of the workshop participants, topics to be covered, and group activity for providing recommendations.

Candidate behaviors and situations for potential monitoring (Neil Lerner, Westat):

This presentation addressed the range of behaviors and situations that might be appropriate to consider for monitoring, based on established or likely relationships to teen crashes. It presented numerous driver behaviors, under the categories of: vehicle control; risky/aggressive driving acts; in-vehicle activity; hazard recognition/risk perception; driver status; and prohibited tripmaking. It presented driving situations that might be monitored, under the categories of: passenger presence; environmental conditions; trip characteristics; and roadway characteristics.

Associated technologies (Nic Ward, Montana State University; Max Donath, Michael Manser, and Rich Hoglund, University of Minnesota):

This presentation provided an overview of the technologies available to support driver monitoring systems. Examples were shown of systems that provided driver feedback, reports, and vehicle adaptation. Enabling technology was described for: measuring "who;" measuring "what and where;" communication; and user interfaces, for drivers and for parents.

Parent and teen focus group findings (James Jenness, Westat):

The methods and findings of a set of focus groups were presented. The purpose of the focus groups was to assess parents' and teens' acceptance of various strategies for employing novice teen driver monitoring. There were two focus groups of parents and two focus groups of teens (children of the parents in the parental focus groups). The group discussion covered: parental concerns and controls; use of in-vehicle monitoring technology; reaction to four specific (though hypothetical) systems; and the programmatic use of teen driver monitoring technology. Parent and teen opinions were compared in terms of major concerns, preferences for hypothetical systems, technology-based programs, incentive ideas, and other factors.

Forty-teen naturalistic driving study

The Virginia Tech Transportation Institute (VTTI) is conducting a teen driver naturalistic driving study, co-funded by NHTSA (through the present project) and the National Institute of Child Health and Human Development. At the time of this presentation, 42 private vehicles had been instrumented, driven either primarily by the teen (22 teens) or shared with the parents (20 teens). A suite of vehicle-based sensors provides unobtrusive measurement of many aspects of driving behavior and the in-vehicle and external situation. This presentation described the experimental design and data collection system and showed some illustrative video clips. Data collection was still ongoing but the general plans for data treatment were discussed, particularly as they relate to issues of teen driver monitoring. Some preliminary results were also noted.

4.3 Breakout group procedure

The workshop participants were broken into five groups of about ten people each for purposes of focused discussion and the development of recommendations. Each group included a group leader who led the discussion and a recorder who took notes about the discussion. The instructions emphasized that it was most important to hear a range of opinions from various perspectives, rather than attempting to find some consensus. A two-hour period was provided for the breakout group discussions, followed by a re-convening of the full workshop group to hear and discuss the individual group outcomes. As a means of structuring the problem and giving each group a manageable theme, the breakout groups were structured around different driver monitoring strategies. A definition, with several examples, was provided for each strategy. The three examples provided for each category were selected to illustrate a range of possibilities. There was no implication that these were necessarily good, or bad, concepts and they were not intended to be the focus of discussion; they were simply a variety of possibilities meant to stimulate thinking. The five general categories of monitoring strategies were:

Driver feedback: Teen drivers could receive real-time feedback about errors or risks. Feedback might also be delayed somewhat, so that it is presented at a safe time. The key point is that the driver is made aware of errors or poor driving judgment at about the time the behavior occurs. The specific purpose of driver feedback is to make an error explicit and provide an opportunity to correct it. For example, a signal might sound when the vehicle exceeds the posted speed by a criterion amount. A voice display might inform the driver if an eyes-off-road time exceeds some duration (e.g., 2 seconds). A visual message might be presented if the vehicle enters a prohibited (“geofenced”) location.

Vehicle adaptation: Based on what the driver is doing or the situation the driver is in, some aspect of vehicle functioning can be altered. The specific purpose of vehicle adaptation is to prevent, terminate, or discourage certain behavior. For example, if the vehicle is speeding, the infotainment system could be locked out. If the system senses that the driver is distracted, the criteria for issuing warnings could be modified (e.g., longer time-to-collision criterion). If some potentially hazardous condition is sensed (e.g., the driver is not wearing a seat belt, road is wet, excessive driver-passenger interaction), the maximum vehicle speed may be limited.

Reporting: Reporting refers to recording, and perhaps summarizing, behaviors for review at a later time. The report might be intended for the teen, parents, or other parties such as insurers, driver educators, or licensing authorities. The specific purpose of reporting is to characterize past performance in order to inform and to provide deterrence for negative behaviors or promote positive behaviors. Various technologies might be used to download and transmit the information. The report could include summary statistics, listings of events, details of incidents, evaluative ratings, or other information. For example, a report might provide a detailed log of speeding events, showing dates, times, locations, speed limits, and travel speeds. A report might compile a weekly index of driver performance and show the driver's score relative to a comparison group. A report might include video clips of the scene immediately before and after hard braking events.

Coaching: An intermediary might process and interpret the monitored information and provide the teen driver with explanations of errors and advice for improved performance. The key aspect of coaching is that events are *interpreted* by someone with the relevant skills, so that the feedback to the driver is guidance and not just descriptive. The specific purpose of coaching is to provide the teen driver with critical feedback that makes errors explicit and more appropriate actions evident. For example, video recordings triggered by hard braking events could be transmitted to a service that interprets the scenes and determines what the driver could have done differently. Event data or video might be directly provided to a teen's driving instructor, who in turn uses the information to coach their students during training sessions. Teen peer groups might share event reports and discuss their suggestions of how to handle the situation better.

External motivation: This category highlights how formal positive or negative incentives could be incorporated into a monitoring program. Generally teen monitoring systems have provided information for the teen driver or parent. The use of that information is a family matter. However, there may be incentives, such as lowered insurance premiums, simply for using a monitoring system. Benefits or disincentives might further be made contingent on performance as well. The specific purpose of external motivation is to motivate improved behavior. For example, pay-as-you-go insurance programs might adjust teen drivers' insurance costs based on the amount of high-risk driving they are involved in. Schools might reward students with privileged parking spaces based on safe performance scores from summary reports. A GDL system might extend a provisional period if there is a high incidence of aggressive or risky events.

It was acknowledged that this taxonomy of general strategies was somewhat arbitrary and that the strategies are not mutually exclusive. An effective program might draw on a combination of multiple strategies. However, each of these general categories provided a substantial range of possibilities, issues, and research needs and could serve as the basis for productive discussion without being so broad that the discussion might be unfocused.

The breakout groups covered the following topics in their discussions:

- Successes of current applications of this strategy
    - What has been successful
    - Why did it work?
- Limitations of current practice with this strategy
    - Limited successes
    - Limited range of concepts
- Promising new ideas, expansions, refinements
    - Additional behaviors, situations, measurement refinement
    - New designs, concepts, implementations
- Barriers to new approaches

    - Acceptance: public, consumer, political
    - Technology
    - Institutional
    - Practicality and cost
- Needed research
    - Short term research
    - Long term research

Following the discussion, the breakout group leader and recorder summarized the major points of discussion, for presentation to the full workshop group.

4.4 Breakout group reports

The reporter for each of the breakout groups provided a ten-minute summary of the key findings from their group's discussion. Highlights for each group are presented below. The bulleted key points are organized under five headings for each group:

- Current practice
- Limitations in current practice
- Promising ideas
- Barriers to new approaches
- Research needs

The dynamics of each group's discussion were unique and the various topics received different degrees of emphasis in each report. Key points from each breakout group are summarized in the sections that follow.

4.4.1 Driver feedback breakout group report

<u>Current practice</u>

- Seat belt reminders (extensive ones; mild ones not effective, obnoxious ones effective but annoying). Reason they work: Remind drivers to comply, motivate to remove nasty signal.
- Backup warning device (warning vs. information about distance). Reason they work: Warn or inform drivers of potential collision
- Lane Support System (auditory, visual, haptic). Reason they work: Inform about criticality of developing situation
- DriveCam – limited driver feedback. Reason they work: Feedback and parental feedback/motivation
- Toyota Eye Closure Detection – fatigue detection warning.

<u>Limitations in current practice</u>

- Retrospective Only - the systems typically tell you when you are or have been in an event. Systems are not predictive in that they don't warn drivers far enough in advance to prevent the situation from developing further.
- Arbitrary determination of the threshold of risk at which the warning or information is provided to the driver.

- Feedback should be more informative (e.g., inform the driver what to do in addition to information simply indicating an event will happen shortly or is happening). There must be a low cost to compliance.
- Feedback is often only binary (i.e., warning or no warning; not informative).
- No higher level feedback (information about behaviors/responses that should be implemented by drivers).
- No teaching function (there is a need to teach the driver to recognize developing events; it is always better to prevent a situation from developing than to address it once it has developed).
- Challenge in recognizing driver (i.e. biophysical measures, eye tracking, weight on seat, voice).
- Systems do not account for passenger behaviors.
- Cost is a limitation. Willingness to pay is an issue.
- Limited documentation of system efficacy.
- Systems may promote false sense of security.

Promising ideas

- Systems should include predictive capability.
- Systems should include coaching capability (feedback about errors and proper actions).
- Systems should account for passenger influence (however, how can a system recognize passenger influence?).
- Develop accurate or redundant metrics to identify a driver.
- Increase system capabilities.
    - Cell phone call management: block cell phone calls or let particular calls through (when and what calls?).
    - Systems should evolve based on progression (skill, knowledge, competence) (e.g., restrictions decrease as driver skills improve).
    - Systems adapt to situations (e.g., need for more liberal thresholds under high workload conditions).

Barriers to new approaches

- 'Ignorance Momentum' –many people are not familiar with this technology and it may take quite some time to help them understand the purpose of the technology and convince them to adopt it.
- Potential political ramifications. Politicians may not be motivated to support the technology, which may limit opportunities and incentives for use. Research demonstrating system effectiveness and effective communication of system benefits may help to overcome resistance.
- System use may foster a false sense of security that the system will protect the young driver.
- Insurance legislation. Reduction of insurance fees may be possible, but the fees would have to be deregulated safely by States.
- OEM and 'retrofittable' – systems need the capacity to be installed in all ages of vehicles (i.e., new and older)

- Standardized protocol – A uniform CAN Bus data (open source) format would facilitate the ability of a system to be deployed across a wide variety of vehicles brands.
- Equipment reliability/availability – systems must be reliable and widely available.
- Uniformity of data across geography – for those systems that rely on geospecific maps (for speed data) there is a need for those maps to be widely available (i.e., across States). Some States have this information while others do not).

<u>Research needs</u>

- There is a need to examine how driver feedback systems promote immediate and long-term behavior changes.
- What happens to driving performance/attitudes once the system is removed? Is there any negative behavior adaptation?
- What are appropriate incentives and disincentives?
- What is an appropriate definition of risk? This is important because it directly impacts the level of behavior at which feedback is provided to drivers.
- What is the role and extent of system information? For example, should systems simply warn or should they inform a driver of the criticality. Or should they coach the drivers as to the appropriate behavioral response.
- What is an acceptable price point? (This could have a significant impact on overall adoption of systems.)
    - Insurance premium reduction of some amount?
    - Money paid for a system?
- There is a need to identify the primary factors associated with teen crashes and to develop systems that directly address these. What are the behaviors that a system should address that will provide the “biggest bang for the buck”?

4.4.2 Reporting breakout group report

<u>Current practice</u>

- Aftermarket devices have positive effect on crash rates, but body of evidence is small.
- Reporting can be used to start conversation between parent and teen.
- Reporting may often emphasize negative rather than positive.
- Reporting system is only effective if someone pays attention and makes use of it – there must be consequences.

<u>Limitations in current practice</u>

- Major limitation is getting family acceptance.
- Insurance companies get resistance from customers regarding attempts to collect more data on which to base insurance rates.
- Risky behaviors that are deterred or corrected by reporting may reemerge after reporting stops.

<u>Promising ideas</u>

- Reporting to parents is most promising (short term).
- Incorporate into GDL – report to licensing agency as well as parents (longer term). Reporting could start in the learners permit phase and extend beyond that.

- School-based program.
- Law enforcement involvement is seen as not promising.
- Provide incentive for good behaviors rather than punish bad behaviors.
- New generations of teens are more accustomed to technology, may be more accepting.

Barriers to new approaches

- Reporting to parent strategy requires committed parent or other responsible adult.
- Identification of driver is a barrier which may be overcome eventually through technology.
- Parental and cultural acceptance; trust between parent and teen as well as trust in the system to have positive results.
- Too much information to the parent (e.g., overly large, detailed, or frequent reports) may inhibit parental use.
- Legislators are not ready to accept systems.
- Lack of empirical data on effectiveness of approach; limits acceptance.
- Unsure what best measures are to predict crashes or unsafe driving.
- If reporting becomes pervasive among teens, insurance companies will be less able to provide incentives for their use.
- Significant delay in fleet penetration.

Research needs

Short term:

- How to make reporting acceptable to families?
- What information do parents want?
- How often/frequent should reports be delivered? What format/medium?
- Should reports be delivered to teens, parent, or both?
- How much would parents spend to use a reporting system?
- What measures best predict risk factors, unsafe driving?
- How do parents use reporting information?
- What are the right incentives for teens?
- What happens when reporting is removed? Is long term learning preserved? Do unsafe behaviors emerge in absence of reporting?

Long term:

- How can reporting be integrated in GDL logistically? What are the consequences of doing this? Safety benefits?
- Research focus on families who are not inclined to use reporting system. What would they need to accept and use a system?
- Cost/benefit analysis.
- Use aggregate reported data from many vehicles (anonymously) to answer research questions.
- Vehicle/infrastructure cooperation – can this be used to enhance reporting?

4.4.3 Vehicle adaptation breakout group report

Current practice

- Seat belt reminders – seem to work
- Adaptive cruise control – somewhat controversial; teens do not get needed experience
- Electronic stability control
- Alcohol interlock

Promising ideas

- Distraction monitor: lane departure warning, eyes off road warning, teen passenger occupancy, cell phone use control (text messaging), infotainment use control
- "Around the corner/over the hill" obstacle detection
- Use fuel efficiency sensing (typically highly correlated to good driving behavior)
- Headway monitor
- Seatbelt interlock
- Intelligent speed adaptation
- Curve/speed warning
- Risky driving monitor (e.g., acceleration/deceleration sensing at stop signs or traffic signals)
- Biometric ID sensor
- Driver task demand sensor
- Wireless communication (parent, authorities, insurance)

Barriers to new approaches

- Requirement for accurate map database of speed limits
- Requirement for better curve data
- Lack of incentives provided by insurance industry
- OEM buy-in (may require Federal regulation or mandate) to provide access to in-vehicle data
- Concerns about vehicle data access by police
- Anti-hacking software and hardware
- Political and institutional barriers (e.g., seat belt interlock prohibition)
- Cost of systems (mandate may help supply and demand; state by state variation may limit demand)

Research needs

Short term:

- Research on novice drivers' response to warnings
    - Intelligent speed adaptation, curve speed warning, eyes off road time
    - Feedback modality: sound, voice type
    - Threshold for automated control (e.g., take over if the teen is not taking appropriate action)
    - Threshold for reporting
    - Threshold for progressing through stages of GDL

- Research on risky driving sensing and how to identify it in teens
- For intelligent speed adaptation, thresholds for over-speed driving
- Research investigating real-time feedback (e.g. increase in car noise proportional to speed; lower suspension if speed is too high; haptic feedback in pedals for high speed)

Long term:

- Behavioral adaptation with teen driving countermeasures – will teens become dependent?
- Field operation test to evaluate unintended consequences of automated/new devices

4.4.4 Coaching breakout group report

Descriptive aspects of coaching

- Who: coaches may be parents, instructors, avatars, peer-to-peer, state/licensing, insurance companies, trainers (of instructors)
- What: video, raw event data, summarized data, comparative (normed) data
- Defining coaching: interpretive feedback, motivating, correcting, adaptive instructional message, providing incentives (rewards and punishments), building credibility
- When: the more proximal the feedback, the better – immediate (within an hour), delayed (2-7 days), periodic (weekly), variable (event-driven)

Current practice

- Various recent or under-way video-based coaching programs look promising. Behavior changes are seen, including seat belt compliance near 100%
- Israeli work (GreenRoad Technology) where feedback for coaching is based on monitored aspects of performance (rather than video) has appeared promising but may not necessarily transfer to the North American market because of different driving cultures. Also do not know details of the algorithms.

Limitations in current practice

- Lack of baseline data that accounts for maturation effects.
- Parenting styles, parent knowledge.
- Permissive, authoritarian, authoritative – how to predict relation of parenting style to risky driving.
- How do we increase parental involvement?

Promising ideas

- Less is more; driver generally knows what they did, don’t get too preachy.
- Event-based snapshots (rather than video); don’t know if this would be effective.
- Coaching metaphor itself – providing support and reinforcing; special role of parent.
- Sources for potential funding to support use of systems.
- Promote recognition that the technology exists, pays for itself.
- Technology facilitates conversation between parents and teens, more parental involvement.

Barriers to new approaches

- Lack of recognition of technology and its helpfulness, by parents and teens.

- Too much data – parent could get inundated.
- Adults may not be comfortable with technology; and some technology may be too complex.
- Cost.
- Effects on parent/child relationship.
- Limitations to parent knowledge, needs for parent training.

Research needs

Short term:

- Baseline data against which to evaluate effectiveness. Data must be specific to the behaviors the technology addresses.
- Adoption of technology – marketing research on how to make the service attractive; how to get past the negative aspects of "monitoring."
- How to best implement programs.
- Parent/teen communication.
- Who quits program and why.
- Benefits of coaching from varied sources (e.g., parent, professional instructor, monitoring service provider).

Long term:

- Effects of coaching on crash involvement: injuries, fatalities, property loss; both short term and longer lasting effects on crashes.
- What type of information should be given, how much?
- Who benefits most from the program? (e.g., high event frequency drivers, certain parenting types)
- Influence of the program on *parents'* driving.
- Influence on teen peers' driving.
- Influence on passenger behavior.

4.4.5 External motivation breakout group report

Current practice

- The group did not know of any *teen-specific* monitoring systems and external motivators associated with such a system. However, several monitoring and feedback systems were noted as successes:
    - Monitoring with ignition interlocks: This system is based on progressive sanctions and is activated when a driver registers with a BAC above the legal limit. The car won't start—extending the driver on the program which can lead up to suspension of the license. When there is the possibility of suspension status on a license it tends to make people more careful drivers. After 2 years of the program this effect lasts longer.
    - Seat belt reminders: Passenger vehicles with these systems have shown belt use rates about 3-4% higher than other passenger vehicles. They motivate belt use by providing supplementary auditory and visual reminders.
    - Lane departure warning system: Resulted in increased turn signal use.

- Other known external motivators related to teen driving (but not related to teen monitoring through vehicle adaptation or feedback).
  - Good student discount programs: insurance companies award discounts based on good grades in school.
  - Economic incentives, such as “Pay as you go” programs (people respond to price) in which if you drive fewer miles you get lower insurance premiums; based on exposure risk (used in UK and they have extensive policies; successful financially for companies).
  - Traffic law enforcement is an external motivator; enforcement efforts drive home the point during enforcement campaigns (such as Click it or Ticket and Over the Limit/Under Arrest) but this is reinforced throughout the year.
  - Parent programs with insurance company: parents and teens watch safety video followed by discussion, sign a contract and get insurance premium discount for participating in program. There is a correlation with fewer incidents or claims for these participants (may be self selection).
  - Driver improvement programs triggered by driving violations (many teens wind up in these). Effectiveness is unknown.
  - Signage that tells communities about seat belt rates and other traffic safety feedback.
  - Peer feedback; social norming.
  - Social marketing campaigns, such as “The Truth Campaign” against tobacco companies. This influenced teen smoking behaviors and could inform programs/strategies aimed at providing external motivators for teen driving.
  - GDL has some rewards— new drivers graduate to full licensure if they have a clean record. The unrestricted license itself is a big motivator.
  - Checkpoints program: parental monitoring and parent and teen contract seem to reduce risky driving. The program is primarily based on disincentives for bad behavior, but could build in rewards for good behavior.

<u>Limitations in current practice</u>

- The judiciary system can sometimes be counterproductive; judges are lenient on new drivers and first time offenders. This goes against teaching kids logical consequences; does not provide the needed structure and can undermine the process. Kids know this and spread the word.
- Time discounts (reduced duration of restriction for good performance) are bad for GDL because they lessen practice time.
- Parents are not always the best enforcers of traffic safety laws and rules. Parents sometimes pay for teens’ cars, insurance, and citations. Parents often don’t like to be punitive or the “bad guy.”
- Peer interactions in car (e.g., too many passengers) can be harmful.
- Education-only programs do not result in desired behavior changes, except that personal stories can be effective and can set a foundation for establishing safe behaviors.
- Teen training on extreme driving courses has not yet been supported by evidence.

<u>Promising ideas</u>

- Build in fun/positive aspect to technology; give the driver feedback and data not related to the safety aspects as an incentive to use the technology. For example, the “OnStar” feature in cars provides GPS navigation but it also serves many safety functions. Technologies currently available in vehicles may be adapted to provide novice driver safety features.

- Parents can use feedback and information that is documented through the vehicle technology to give positive feedback for teens and rewards or privileges—research how to motivate parents to do this.
- Don't isolate teens as the problem. Provide adult and teen driver improvement programs and allow participants to see where they stand compared to other drivers in the family.
- Parents and teens compete—compare results of teen and parent driving.
- Have monitoring system used only as a trigger, e.g., when something bad happens (teen violates traffic law, etc.), trigger the use of monitoring.
- Have technology offer information that helps improve car performance but will also improve driving behavior (e.g., show how slower speeds help reduce fuel consumption—this may impact speeding and aggressive driving). Video screens in cars can be used to include such information.
- Whatever we're monitoring should be good for *everyone*. Need to attract a broader audience.
- Raffles/prizes to get people in studies or prizes for good behavior.
- Pre test of students, deliver programming with incentives (movies, food, etc.) and do another post test. Some local programs have shown improvement with this type of strategy.
- Take usage information and compare it against norms. Show how often positive driving behaviors occur.
- Compete on the Internet. Be able to link together and compete to be the best driver.
- Require a parent meeting and parent involvement and give discounts for people participating; discount on license or drivers education.
- General theme: for external motivators to work they should primarily be positive.

Barriers to new approaches

- Monitoring systems bring up issues of distrust that parents and teens do not like. For example, an insurance company started the "I Saw You" program- similar to the commercial fleet concept of "How Am I Driving?" Very few people took up the offer.
- Feedback reports: They may not be an incentive if they are too long, complicated and cumbersome. Is there a different way to give feedback?
- Down side of positive feedback—could it make teen drivers complacent? What if they're better but still not good? Keep in mind there is always room for improvement.
- Monitoring features/programs can't have negative impact on insurance. Customers don't want to pay or see the cost of technology/device or program (better to build the cost of the program in the premium).
- It may be unwise to tie traffic safety programs to school performance. Parents and students would be reluctant to have any program that jeopardizes academic standing.

Research needs

- Is monitoring appropriate to implement at this point or are there questions we need to answer before we start monitoring? What should be monitored?

- How can parents be motivated to use technology options? There are free programs that few families have taken advantage of (i.e., Drive Cam—giving away for free but the penetration rate is small—but it may be seen as an intrusive system. If it was less intrusive or monitored less, more people might participate).
- Conduct a multivariate analysis that predicts losses from OBD (black box). If we knew what was resulting in a better rate we could reward drivers. Every year on average everyone has a loss.
- Acceptability versus effectiveness. If we make technology too aggressive it may be rejected. What do we need to do to offset irritation for teens and parents so they will put up with the annoyance? Can we go further if we provide more?
- What are the effects of incentives on teen driving? Positive and negative incentive effects.
- Would need large studies with many subjects and control groups to ascertain effectiveness of external motivators (teen driving improves naturally over time so control groups would be needed to account for this factor).
- Black boxes: get more info out of black boxes to see if data would help us understand external motivators. This goes beyond GDL, but there are privacy concerns.
- Teen market: if insurance rates could be affected in substantial way we could see benefits. Price the riskiest drivers. National program; put in reauthorization. Give insurance companies incentive dollars or tax credits to implement.

4.5 Additional discussion points

A number of additional points or areas of emphasis were raised in group discussion. One concern was with the semantic issue of using the term “monitoring.” This was seen as having negative connotations and implying a punitive or invasive approach. It was also suggested that this terminology would make the concept unappealing to lawmakers. There were suggestions to use terminology that emphasized the positive aspects of these technologies. Others felt that “monitoring” was an accurate descriptive term for this broad enterprise of sensing and responding to driver behaviors and situations. The term may be appropriate for the scientific enterprise even if other terminology may be more desirable for interaction with the public.

There was considerable discussion of the need to find ways to promote greater interest in and use of teen driver monitoring technology by the public. Research on how to stimulate use and acceptance by parents and teens was called for. The need for political interest and action was also discussed. Some felt that formal legal or administrative requirements were concerns to be dealt with in the future and that the current focus should be on motivating individuals. Others felt that it was appropriate to seek legislative interest at this time.

The Coaching breakout group raised the concept of an avatar for communicating information and advice to the teen. This raised more general discussion of a “teen-centric” approach and the need to consider teen preferences and culture in developing feedback and communication for driver monitoring programs. The avatar concept was seen as potentially appropriate for both real time feedback and off-line monitoring.

The link between safer driving and environmentally conscientious driving, as well as economical driving, came up several times. There was interest in trying to tie these issues together in promoting improved driver behavior. There was also a suggestion that this may provide an avenue for engaging oil industry support, particularly as it might help improve this industry's public image.

Other discussion centered on the question of whether the very high rate of teen driver crashes reflects a generally high risk for this population as a whole or whether it is particularly attributable to a subgroup of extremely high risk drivers. The answer is important in that it has implications for how one might design feedback and programs for teen drivers. It also relates to fairness issues for various policies. The answer to the question was not apparent, and strong opinions were expressed for both positions. Some driving studies (e.g., McGehee, Carney et al., 2007) have observed low event rates among many teens but high rates (at least initially) for a subgroup of the teens. There was some discussion of the possibility of addressing this through large scale naturalistic driving studies. While studies such as the VTTI 40-teen study may shed some light on this issue in terms of the prevalence of undesirable driving acts, it would take a much larger study to address actual crash risk.

4.6 Conclusion

The NHTSA Workshop on Novice Teen Driver Monitoring brought together fifty experts with diverse backgrounds and perspectives to explore the potential of monitoring strategies and consider subsequent steps. The group considered the range of strategies, successes and limitations of current practice, innovative implementations of monitoring technology, barriers to implementation, and research needs. There was clear enthusiasm for the potential of in-vehicle monitoring technology to help address the exceptionally high crash rates experienced by novice teen drivers. However, the group also raised questions and concerns. The ultimate effectiveness, public acceptance, and optimal approaches for using monitoring technology remain open issues. Numerous research issues were raised, but also issues of public education, social marketing, economics, privacy, and public policy. Monitoring-associated technologies for recognizing individual drivers, sensing driver behavior, sensing driver state, sensing the immediate and upcoming driving environment, and communicating information to various users (teen driver, parent, instructors/coaches, other parties) are expanding and have become increasingly practical and the vehicle itself may provide many opportunities as a platform for these systems. However, the workshop also identified some limitations to current technology and information systems that might be addressed in order to promote better monitoring systems. Among these issues were: adequate (complete, accurate, accessible) databases for posted speeds limits; adequate databases for road geometry (e.g., curves) and other features (e.g., traffic signals); better access to in-place vehicle capabilities and data and uniformity in access (e.g., CAN Bus); better capabilities related to passengers (passenger presence, passenger attributes, driver-passenger interaction); and data security.

A final point that is difficult to quantify, but clearly came through in the breakout group presentations and the group discussion, is that there is a strong sense of optimism and opportunity among the diverse stakeholder groups represented at the meeting. Despite progress made through past advances, such as graduated licensing programs, novice teen crash involvement rates remain high. Vehicle-based sensing technology is seen as a new approach that could have a very substantial impact on teen driver behavior. There obviously will be challenges in getting teen driver monitoring technologies refined and into mainstream practice but the opportunity to reduce death and injury, and foster long-term improvements to driving habits, is seen as substantial.

5 Findings from teen naturalistic driving study

In parallel with the information search and analytic activities of this project, a research study was conducted to collect new data on teen driving under naturalistic conditions. The study was conducted in collaboration with the National Institute of Child Health and Human Development. The purpose of the study was to instrument the personal vehicles driven by a group of novice teen drivers and record extensive detail on their behavior in the course of naturally occurring travel. The NHTSA contribution to this effort allowed an increase in the number of participants and the sophistication of the data collection system. It also provided for statistical analyses specifically relevant to the development of teen driver monitoring systems. Although complete analysis of the naturalistic driving study requires a time period that exceeds the duration of the present project, many analyses are available at present to complement other project activities.

The Naturalistic Teenage Driving Study collected naturalistic data on 42 teenage drivers, beginning within 3 weeks of licensure and extending through the first 18 months of independent driving. This dataset represents the first data collected on newly licensed teenage drivers to assess both the prevalence of risky driving behaviors as well as the relationship between risky behaviors and actual crash and near-crash involvement. Five research questions were addressed in regard to these two general objectives:

1. How does teen driving performance differ from adult driving performance?
2. How does teen driving performance differ between teens with high versus low involvement in crash and near-crash events?
3. Which driving performance variables are the best predictors of crash and near-crash event involvement for teens?
4. How do teen risk factors (e.g., speeding, presence of teen passengers, etc.) relate to teen driving performance and crash and near-crash event involvement?
5. Using the trigger criteria developed for the Naturalistic Teenage Driving Study, provide an assessment of the effectiveness of the triggers used (i.e., what percentage of triggered events were valid?). What would be the cost/benefit of altering these trigger criteria to be suitable for a teen driver monitoring system?

A brief description of the project methods and key findings are presented in this section. The complete report is included as Appendix E of this report.

5.1 Method

5.1.1 Participants

Forty-two newly licensed teen drivers (*M* = 16.4 years old) and 20 parents (M = 46.8 years old) were tested in this study. Participants' vehicles were instrumented within a period of ±2 weeks of receiving their valid driver's license. Gender was approximately equally divided among teens (51% male and 49% female) but the parent sample was mostly female (69%). Participants were recruited through driving schools and newspaper advertisements. All participants were licensed to drive in the Commonwealth of Virginia and had at least 20/40 corrected vision. Written parental consent, teen assent, and adult consent were obtained for each participant.

5.1.2 Apparatus

The 40-Teen instrumentation package, designed and developed by staff at the Virginia Tech Transportation Institute (VTTI), consisted of a computer (LINUX-based PC) that received and stored data from a network of sensors in the vehicle. In addition to data collected directly from the vehicle network, sensors included an accelerometer box that obtained longitudinal, lateral, and yaw kinematic information, a radar-based headway detection system to provide information on leading vehicles, an incident box to allow drivers to flag incidents, a video-based lane tracking system, and video to validate any sensor-based findings. As illustrated in Figure 1, the video subsystem included four continuous camera views monitoring the driver's face and driver side of the vehicle, the forward view, the rear view, and an over-the-shoulder view for the driver's hands and surrounding areas. Two other cameras provided periodic still shots of the interior vehicle cabin as well as the lap area of the rear passenger seat (Figure 2). The interior cabin view was blurred to protect the anonymity of the passengers yet still allowing reductionists to assess the number of passengers in the vehicle cabin, as well as the general age and seatbelt use of the front seat passenger. The rear-seat lap camera was not blurred as passenger faces were obstructed from view, but still allowed seat belt use, and assessments of age and gender of rear-seat passengers (based on clothing and physical body size) to be estimated. Also included was a global positioning subsystem (GPS) that collected information on vehicle position.

Figure 1. The quad-image of the 4 continuous video camera locations. From upper left to right: driver face camera, forward view, over-the-shoulder, and rear-view

Figure 2. The quad image with two continuous cameras on the top two locations with the still frames in the two bottom locations. From upper left to right: driver face view, forward view, the blurred image of the vehicle cabin, and the back seat passenger lap camera

5.1.3 Data reduction

The data reduction process pertinent to the following analyses included three separate tasks: initial data reduction, straight road segment data reduction, and event data reduction. These three processes are discussed in detail below.

Initial data reduction: Trained data reductionists reviewed every trip taken by each instrumented vehicle. A trip, or trip file, is operationally defined as beginning when the vehicle ignition is turned on and ending when the ignition is turned off. Data reductionists opened every trip and recorded the participant identification number for the driver, the number of passengers present, an estimate of the age category and gender of each passenger, and whether each passenger had a seat belt fastened. This information is not available automatically by any vehicle sensor, and thus had to be performed manually.

Straight road segment reduction: Trained data reductionists also reviewed and recorded a battery of variables for 22 *a priori* selected straight segments of roadway. These segments did not contain any primary or secondary roadway junctions, though entrances into parking lots were sometimes present. Segments were also chosen to represent one of four types of roadways:

1. Two lane undivided highway
2. Divided highway
3. Undivided urban/suburban roadway
4. Divided urban/suburban roadway

The selection process for these road segments and road types focused on relatively high traffic roadways to maximize the frequency of travel for study participants. GPS coordinates for each end of the roadway segment were obtained using mapping software. Each pair of GPS coordinates was then used as a geo-fence: every time a participant vehicle sequentially passed through each of the GPS coordinates (on either end of the road segment), then this segment of data was flagged in the data stream and reviewed by a trained reductionist. Once it was verified that the vehicle did, in fact, traverse the appropriate road segment, the reductionist recorded a variety of variables regarding driver behavior and performance on this straight road segment. Of particular interest to this analysis were secondary task engagement and speeding 10MPH above the speed limit.

The reduction of secondary task engagement involved data reductionists reviewing the video and assessing whether the driver engaged in any of the secondary tasks while negotiating the road segment. The list of secondary tasks and the operational definitions for each are presented in the full report, which is presented as Appendix E, attached to this report.

Speeding was also assessed by data reductionists. The speed limit for each road segment was provided to the reductionists. If the driver ever exceeded the speed limit by 10 or more mph during the segment, the reductionists would record that the driver had exceeded the speed limit by 10 mph.

Event Reduction: Trained data reductionists also reviewed video and the corresponding driving performance data for potential crashes and near-crashes (collectively referred to as *events*). Due to the continuous data collection that resulted in over 6 Terabytes of video and driving performance data, events are identified in the data stream using kinematic data triggers.

Once a potential event was identified, data reductionists reviewed the corresponding video and assessed the severity of the event: crash, near-crash, or judgment error. A battery of variables was recorded for the events that were categorized as crash or near-crash.

5.2 Results

Question One: How does teen driving performance differ from adult driving performance?

Results indicated that teen drivers were involved in more than four times as many crashes or near-crashes per 10,000 vehicle miles traveled (VMT) as the adult drivers (parents of 20 teen drivers) over the first five months of independent driving (6.5/10,000 VMT for teens and 1.4/10,000 VMT for adults). Teen driving performance is thus worse than that of adults at a very gross level. Results also showed that adults exhibited more frequent episodes of secondary task engagement, cell phone use, and speeding than did the teens. While teen drivers showed an upward trend in their engagement in these behaviors, the higher crash and near-crash frequencies, as compared to adults over the first few months, cannot be explained by teen over-involvement in these potentially risky activities, since adults surpassed teens over the first four months in nearly all cases.

Additional insight was then gained by examining frequency of driving in risky driving situations over the entire 18 months of the study. Driving at nighttime was almost twice as prevalent for teen drivers as compared to adults. This is a key finding due to the very high fatality rate of teens versus adults for nighttime driving. On a related note, teens are slightly more likely to drive during curfew hours as compared to adults.

Both teens and adults were highly likely to be wearing seat belts (at least 95 percent of the time for each group). However, driver seat belt use was related to passenger seat belt use in several interesting ways. Both teens and adults were very likely to be observed with all passengers belted (90 percent for teen drivers and 94 percent for adult drivers), but teens were more than twice as likely as adult drivers to have all passengers unbelted. Although it occurred rarely, lack of teen driver seat belt use was also found to be important. A teen driver who is unbelted and carrying one or more teen passengers is over seven times more likely to have all teen passengers unbelted than are adult drivers under the same conditions (Figure 3).

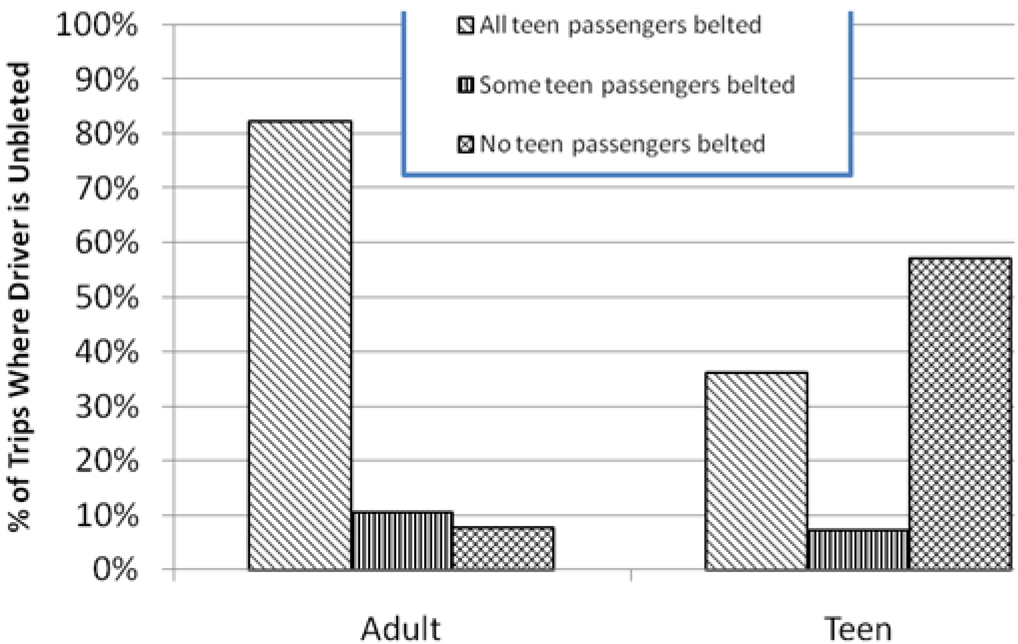

Figure 3. Percentage of trips taken by unbelted teen and adult drivers and teen passenger seat belt use over 18 months of data collection

Question Two: How does teen driving performance differ between teens with high versus low involvement in crash and near-crash events?

The results for this analysis indicate that significant differences existed between the driver groups in that high-risk drivers (teens involved in a crash/near-crash in the first 6 months of driving) engaged in secondary tasks and speeding over the speed limit more frequently than did the low-risk drivers (teen drivers not involved in any crashes/near-crashes in the first 6 months of driving).

The high-risk drivers were not only engaging in secondary tasks of all risk levels more frequently than were the low-risk drivers, but also, and most importantly, more frequently for the known high to moderate risk secondary tasks as well (Figure 4).

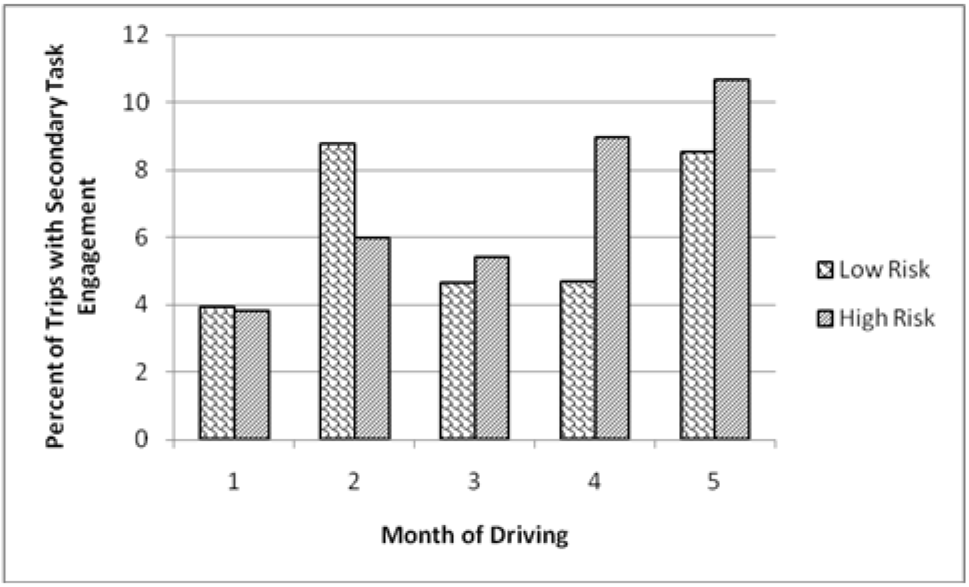

Figure 4. Percentage of teen driver trips where the high- versus low-risk drivers were engaging in high to moderate-risk secondary tasks (those that have previously been shown to increase crash/near-crash risk)

It will also be interesting to follow the two driver groups' propensity for speeding across all 18 months of data collection as the analysis showed that the low-risk drivers' speeding habits were approaching those of the high-risk drivers. Speeding in traffic provides less of a cushion between vehicles, and thus does not provide as much time to react to situations unfolding around the vehicle. Speeding for an inexperienced driver may be the cause of many of the crashes and near-crashes observed for these drivers due to their general inability to accurately judge hazards or to efficiently predict the behavior of other vehicles.

These results provide further evidence that these risky behaviors are associated with higher risks of crash and near-crash involvement. The analyses as discussed in Question 1 demonstrated that while teens actually engaged in these risky behaviors less frequently than did the adult counterparts, the analyses presented here show that the higher risk teens engage in these behaviors more frequently than the lower risk teen drivers and thus these behaviors may be associated with crash/near-crash involvement.

Question Three: Which driving performance variables are the best predictors of crash and near-crash event involvement for teens?

This analysis represents the first attempt to directly assess the relationship between extreme driving performance (hard braking, accelerating, and steering) and crash/near-crash involvement. In order to assess this relationship, 30 trip files per teen driver per month of driving across the first six months were randomly selected and used for this analysis. Using filtered acceleration data (longitudinal and lateral), peak decelerations and accelerations were identified across the entire trip. Maximum acceleration values for each peak were identified. The total mileage per trip file reviewed was also collected and summed for the trip files for each driver. The frequency of peak accelerations for bins (numerical categories) of acceleration was assessed and divided by the VMT per driver.

The results indicated that high-risk drivers braked hard (plus 0.5*g* deceleration) and steered hard (± 0.5*g*) more frequently than did the low-risk drivers. No differences were observed for longitudinal accelerations. Also of interest was an analysis of the percentage of low- and high-risk drivers who engaged in higher levels of braking and swerving past 0.5*g*. The results indicated that nearly 90 percent of the high-risk drivers but fewer than 50 percent of the low-risk drivers performed braking maneuvers greater than 0.5*g*. This represents the point at which the two are most distinguishable and where effective feedback could be provided to bring the high-risk drivers closer to the low-risk drivers' performance levels (Figure 5).

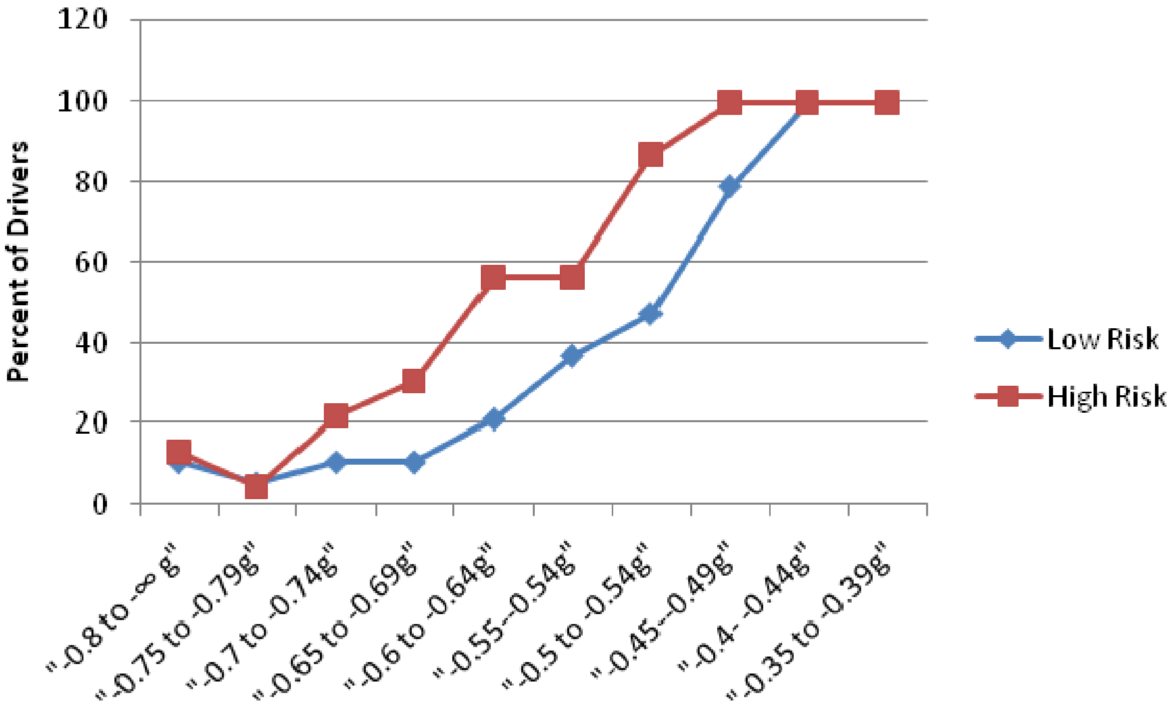

Figure 5. The percentage of teen drivers from each risk group who performed maximum decelerations for each deceleration level

These results also show that extreme driving maneuvers may be associated with crash risk, although more research is necessary before a clear relationship is established. More analyses are required to further assess this relationship; however, these data indicate that if these types of risky driving behaviors can be reduced while the teen is developing driving habits, it may keep teen drivers safer not only as teens but into adulthood.

Question Four: How do teen risk factors (speeding, presence of teen passengers, etc.) interact with teen driving performance and crash and near-crash event involvement?

For this analysis, several teen risk factors were assessed. The results indicated that high risk drivers drove more frequently in the presence of most of these risk factors than did the low risk drivers. The first risk factor studied was driving with passengers. The high-risk drivers were two to three times more likely to violate the law against carrying more than one teen passenger than were the low-risk drivers.

The high-risk drivers appear to have an increased exposure to the high-risk driving condition of driving at night. The percentage of nighttime driving trips was higher for the high-risk drivers, especially for the first five months.

High-risk drivers averaged 1.7 percent of their trips unbelted, and the remaining low-risk drivers were unbelted 0.8 percent of the time on average. An interesting pattern can be observed in that the high-risk drivers dramatically and suddenly increased their seat belt use in the sixth month, and then maintained seat belt use levels near those of the low-risk drivers for the remainder of the study.

Question Five: Using the trigger criteria developed for the Naturalistic Teenage Driving Study, provide an assessment of the effectiveness of the triggers used (i.e., what percentage of triggered events were valid?). What would be the cost/benefit of altering these trigger criteria to be suitable for a teen driver monitoring system?

The trigger criteria for the Naturalistic Teenage Driving Study were developed to identify crashes and near-crashes, which is not the same goal for an electronic co-pilot system. These trigger values would need to be modified slightly; however, the results from Question Three suggest appropriate triggering levels to help reduce risky driving performance behaviors for the high-risk drivers. This analysis focused on the most useful triggers and those that were most easily identified in the kinematic data.

Four triggers were evaluated:

- Forward time-to-collision (*FTTC ≤4 seconds coupled with long decel ≤-0.6g)*
- Forward time-to-collision with range (*FTTC ≤4 seconds coupled with long decel ≤-0.5g and less than 100 feet distance to lead vehicle)*
- Longitudinal deceleration (*≤-0.65g long decel)*
- Lateral deceleration (*≤-0.75g or ≥ 0.75 g lateral acceleration)*

These four triggers identified more than 3,000 possible events. Of the possible triggers reviewed, trained data reductionists validated approximately 12 percent. The two triggers with the highest valid to invalid ratio were the longitudinal deceleration trigger and the forward-time-to-collision trigger (Figure 6). Twenty percent of all longitudinal deceleration triggers and 18 percent of the forward time-to-collision triggers were valid.

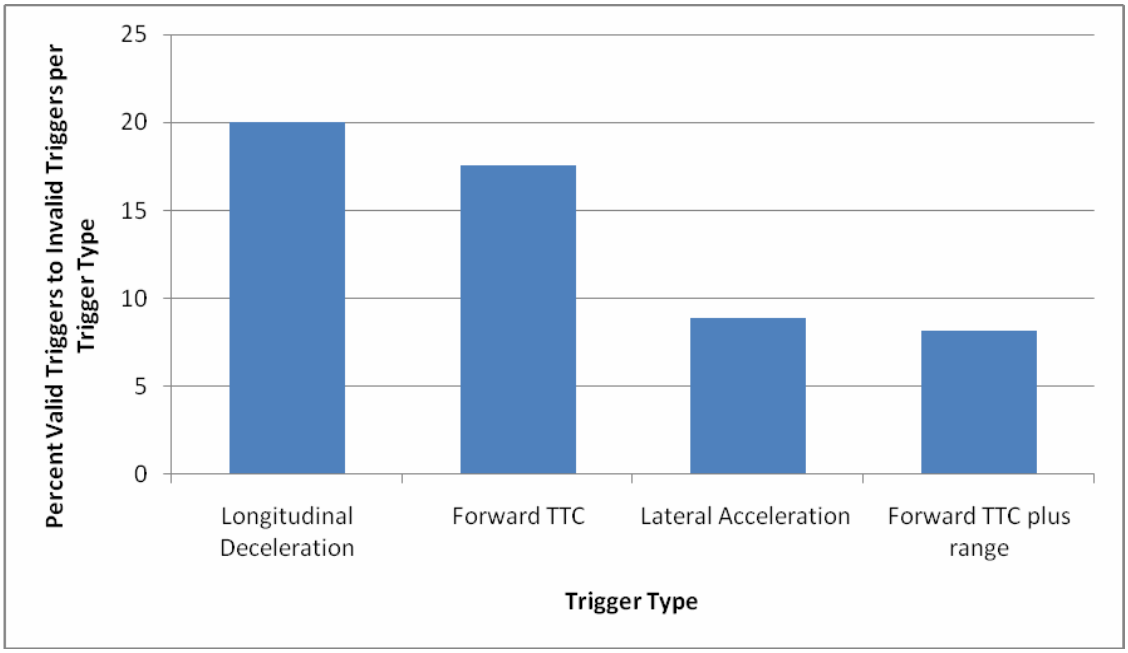

Figure 6. Percentage of valid triggers for each trigger type

Of the triggers that were valid, the percent contribution of each trigger type is shown below in Figure 7. So while longitudinal deceleration is the most easily and efficiently found type of trigger, the forward time-to-collision plus range makes up the greatest percentage of valid events, followed by longitudinal deceleration. This result compounded with the high percent of forward time-to-collision triggers lends credence that both sensors are important for identifying and validating 'coachable' events.

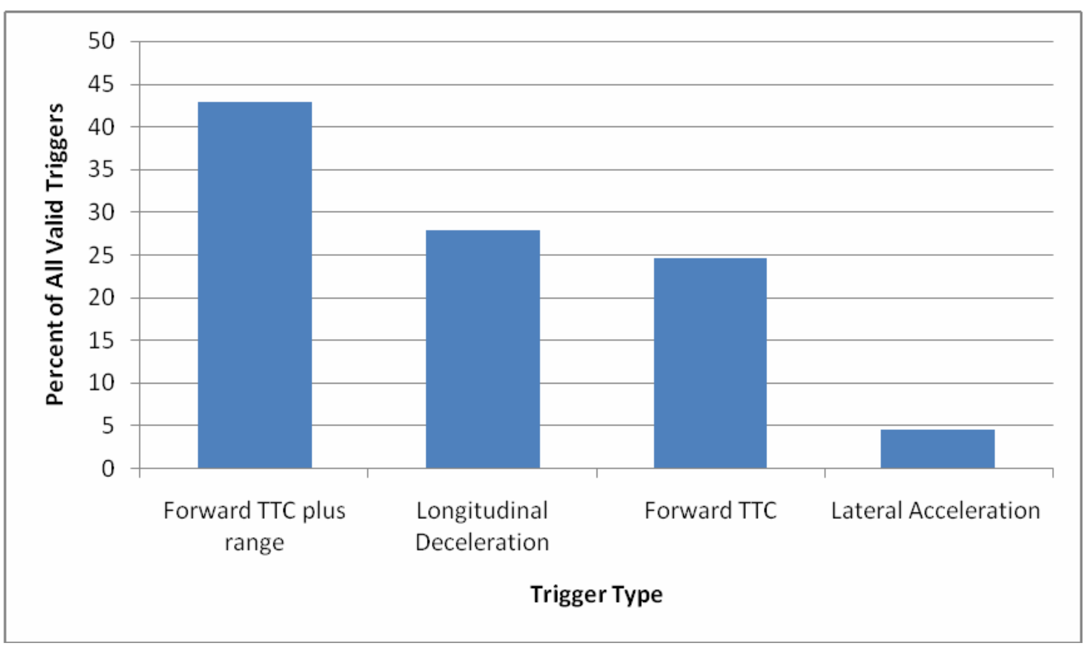

Figure 7. The percent of valid to invalid triggers for each trigger type

Many events are identified through multiple triggers. An analysis was conducted to assess the percentage of these triggers that were identified by both forward TTC plus range and longitudinal deceleration. Twenty-five percent of the Forward TTC plus Range and 50% of the longitudinal deceleration triggers were triggering the same event. These results suggest that not one or two measures can identify the majority of events but that multiple measures are required to identify both critical and 'coachable' events in the data stream.

5.3 General conclusions

The results from these analyses provide support that teens do engage in risky driving behaviors across the first few months of driving. The prevalence of engagement in these risky driving behaviors, in many instances, appears to increase across the first four to five months of driving as the teens become more comfortable with the mechanics of driving. These behaviors that can be easily monitored (hard braking and turning maneuvers) also appear to be associated with increased crash/near-crash involvement. It is not clear whether the association between these behaviors and crash risk is a causal or correlative one. That is, are the "high risk" drivers at greater risk *because* they engage in these behaviors or are the behaviors merely correlates that suggest who the at-risk drivers might be? In either case, the finding may be useful for the design of teen monitoring systems. To the extent that the relationship is causal, effective feedback to teen drivers may decrease the prevalence of these behaviors, so their involvement in crashes may also be reduced. To the extent that the behaviors identify at-risk teen drivers, the information could be used to adapt warning and feedback algorithms to adjust for the greater risk.

The results from this analysis also indicate that secondary task engagement, speeding, hard braking, and steering all appear to be related to crash/near-crash involvement. Teen driver monitoring systems should attempt to include some method of monitoring these behaviors and provide feedback to help reduce teen involvement in crashes and near-crashes.

These analyses represent a first step at assessing not only exposure levels for teen drivers to known risk factors but also the prevalence of various risky teen driving behaviors. There are very little data or analyses on these types of research questions in the teen driving literature and these represent a valuable contribution. Most of the analyses on driver behavior presented in this report were conducted on either the first four, five, or six months of driving (extending to 12 or 18 months in a few cases). In many of these analyses, trends appeared to be or were found to be significant. Most of these analyses should be conducted at a future date on all 18 months of data, as these analyses/results would greatly contribute to the knowledge gaps in the current teen driving literature.

6 Research plan

Teen driver monitoring for the purpose of improving behavior and increasing safety is a new and promising enterprise, and many important questions remain to be answered. The research plan described in this section was devised to address the most critical knowledge gaps, as identified through a literature review and the earlier tasks performed under the present project. As in previous sections of this report, the phrase “driver monitoring” refers to both the monitoring aspect and the use of monitored data (e.g., for driver feedback, reporting, coaching, vehicle adaptation).

6.1 Approach to defining research goals

This section deals with the needs for further research on monitoring technologies for teen drivers and provides recommendations for specific NHTSA research. One of the difficulties in describing research options is the great number of possibilities for novice teen monitoring research applications. As earlier sections of this report indicate, there are many program concepts, options regarding which behaviors to monitor, technological options, feedback strategies, incentive structures, and so forth. Taken together, these options generate more possibilities than we can possibly evaluate in an initial research program. There are so many existing, and near-term, options for the use of vehicle-based technology that we should view teen driver monitoring as a general way to approach novice teen driving problems, not as a strategy that has a single specific “best” solution.

The ultimate objective of the entire novice teen driver monitoring enterprise is to reduce crashes, injuries, and fatalities associated with young, inexperienced drivers. A parallel related factor is retaining an appropriate degree of driver mobility, since that is the purpose of obtaining a driver's license.

In considering the effects on driver behavior of some particular device or program, attention should be given not only to the effects while the system is in place, but also to subsequent longer term effects once the monitoring is no longer taking place. Furthermore, systems cannot be evaluated simply in terms of their influence on the teen driver’s performance. In order to be fully successful from a public safety perspective, a system must be broadly acceptable and usable across a diverse range of families, so that the safety benefits are widespread. Thus in subsequent discussion, when we refer to “effective” monitoring systems, this evaluation should include safety and mobility measures, short term and longer term outcomes, and product usability and acceptability measures as well as driver performance. Not every study must address all of these aspects, but for any comprehensive assessment they ultimately must be considered.

In developing a research plan, we gave consideration to what role NHTSA may best play in promoting the effective use of monitoring technology for improving novice driver safety. Monitoring technologies are ubiquitous, expanding, frequently cost-effective, and increasingly present in passenger vehicles and consumer devices. Given this availability and flexibility, many organizations are likely to independently explore possible systems and programs. These entities might include research organizations, insurers, the driver training industry, fleet management service providers, licensing authorities, safety organizations, individual States, consumer electronics companies, and individual entrepreneurs. There already exists a variety of commercial products, informal program evaluations, and systematic quantitative studies. Based on the enthusiasm shown in the Workshop on Novice Teen Driver Monitoring, it is predictable that a great deal of experimentation with monitoring concepts will occur. Given the wide range of possibilities and the current climate of interest, what research might NHTSA undertake that will advance the field and discourage ineffective or inappropriate systems?

While there are many worthwhile research issues that might be profitably addressed, there are several key areas where research needs may not be adequately met, or addressed with proper rigor, in the absence of NHTSA involvement. In the sections that follow, we summarize the broad range of research needs, and then focus a plan on those issues where NHTSA's role might be most essential. In outline, those key issues include:

- Basic research
    - Aspect(s) of monitoring that matter most for safety and acceptance; minimum and optimum requirements
    - Applications of vehicle adaptation
    - Most critical sets of driver behaviors for monitoring and for evaluation
    - Family-based issues for program effectiveness
- Coordination and integration of research activities and findings
- High-quality field evaluation to quantify safety and other benefits and programmatic lessons learned. The ultimate objective of this evaluation should be to establish performance standards for teen monitoring programs and devices.

6.2 General set of research needs

Many significant research issues were raised through the course of this project, including the information search, analytic activities, and workshop. Table 2 presents a set of 42 research needs under primary headings. The needs are presented at the level of general research questions, rather than narrower research hypotheses. The research needs are grouped into three broad categories: evaluating systems and programs; system design; and use and acceptance. There are then two or three subcategories under each of these. The particular statements of research need are then provided under one of the eight subheads. The structure of the table provides a convenient way to relate the various issues and helps make evident the broader concerns under which these specific needs fall. The suggestions of the breakout groups in the Workshop on Novice Teen Driver Monitoring were an important source for many of these needs, but others are derived from limitations in the literature reviewed for this project. While this set of research needs is not exhaustive, it is a broad set that illustrates the range of questions that merit treatment. The research needs in this table provided a starting point for consideration of the recommended research plan.

Table 2. Research issues

Evaluating Systems and Programs	**Evaluating driving performance and crash effects** • Field test to demonstrate/quantify benefits, including appropriate control groups • Immediate and long-term effects of monitoring • Establishment of baseline normative data, for assessing program effects and for providing feedback on relative performance • Establish match of monitored information to characteristics of teen driver

	crashes (how well do behaviors and situations monitored by the system relate to crash events?)
Evaluating Systems and Programs	**Other possible effects** • Unintended consequences, behavioral adaptation • Effects after monitoring period ends • Costs (financial and other), cost/benefit analysis • Effects on degree of compliance with GDL restrictions (e.g., night driving, multiple teen passengers) • Effects on mobility, exposure, role (as driver or passenger), number of occupants • Effects on "green" driving, fuel and operating costs • Influence on driver's peers (as passengers; as drivers)
System Design	**What works best to influence teen driver behavior?** • Effective incentives and sanctions • Define the critical aspects of monitoring: learning versus motivation; awareness of being monitored; incentive or sanction; parental interaction; relative performance/competition • Relative benefits of positive and negative feedback, consequences • Source of coaching or feedback
System Design	**Vehicle adaptation** • Context-sensitive algorithms • Restrict functions • Modify vehicle performance
System Design	**Features and capabilities of monitoring systems** • Determine optimal set of behaviors and conditions to monitor • Determine appropriate thresholds for system actions (e.g., how to define an "event," when to trigger a message, when to alert parent, when to take intervening action) • Enhance and evaluate capabilities for predictive warnings and instruction • Enhance and evaluate capabilities for monitoring distraction • Enhance and evaluate capabilities for driver recognition and tracking • Enhance and evaluate capabilities for passenger interaction • Enhance and evaluate capabilities for *relative* speed monitoring (relative to posted speed, relative to other traffic) • Adaptive systems: system performance is modified based on current situation (e.g., workload) or progression of driver skill • Develop and validate composite "risk" measures of driving performance
Use and Acceptance	**Family use and dynamics** • Appropriateness for different families, parenting styles • Influences (positive or negative) on parent-teen communication, trust • Ability of parents to use information and provide feedback, coaching • Parental willingness to acquire/review/use information; sustained monitoring over time

	• Communications medium availability and interface usability in home environment: computer, cell phone, PDA • Consumer ability to make required hardware or software installation
Use and Acceptance	**Consumer/user motivation and acceptance** • Motivating parental use, awareness of benefits • Making acceptable to the teen • Customization and personalization of system features and information output by teen and parents • Promoting use by families least inclined to use and/or most in need of use • What information and capabilities do parents want; correct amount, type, and frequency of information • Acceptable burdens of cost, effort, duration
Use and Acceptance	**Cultural and political** • Find ways to link safe driving with more environmentally friendly ("green") driving and/or more economical driving, and associated monitoring of fuel efficiency • Address cultural and political attitudes towards monitoring, intrusion, restriction • General social marketing needs related to awareness of novice teen crash problem and monitoring potential • Making it OK for parents to use monitoring – evaluate strategies that foster use of monitoring devices without generating teen resentment (e.g., insurance breaks, informing about safety benefits, incentives for teen, GDL requirements or recommendations, school programs)

6.3 Research plan

The research plan recommended here has six components. Four of these are areas of fundamental research that will inform any program of teen driver monitoring. These would involve field or laboratory research to understand what aspects of monitoring matter most, what driver behaviors are most appropriate for monitoring and for assessment of benefits, and how systems can be made effective within the family context. These are key research issues that may not be adequately addressed in the absence of NHTSA or other federal support because they are a step removed from actual system design and implementation. They will provide an objective, empirically established basis for system design that is currently lacking.

Another component of the recommended research approach is to foster the coordination and integration of research activities and findings by diverse entities. As discussed earlier in this section, it appears likely that there will be much experimentation and evaluation with very different types of systems and programs, funded through many different private sector, public, and non-profit organizations. Furthermore, the work certainly will be international in scope, as we are already seeing products and programs from other countries (e.g., Israeli "Green Light for Life" program; Lotan & Toledo, 2005). There is no apparent systematic means for identifying such activities, evaluating them, integrating results, sharing findings, and providing a mechanism for these diverse efforts to inform one another. Filling this integrative role may well prove as productive as adding another R&D effort to what is already going on.

A final component of the proposed plan is for a large scale field evaluation of the actual benefit of novice teen driver monitoring. Scientifically rigorous and objective testing on an appropriate scale is required. This type of evaluation is very important for three reasons. First, it is essential to confirm that there is a meaningful and lasting safety improvement, and reasonable cost/benefit analysis, to a monitoring program. Although we anticipate a reduction in crashes, and early (though limited) studies found driving performance improvements, the controversy from the inability to find robust benefits to driver training programs (Vernick, Li, Ogaitis, MacKenzie, Baker, & Gielen, 1999) underscores the need for rigorous empirical, and quantifiable research to demonstrate benefits of monitoring. Second, such evaluations can provide important “lessons learned” for the implementation and operation of large-scale programs. Finally, the findings of such an evaluation can provide a benchmark for assessing other designs of systems and programs. As noted, many alternative designs for sensors, feedback, communications, rewards or punishments, and programmatic aspects are possible. If some basic approaches can be established as valid, and their benefits quantified, then these can serve as benchmarks that other concepts may be tested against.

The order in which the six studies are presented here does not imply a recommended sequence. In fact, some of the recommended studies might be combined or omitted, and budget or other considerations might drive what is ultimately done. The sections that follow describe each of these six recommended research program components in greater detail.

6.3.1 Research study: Contributions of basic aspects of monitoring systems

Background and problem description

Monitoring systems have been implemented in fleet vehicles and in personal vehicles, and these systems vary substantially in terms of implementation strategy, types of feedback and reporting, user interface, incentives, and so forth. Similarly, when these systems are evaluated, the methods and measures used to determine driver response and safety benefits differ from study to study. Evaluations have typically found that monitoring systems have significant safety benefits, but it is not clear what particular aspects of these systems are most effective in improving safety. While studies have found reductions in unsafe behaviors and crashes, the particular features that provide these benefits are unknown. Despite the apparent successes of current monitoring devices, it may be possible to achieve greater safety benefits and greater user satisfaction by specifically including the most effective program components and excluding components that do not have proven benefits.

What has been missing is research that experimentally manipulates and evaluates individual components of monitoring systems to determine their contributions, individually and in combination, to system effectiveness. Discussions at both the 2004 and 2008 workshops on teen driver monitoring (NHTSA, 2006; Lerner, Singer, & Jenness, 2008) made it evident that very basic questions were unaddressed and that there was no expert consensus on what is critical. For example, the question was raised, how much of the benefit of teen monitoring programs comes simply from the fact that the teen is aware of being monitored? Are system features really that critical or are they essentially subtle refinements of a simple basic effect that comes from knowing performance is under scrutiny? Another fundamental question is whether the benefits of teen driver monitoring come from enhancing driving skills or from inhibiting willingness to engage in risky acts (the driver behavior/performance distinction)? Some systems under development (and some current products) may be rather elaborate and expensive to administer. If they prove highly effective, we may not know to what extent the complexity is required. What will generate a minimally acceptable effect? What is the cost of incremental improvements toward some optimal effectiveness?

The types of questions indicated here are difficult to answer comprehensively, but some basic understanding could provide important guidance for system developers.

Research objective

The objective of the research is to identify the extent to which certain system or program attributes make, or do not make, substantial contributions to outcomes. The intent is not to design some “ideal” system, or to provide detailed cost/benefit assessments of any particular approach. Rather, it is to use reasonable exemplars of particular system attributes in order to characterize the extent to which various features are necessary or effective in improving teen driver behavior and performance. Based on this, the more promising basic frameworks can be expanded and refined in future work and features that do not contribute much can be downgraded.

Approach/anticipated methods

The issue in this study is how driver behavior or performance is influenced (over some extended training period) by various aspects of the monitoring system. As such, the issue is not well-suited for laboratory or simulator research. Ideally, some “base” system can be defined, and then various changes made to it to investigate the contribution of various system features. In the initial stage of the work, the researchers should identify the fundamental attributes of teen monitoring systems that may merit inclusion in the research. Possibilities include:

- Awareness of being monitored versus consequences of being monitored
- Real-time driver feedback versus summary data
- Positive incentives versus sanctions
- Skill training versus inappropriate behavior monitoring (learning vs. motivation)
- Feedback that includes relative performance indices (to some reference group) versus individual data only
- Inclusion of video recording
- Source of feedback: summary reporting, through parents, third party coaching, real-time presentation to driver
- User-selectable features or thresholds

It likely will not be feasible to include all of the factors of interest in the study. Vehicle adaptation strategies are not included in this list because they are explicitly treated in a separate proposed study (Section 6.3.3). Some factors may already be understood on the basis of previous literature. Others will need to be prioritized for inclusion. User focus groups, structured interviews, demonstration trials, or other efficient techniques may help provide some guidance for these decisions. Then the researchers should develop a simple basic novice driver monitoring system that, based on experience to date, will provide a realistic platform from which modifications can be evaluated.

Primary data collection should be based on field trials with volunteer teen driver families, with random assignment to monitoring treatment groups. The intent of the study is to determine if certain basic characteristics of monitoring systems and programs have substantial benefits over others. Given time and cost considerations, surrogate safety measures can be used in place of crashes, and long term effects or highly quantifiable benefits are not necessary.

Potential benefits/payoff

This research will guide further development of products, technologies, and programs toward the most effective general strategies. The relative benefits of fundamental "starting point" choices will be evident so that system developers can devote their refinements to the most productive concepts. The research findings should be adapted into a set of formal recommendations which can be made widely available to industry, researchers, program developers, and other stakeholders.

6.3.2 Research study: Applications of vehicle adaptation

Problem description

Many driver feedback and reporting strategies simply passively monitor what is occurring, and provide feedback/reporting based on that. However, a system could also use monitored information to actively change some aspect of vehicle functioning. The system could directly prevent, impede, or discourage selected behaviors. Vehicle adaptation strategies supplement information intended to promote learning with control that may directly modify behavior. For example, if the system recognizes that a teen is driving, it may limit maximum vehicle speed to some ceiling value (e.g., 65 mph) or to some level above the posted speed limit (e.g., 5 mph over posted speed). As another example, the system might sense some unsafe behavior (non-use of seat belt, excessive speed) and then restrict use of the vehicle's infotainment systems (e.g., lockout the system or limit volume). The system might also restrict or limit access to peripheral devices such as cell phones or other nomadic devices.

Vehicle adaptation strategies may prove quite effective in reducing unsafe actions by teen drivers. However, there is also potential for various negative consequences. They may generate unintended behaviors that may be undesirable. For example, the infotainment system lockout might result in the uncontrolled use of nomadic devices, such as portable media players, with poor interface characteristics for use while driving. They may place the driver in unforeseen risky situations, for example in cases where higher speeds are transiently needed for safety maneuvers or where there are occasional errors in a coded database of speed limits. Conceivably, vehicle adaptation could lead to less learning, or less persistent training effects, because the preclusion of errors prevents good feedback or experiencing of marginal performance or because parents may feel less need for monitoring and intervention. Finally, lockouts and limiters could result in poor consumer acceptance, less use of monitoring technology, and system defeat.

Vehicle adaptation is a strategy that has been used for some time in various fleet management applications. NHTSA has been conducting research in adaptive interface and driver assistance technologies (the SAVE-IT program) that may have great relevance for adaptation to teen driver applications. There is thus a basis of advanced vehicle-based technology research, as well as practical real-world applications, which could be brought to the teen monitoring issue for vehicle adaptation.

Vehicle adaptation strategies thus hold promise because of the potential for active involvement in the ongoing situation. At the same time, they require careful evaluation and cautious application because of the potential for negative effects. Because vehicle adaptation is a special and complex subset of more general driver monitoring approaches, it merits specific attention as a target for a systematic program of research.

Research objective

The objectives of this research are to systematically examine the various sorts of vehicle adaptation strategies, determine their effects on teen driver behavior, and evaluate the best methods for vehicle-based adaptive system design. The study should include the following sorts of adaptive strategies:

- Systems that restrict vehicle or product functions (e.g., infotainment system lockout, communications device jamming)
- Systems that limit some aspect of vehicle performance (e.g., speed limiters, acceleration rate)
- Systems that lockout or limit some aspect of vehicle performance based on driver status (e.g., unbelted seat belt ignition lockouts, alcohol-sensing lockouts, distraction sensing)
- Systems that adapt driver feedback or reporting based on the current situation (e.g., triggers for speed warnings are modified due to passengers, environmental conditions, driver performance history).

Approach/anticipated methods

In many respects, the approach to the evaluation of vehicle adaptation strategies parallels the approach to the evaluation of basic aspects of monitoring, discussed in the previous section. Some preliminary concepts may be screened or refined in simulator or on road testing, but the primary question – how performance is influenced over time – will require some actual implementation with subject drivers.

An important step in this project will be the development of an intelligent system capable of implementing the various strategies and providing the necessary controlling actions, driver feedback, and reporting. The project should make full use of lessons learned from SAVE-IT, as well as other instrumented vehicle monitoring projects (e.g., SHRP 2). The project should identify a key set of alternative vehicle adaptation strategies and provide a demonstration of these using the experimental system.

Primary data collection should be based on field trials with volunteer teen drivers, with random assignment to the various vehicle adaptation and control groups. It will be important to periodically monitor driver subjective response, as well as objective performance measures. This will include system acceptability, driver attitudes, reported changes in behavior, conditions where the system was a problem, etc. The intent in this project is not the highly quantitative evaluation of a specific product or system, but rather the identification of strengths and weaknesses of alternative adaptation strategies. Given time and cost considerations, surrogate safety measures can be used in place of crashes.

Potential benefits/payoff

This research will support the improved design and implementation of vehicle-based adaptive systems for teen drivers. It will help identify potentially dangerous or counterproductive aspects of some vehicle adaptation techniques, in addition to pointing to high-performing strategies. The findings should be cast as guidelines and recommendations for OEMs, product developers, system implementers, and evaluators.

6.3.3 Research study: Driver behaviors for monitoring/feedback and for safety benefit evaluation

Problem description

A very basic consideration for any monitoring system is precisely what behaviors should be monitored. The literature search conducted during the present project (Section 2.2) revealed a sizable set of candidate driver behaviors that are potentially related to teen driver crashes and/or appear to be viable candidates for use in monitoring systems. Multiple candidate behaviors were found under each of various broad categories, such as vehicle control behaviors, risky/aggressive driving acts, in-vehicle activity, visual search, physical status, and trip features. This same literature, however, was quite lacking in providing a good empirical basis for selecting a specific set of behaviors for use in monitoring systems. The teen driver naturalistic driving study (Section 5.0) is not fully analyzed at this point, and may provide some additional insights. Basically, however, we are at a point where a case can be made for many possible teen driver measures, but there is little basis for objective choices. Decisions need to be made regarding both the behaviors that are directly sensed by the system and the descriptive or summary information that is provided as feedback to the driver, parent, or other involved party.

In expert discussion during the 2008 workshop on novice teen driver monitoring, two general philosophies regarding behaviors to monitor were expressed by participants. Some argued that systems should be kept simple. A few basic measures that are obviously related to risky driving, such as speeding and braking, will presumably provide an adequate basis for monitoring and would yield a simple and interpretable outcome for reporting. Others argued that a more comprehensive set of monitored behaviors may produce a greater influence on driver behavior and that the question of what best to monitor is an empirical one. There was also debate over the need to detect and incorporate aspects of the driving context into the monitoring system. For example, should speed feedback take account of the speeds of surrounding traffic, should tailgating definitions reflect traffic density, or should the presence of teen passengers modify the system response? There was no consensus or resolution of these questions at the workshop.

The question of the “best” behaviors to monitor also depends on the criteria for selection. Monitoring aspects that modify teen driver behavior most during the period that monitoring is in effect may not necessarily be the same ones that best maintain performance over the longer term. For example, speed reporting might limit risky behavior most during monitoring, but might have no lasting effect, whereas coaching feedback based on hard deceleration events might result in fewer crashes after the monitoring period ends. Furthermore, the monitored acts that are most effective for use in modifying teen driver behavior are not necessarily the best indices to use in measuring system safety benefits. For example, perhaps speed reporting changes behavior most, but the frequency of hard braking events is a more sensitive measure of crash likelihood than is speed. Thus we might choose one behavior to monitor for use as feedback and another behavior to monitor as an outcome performance measure. Some outcome measures might require sensors or recording in addition to those used for monitoring (e.g., forward radar to measure headway and time-to-collision). While these are hypothetical examples, they illustrate the point that there are multiple criteria that may be used in selecting alternative driver behaviors to monitor. In addition, alternative behaviors may vary in practical considerations such as the cost of sensors, reliability, sensitivity, susceptibility to system defeat, and so forth.

Research objective

The intent of this project is to provide an objective basis for the choice of behaviors and situations to monitor, as well as the conditions and behaviors that warrant reporting or feedback. The goal is not necessarily to define a single “best” behavioral set, but rather to determine the relative benefits of various alternative or additional behaviors. The ultimate choices for actual use in monitoring systems and programs may depend on product-specific considerations, such as target drivers, target consumers, cost, program aspects, and so forth. The project should provide a comparison of alternatives so that system designers know which behaviors provide an adequate basis for a monitoring system, which are most effective in influencing behavior, what added benefits come from expanding the set of monitored behaviors, and what measures are good indices of actual safety benefits.

Approach/anticipated methods

The project should involve both analytic activities and new empirical data collection. It is evident that the very extensive list of potential behaviors is longer than can be incorporated into any practical research study. Initial project activity to identify promising alternatives may take advantage of existing resources. These include major crash data base analyses, meta analyses or other procedures for assessing monitoring studies to date (of which a number are currently in process), and focused analyses of existing data from naturalistic driving studies. The teen naturalistic driving study (Section 5.0) will be one such source. Others may include the currently-planned large scale naturalistic study to be conducted under the SHRP 2 program, which may or may not be available within the time frame of this effort. Other naturalistic studies or field operational tests may not include teen drivers but may suggest the relative sensitivity of alternative measures. The various analytic activities should be used to derive a smaller set of alternatives for the empirical research.

Empirical data collection should involve experimental manipulation of the monitored behaviors. Some data collection will need to be done using actual teen drivers, but it may also be possible to conduct some of this work in extended simulator driving environments. It may also be possible to use within-subjects designs for greater efficiency. As noted, it would be valuable to assess alternatives not only for their effectiveness while the monitoring program is in effect, but also for longer lasting effects on driver performance, once the monitoring has ceased. The longer term effects will be more difficult to assess in a practical manner. Therefore it is assumed that the study will focus primarily on the evaluation of behavior during the monitoring period, but that some resources should be dedicated to the longer term effects, for a selected subset of behaviors.

Potential benefits/payoff

This study will provide a fundamental piece of knowledge for effective monitoring system design that is unlikely to be derived from more piecemeal efforts in individual system development. It should permit systems to be optimally effective without being overly burdensome or expensive. Therefore there should be benefits both in terms of system effectiveness and in terms of consumer use and public acceptance.

6.3.4 Research study: Design for family use of monitoring systems

Problem description

For a novice driver monitoring system to be successful, it must appeal to the families that may use it, must be informative, and must be usable. No monitoring device and associated reporting can have a benefit if the system is not acquired, properly installed and programmed, understood, and used. Therefore it is important to understand what motivates families to use monitoring systems and the success with which they are able to use the system. There is currently very little research that deals with these issues. Most of the initial work has understandably focused on the influence a system has on the teen driver from some specifically recruited population, *given* its presence and assumed proper use. However, there will be little impact on public safety if novice teen driver monitoring systems are not widely used, and particularly if they are only implemented by the most safety-motivated families or lowest-risk teen driver groups.

One aspect of this problem is that families may differ widely in parenting styles, safety attitudes, personal computer (or other communication device) availability and competence, financial resources, and available time. There may not be a one-size-fits-all solution to the optimal design of a program and system.

Research objective

The intent of this line of research is to look broadly at all of the aspects of system design and use that relate to the family as the "user" of the system. The objective is to derive guidance for designing a product or program that is successful at the family household level. This specifically includes consideration of the following:

- Household capabilities
  - Ability to install, program, implement systems
  - Computer/communications availability
  - Parent capabilities for system use
  - Family concerns of privacy, security
- Parental use of information
  - Match to information wanted/needed
  - Understandability of information
  - Appropriate amount of information
  - Requirements for downloading or acquiring information and parental willingness to do this over the monitoring period
  - Ability of parents to use information for coaching, discussion, incentive
- Parent-teen interaction
  - Adaptability, appropriateness of system to different parenting styles
  - Integration of monitoring system into broader parental role in child's driving safety
  - Positive and negative influences on parent-teen interaction, relationship
  - Relationship between feedback to teen and reporting to parents
- What motivates household use of monitoring systems?
  - How to create awareness of options and their benefits
  - As a function of household characteristics
  - Family harmony – acceptance by the teen

- o Appeal to families least inclined to use devices and/or most in need of the benefits of monitoring devices
- o Legal requirements for teen drivers such as those related to GDL or provisional licensure

Approach/anticipated methods

The questions to be addressed in this effort will require a range of approaches, probably including lab and/or home-based usability evaluations, parental focus groups, social marketing studies, and small-scale implementation studies (essentially “beta testing”). The purpose of the implementation studies is not to quantify the ultimate outcomes on teen driver performance, but rather to identify problems and successes in the family’s actual use of the system. This can be accomplished through user logs, automated monitoring of system use, periodic questionnaires, etc. The initial phases of the work would include usability evaluations, user needs definition through various techniques (interview, focus group, survey), and social marketing evaluation. Once options are well-defined, experimental studies can be implemented with various alternatives for system design. A “base” system can be designed, and various modifications or additional requirements can be manipulated. The study should evaluate parental usage of the reported information (frequency, changes over time), problems in usage or comprehension, parental strategies in using the information, and perceived effectiveness. A recurring theme in focus groups and literature has been that some parents (and some teens) fear that monitoring may damage trust and threaten the parent-teen relationship, while others feel it may provide opportunities to improve cooperation and communication. Therefore the study should include specific evaluation of how, if at all, the parent-child interaction is influenced by implementation of monitoring systems.

Findings should be adapted into recommendations, including the match of considerations to household family attributes. Recommendations should also be made regarding how to promote public awareness and acceptance of teen driver monitoring systems.

Potential benefits/payoff

This research will contribute to the wider use of teen monitoring systems, the broader applicability of products and programs to the range of potential users, and the more effective implementation of systems by families, through improved usability. It will help define design criteria and system operational aspects in the same way that in-vehicle studies can help define driver-vehicle interface aspects. Since the ultimate public safety benefit is the product of the effectiveness of a system in modifying teen driver behavior and the penetration of the technology among the population of households with teen drivers, this research will advance an important and little-researched dimension system and program design. The research findings should result in guidelines for usability and acceptability and in strategies for promoting the use of teen monitoring products.

6.3.5 Research study: Coordination and integration of research activities

Problem description

The present project has made clear the fact that driver monitoring is a broad enterprise for dealing with novice teen drivers. It is in its infancy. There are likely to be many behavioral strategies, sensor systems, communications technologies, and programmatic approaches that emerge. Products and services may be developed with different costs, demands on the user, target drivers, or target consumer families. The stakeholders engaged in the development, distribution, and evaluation of monitoring systems will also be diverse, including universities and research organizations, Federal or State government agencies, insurers, safety organizations, the driver training field, law enforcement and judicial programs, and many sorts of entrepreneurial organizations (e.g., automotive industry, sensor developers, fleet monitoring companies). The quality of the systems, user interfaces, and programs will undoubtedly vary greatly (as is already seen) and the extent of formal assessment will also vary. It would be unrealistic to view the teen monitoring enterprise as a coordinated effort to converge on some "optimal" system. Perhaps a good parallel would be the area of intelligent transportation systems (ITS). Many diverse products and stakeholders are involved in ITS, often with quite different objectives, but they share some common themes and issues in terms of technology. Teen driver monitoring, at least for some time, is likely to be similar.

Given a diverse range of efforts, both domestic and international, there currently is no good means for these efforts to inform one another. There is no sharing of information, no regular scientific evaluation or critique, no benefits from "lessons learned," no systematic guidance. Again using ITS as a more mature (and admittedly larger) example, researchers and implementers gain technological and programmatic advancements through professional organizations, web sites, conferences, workshops, publications, clearinghouses, formal guidelines, equipment guides, and other means.

In order to help advance the technological basis and program effectiveness of novice driver monitoring efforts, and to help protect users from ineffective or dangerous products, it would be beneficial to put in place some means for coordination and integration of research and development activities. Researchers and implementers need to be aware of what activities are taking place, what is being found, and how this should influence system design.

Research objective

The objective of this effort is to establish and maintain a NHTSA-coordinated resource for the integration of information on teen monitoring, the promotion of communication and coordination among researchers and implementers, and the development of recommendations in the form of guidelines, best practices, or lessons-learned documents. It should make the factors that are associated with success, or failure, known to the larger stakeholder community. These objectives will require a variety of activities.

Approach/anticipated methods

The initial step is to establish some form of Center or clearinghouse that will coordinate all of the required activities and sustain the effort over some extended period so as to remain a resource to the field. A separate information center may be created to provide information to non-professionals (e.g., parents, teens, and media). The following activities should then be undertaken:

- Identify key stakeholders, related professional organizations and technical committees, industry groups, and so forth, and bring them in to the effort. This should include any who might be directly involved in the R&D enterprise, and also those who might ultimately interface with them, such as licensing authorities, enforcement, etc.
- Create a web site to house the effort and serve as a central source of information.

- Conduct a thorough literature search, technology scan, and identification of ongoing research and programs. Make the findings broadly available, and update the document periodically.
- Conduct periodic workshops, webinars, conferences, or other mechanisms for promoting communication among researchers, implementers, evaluators. These should provide awareness of ongoing efforts, new technologies, program outcomes, problems and lessons-learned, innovations, etc.
- Critically review emerging findings, conduct meta-analyses, evaluate sensor performance, etc., to provide an objective, third-party assessment.
- Based on the above, develop recommendations in whatever form is most appropriate – guidelines, best practices, success stories, etc.
- Provide some form of technical clearinghouse function for those who have technical issues. This feedback could be provided directly from project staff or through the establishment of an expert resource directory.
- Determine whether there is a need for an information center for non-professionals, and if so, what form it should take and what information should be provided.

The effort is most meaningful as a sustained resource, rather than viewed as a one-time effort. As the driver monitoring effort expands and matures, there will be a continued need for information sharing, communication, and guidance. Given the diverse nature expected for the enterprise, no organization is likely to initiate and oversee this role other than NHTSA.

<u>Potential benefits/payoff</u>

The potential benefit of this effort is to amplify the benefits of the many anticipated activities, small and large, formal and informal, associated with teen monitoring technologies and programs. This will improve the quality of research and development efforts, help eliminate ineffective practices, focus on efficient strategies, and speed the evolution of the entire teen monitoring enterprise. It will foster collaboration of teen monitoring system developers with other institutions involved with teen driver safety, such as licensing, enforcement, driver training, schools, etc.

6.3.6 Research study: Large scale field evaluation

<u>Problem description</u>

Assessing the effectiveness of novice teen driver monitoring programs requires scientifically rigorous testing with an adequately large sample of teen drivers over an extended period of time. The sample must be large enough to provide a reliable estimate of the treatment effects. A field evaluation must also determine whether there are immediate safety benefits when the system is being used and whether there are safety benefits that extend beyond the period when the system is being used. It is possible that the use of a monitoring system will help teenage drivers develop safe driving habits that carry over to adulthood. On the other hand, it is possible that monitoring programs will affect driving behavior only during the period of active monitoring and that there are no lasting benefits.

There are many possibilities for systems (and system features) to include in the large scale field evaluation and at this point it isn’t clear which systems and features are optimal. While it would be interesting to include many monitoring system variations in the study, a study of this nature requires a large sample of participants using each system to acquire meaningful data. Therefore, we recommend that only two systems be used in the field evaluation. As new devices and new approaches are introduced to the marketplace it would be useful to have valid information about the safety benefits of these two “benchmark” monitoring systems which can be used as a standard of comparison for new systems that are introduced with innovative features. One of the most fundamental differences between driver monitoring systems now available is whether the systems use video cameras. The proposed study should include one system that has cameras and provides event-based videos as feedback to parents and teen drivers. A second system to be included in the study should have cameras but should provide no video feedback to parents or teen drivers. Both systems should provide similar notifications about potentially unsafe events and driving data to parents.

Research objectives

The objectives of the field evaluation are:

1) To quantify both the immediate and sustained safety benefits of using a monitoring system with novice teen drivers during their first year of independent driving.

2) To measure the relative safety benefits of two prototypical teen driver monitoring systems to determine if the use of event-triggered video feedback to parents produces safety benefits different from those achieved with in-vehicle driver feedback and parental notification of unsafe events.

3) To measure changes over time in teens’ driving styles as they progress from having a learner’s permit (and can drive only under direct supervision) to having a driver’s license and driving independently for a year.

4) To assess family use and acceptance of the monitoring systems.

5) To help establish benchmark performance criteria for teen driver monitoring systems.

Approach/anticipated methods

A between-subjects experimental design should be used. A total of 300 families with a novice teenage driver should be recruited to participate in the study for approximately 13 months. Each participating family should be randomly assigned to one of three treatment groups (n = 100 per group):

- Group A: Monitoring with auditory event-based in-vehicle alerts and parental notifications.
- Group B: Monitoring with auditory event-based in-vehicle alerts, parental notification, and event-based video clips provided to parents via an email link to a secure website.
- Control group: Unobtrusive monitoring by researchers with no feedback to drivers or parents.

The feedback and reporting elements presented to the treatment groups are described in general terms and are based on the types of information that are provided by current monitoring systems. For purposes of this study, the details of these elements should be designed with consideration of human factors principles and best practices identified in relevant research. To ensure that data are strictly comparable between groups and study sites, the hardware installed in all vehicles and the data elements measured by researchers should be the same. Differences between the treatment groups occur in the types of data that the system provides to each family.

Families with a teenager who holds a learners' permit should be recruited and enrolled in the study. The monitoring device should be installed at least several weeks prior to the date when the teen plans to take the road test to obtain a driving license. Data collection should begin immediately after installation and should continue for the entire first year of independent driving. Having the device in the vehicle for several weeks before the teen obtains a driving license would allow parents and teen drivers to become familiar with the system under supervised driving conditions. This would also help parents set their expectations and understanding of how driving behaviors are related to the feedback provided by the monitoring system.

The monitoring device should be installed in the vehicle that the teen drives most frequently. A form of driver identification technology such as an electronic key fob or biometric control should be used so that if the monitoring device is installed in a shared use vehicle, it will be operational only when the vehicle is driven by the participating teen driver. Researchers should be prepared to move the monitoring device from one vehicle to another during the course of the study if the teen driver's primary vehicle changes. The monitoring device should provide monitoring data to the family until the teen driver has been in possession of his or her driving license for 10 months. At that time, the family's access to the data should be shut off, and two additional months of post-treatment data should be collected by researchers. This post-treatment data would be used to determine if driving behavior changes immediately after the driving feedback to the family stops. The monitoring device should be removed from the vehicle approximately one year after it was installed. As described below, participants should be contacted one year after the device has been removed to participate in a short follow-up interview.

Summary timeline for data collection (Groups A & B) is as follows:

1) Several weeks of baseline data (while teen hold a learner's permit); family has full access to the monitoring data.

2) Ten months of data collection during treatment period; family has access to the monitoring data.

3) Two months of "post-treatment" data collection after the family's access to monitoring data has ended.

4) Device is removed from the vehicle one year after the teen participant obtains his or her driver's license.

5) One year after the device is removed from the vehicle, the driver should be contacted for a follow-up interview that focuses on traffic violations, crash experiences, and indications of safe driving habits.

Participants: An equal number of boys and girls should participate as drivers in the study. Efforts should be made to ensure socioeconomic diversity. Requirements to obtain a driving license vary from State to State with respect to driver's education requirements, eligibility age for licensure, and so forth. Therefore, the research should be conducted simultaneously at study sites in at least two different States. A State that has GDL restrictions including some form of required driver's education program should be used for one of the study sites and another State with less restrictive licensing requirements should be used for the other study site. Monetary incentives should be provided to encourage participation. (For costing purposes we have assumed that $80 per month per family may be required to recruit a wide variety of interested families.) Participants may be recruited from advertisements in local media, through high school PTA organizations, and possibly through direct solicitation of families through State motor vehicle administration offices.

Potential participating drivers should be interviewed and given a brief screening questionnaire to assess risk-taking propensity and expected amount of driving during the study period. Assuming that the recruiting efforts yield more than 300 interested families, certain families should be selected for participation and assigned to treatment groups randomly with the constraints that the final groups be matched as closely as possible in terms of gender distribution, risk taking propensity, socioeconomic levels, and geographic factors. Teens who expect to do very little driving during their first year as a licensed driver should not be included in the study. Teen drivers who have or who expect to obtain a vehicle that is dedicated for their use should be given preference in selection for the study in order to maximize the amount of driving data collected.

Monitoring technologies and behaviors monitored: The choice of behaviors to monitor and how to deliver monitoring data to families in the large scale field study should depend to a large extent on the findings of the teen naturalistic driving study (described in Section 5 of this report) and on the other research projects proposed in this research plan. The monitoring systems used in the large scale field study should collect and report event-based data including hard turns, hard braking, hard forward acceleration, exceeding the posted speed limit by more than 10 miles per hour, and seat belt nonuse. We expect that all monitoring requirements can be achieved using commercially available monitoring systems, though more than one product may be needed for each vehicle to provide all of the required functionality. Alternatively, commercially available products may be modified to provide the required functionality. The use of commercially available monitoring products as a basis for data collection and feedback systems is intended to reduce the costs of system development and production; this study is not intended as an evaluation of any commercially available products. Implementers may consider developing a new system specifically for this study if system requirements can be met with in a way that is cost-effective and reliable. The monitoring systems should include video cameras mounted on the windshield under the rear-view mirror. Two small cameras should operate continuously, recording views of the driver and the forward roadway, but only short (e.g. 30 second) video segments should be provided to Group B families to document when potentially unsafe events occur. Researchers should apply for a Certificate of Confidentiality for this study to aid in protecting participants' personal data from being disclosed to insurance providers or other parties who may seek to legally compel its release.

Safety measures: Primary safety measures may include the number of crashes (and crash severity) and traffic violations as well as several crash surrogate measures obtained from the data stream from the monitoring systems. These include triggered potentially unsafe events such as speeding, hard braking, and analysis of the triggered video segments to determine the number of near crashes.

In the recent naturalistic driving study of novice teen drivers that was conducted by Virginia Tech Transportation Institute as part of the current project, 19 crashes were observed among 42 teen drivers over the first 18 months of driving. In other words, 19 crashes were observed in 756 months of teen driving exposure. In the planned study there are 3000 months of teen driving exposure within the 10-month treatment period, and 3600 months of teen driving exposure during the entire first year (including the two-month post-feedback monitoring period). Thus, in the absence of any positive safety benefits from the monitoring systems, we would expect to observe at least 75 crashes in the first 10 months, and at least 90 in the first year. The number of crashes observed could be even higher because the crash rate for teens is highest during the first 10 months of driving and decreases in months 13 to 18.

Family use and acceptance: Parents and teens should be interviewed during the study (perhaps after 3 months of system use and again at the conclusion of the study) to solicit information about their usage of the monitoring system and their opinions regarding ease of use, perceived effectiveness of the system, and how the parent and teen use the information provided by the system. Also, website usage should be monitored to determine how often parents view driving data.

Follow-up study of traffic violations and crash experience: One year after the monitoring systems are removed from the vehicles, researchers should contact participating drivers to determine how many crashes and moving violation citations they have received in the year since the system was removed. The interview may also include questions about other safety related driving habits, such as speeding, seat belt use, etc.

Project tasks: The field study is a large scale effort that may be broken down into a set of discrete project tasks as follows:

TASK 1: Create work plan, design data collection systems and procedures, obtain IRB approval for study
TASK 2: Prepare study equipment, materials, and sites
TASK 3: Recruit and enroll participants
TASK 4: Install monitoring equipment, collect data, maintain and troubleshoot equipment
TASK 5: Analyze data
TASK 6: Final report
TASK 7: Follow-up study of safety experience (interviews)

Estimated costs: A preliminary cost estimate for the large scale evaluation study proposed here is given below. Note that the cost to produce each monitoring system unit is highly variable depending upon the measures that are deemed to be necessary to sense and record, as well as the mode of feedback, recording, data storage, and communication. Off-the-shelf monitoring systems that use inexpensive sensors or take advantage of vehicles' on-board computers may cost a few hundred dollars per unit, while custom systems with advanced sensors such as forward radar and lane position detection may cost thousands of dollars. Additional sensors and other equipment might also be required for data collection and evaluation of system effects on driving behaviors. The cost estimate below incorporates a range of possible costs depending on required features. Depending on equipment costs, the total cost of the large scale field evaluation is estimated to be between $2.8-3.8 million.

Study design, work plan	=	$70,000
Recruiting, screening, and selecting participants	=	$80,000
Participant incentives (300 x 13 mo.x $80/mo.)	=	$312,000
Monitoring and data collection systems (320 units x $2,000-$5,000/unit)	=	$640,000 - $1,600,000
Design and assembly of data collection systems	=	$100,000 - $ 200,000

Monitoring data delivery via cell phone network to Email server and website (system integration and network usage charges)	=	$100,000
Installation and study management (at 2 sites)	=	$1,000,000
Data reduction (including video data coding), data analysis, and report	=	$400,000
Follow-up study interviews (n = 300), analysis, and report on interview data	=	$100,000
Total Cost	=	$2,802,000 - $3,862,000

Potential benefits/payoff

This project will quantify the immediate and long term safety benefits of using monitoring technologies for novice teenage drivers. Assuming that teenage drivers with monitoring systems are shown to be safer than the control group of teenage drivers, this result will foster greater use of such systems. The results of this study also will provide an objective basis for evaluation of other systems.

7 Summary

This is an opportune time to consider the possibilities for monitoring strategies that may address the high crash rates of novice teen drivers. Awareness of the teen driver safety issue is high and the limitations of previous approaches have been recognized. Sensor and communications technologies to support driver monitoring are available and ever increasing in terms of capabilities and practicality. Fleet monitoring programs have established the practical feasibility of monitoring and the potential effectiveness of feedback for mature driver populations. Initial teen driver monitoring programs suggest very promising outcomes. Enthusiasm for pursuing monitoring strategies is high among a variety of expert and stakeholder groups, as evidenced by the workshop conducted under this project.

At the same time, there are reasons for caution. The difficulty in empirically establishing substantial benefits from driver education programs provides a caveat to overly-enthusiastic support and widespread implementation without a clear demonstration of the net benefits. There are many options in terms of the behaviors to monitor, the feedback strategies, communications, reward structures, and programmatic implementation. We do not know what is most effective for the short term reduction of crash risk, the longer term improvement of driver performance, and the degree of public acceptance and use of teen driver monitoring. Some commercial products related to monitoring teen drivers have been available to the public but their use has not become widespread.

This project has identified key issues and options in advancing the use and effectiveness of teen driver monitoring. It has defined a number of important research topics and has developed a set of recommended research studies. Expanded use of teen monitoring technology and trials with various implementations are likely to take place in the future. However, in the absence of a systematic program of quality research, the full benefits of widespread and effective devices and strategies may not be realized, and poor solutions may even increase public or institutional resistance to monitoring approaches. It is important that subsequent empirical work follow this project, to help establish the most promising features and strategies for teen driver monitoring.

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Appendix A: Novice teen research findings

Contents: **Page:**

Appendix A1: Novice driver research findings: Teen behaviors

Behavior	Novice/Teen Considerations
General	• Teen driver crashes statistics indicate that the individual behaviors most often associated with fatal teen crashes are speeding, seat belt nonuse, and driving under the influence of alcohol, (Brovold, Ward, Donath, Simon, Shankwitz, & Creaser 2007)
Vehicle control: General	• Driver error was a factor in 76% of fatal crashes involving novice drivers, 71% involving 17-19 year old drivers, and 56% involving adult drivers (ages 20-49), (Beginning teenage drivers). • Single vehicle crashes accounted for 52% of crashes involving novice drivers, 48% involving drivers ages 17-19, and 41% involving adult drivers, (Beginning teenage drivers)
Vehicle control: Lane keeping	• The most common critical events leading to crashes involving teen drivers (16-19) were encroachment on another vehicle's lane and entering another vehicle's lane, (Ulmer, Williams, & Preusser, 1997) • 45% of the critical events for novice drivers (age 16) involved encroaching upon another vehicles lane compared to only 32% for middle age drivers (ages 25-49), (Ulmer, Williams, & Pruesser, 1997) • Novice drivers' (ages 16-32, each with less than 5 hours of on-road driving experience) lane position variance during a simulated lane change maneuver was significantly greater than experienced drivers (21-45 years; at least 5 years of driving experience) and increased with driving difficulty, (Yang, Jaeger, & Mourant, 2006) • 32.5% of teen drivers' (ages 16-19) crashes were attributable to deficiencies in lane keeping, (McKnight & McKnight, 2003) • Novice drivers (10 hours of driver training) deviated out of the lane significantly more than expert drivers (7 years of experience), (Lansdown, 2002) • Experienced drivers are more adept at using peripheral vision for lane keeping whereas novice drivers use more foveal vision, (Summalan, Nieminen, & Punto, 1996, in Lerner, Tornow, Freedman, Llaneras, Rabinovich, & Steinberg, 1999, p 63)
Vehicle control: Curve negotiation	• Novice drivers (ages 16-17) were found to be 3.4 times more likely to be involved in fatal collisions than a older drivers (ages 30-49) when negotiating a curve, (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 78) • Teen drivers (ages 17-19) were involved in twice the proportion of accidents while negotiating a curve than older drivers (ages 30-39). Additionally, negotiating a curve was an overrepresented feature of single vehicle crashes in young drivers, (Clarke, Ward, Bartle, & Truman, 2006) • About 29% of crashes attributable to young drivers (ages 16-19) occurred on curves because of deficiencies in adjusting their speed, (McKnight & McKnight, 2003) • Teen drivers (ages 15-20) are particularly prone to going too fast around curves, (McKay, 2005) • Novice drivers do not use appropriate visual cues to anticipate the trajectory of their vehicle in curves, (Cavallo, Brun-Die, Laya, & Neboit, 1988, in Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 64) • Novice drivers tend to have small initial steering wheel movements when entering a curve leading to slow directional changes, (Duncan, Williams, & Brown, 1991, in Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 66) • Novice drivers underestimate the beginning of left hand curves during the approach whereas experienced drivers fixate well ahead of curves demonstrating anticipatory skills, (Cavallo, Brun-Die, Laya, & Neboit, 1988, in Lerner, Tornow, Freedman, Llaneras, Rabinovich, & Steinberg, 1999, p 66) • Based upon requests for vision using occlusion goggles, one study found that as the radius of a curve decreases, young drivers experience increased visual demand. However, this study found that young drivers generally experience significantly less visual

Behavior	Novice/Teen Considerations
	demand in curves than middle age and older drivers (Tsimhoni, & Green, 1999) • Experienced drivers used different scanning patterns between left and right curves (longer fixations for left curves) and fixate toward the future driving path while inexperienced drivers visual search patterns were not different between the two curve types nor showed anticipation of the future driving path (Cohen & Studach, 1977)
Vehicle control: Speed perception/ choice	• Young drivers (ages 16-24) were 2.1 times more likely to be exceeding the proper speed for conditions at the time of a fatal crash compared to more experienced drivers (ages 25-64), (Zhang, Fraser, Lindsay, Clarke, & Mao, 1998) • A larger proportion of younger drivers (16-19) crashes were due to driving too fast for conditions compared to older drivers, (McKnight & McKnight, 2003) • More than half of all speeding-related crashes among novice drivers (age 16) were due to driving too fast for the current conditions, (Braitman, Kirley, McCartt, & Chaudhary, 2007) • Young adults (ages 17-20) reported frequent speeding when driving with other young adults, (Ulleberg, 2005) • Young drivers in a focus group said they were comfortable with speeding and valued it as a way to save time. Additionally, they were impatient with slower drivers and thought that driving 10-20 km/h (6-12 mph) above the speed limit was normal, (Redshaw, 2004 in Hedlund, Shults, & Compton, 2006) • 76-80% of novice drivers (age 16) reported that they had exceeded the speed limit in residential or school zones, (Simons-Morton, Hartos, Leaf, & Preusser, 2006) • 61-69% of novice drivers (age 16) reported that they drove 10-19 mph over the speed limit, (Simons-Morton, Hartos, Leaf, & Preusser, 2006) • High school survey respondents reported that speeding is doing more than 10 miles per hour over the posted speed limits and half of the respondents reported driving 10 mph or more over the posted limit at least sometimes, (Children's Hospital of Philadelphia & State Farm, 2007) • High school drivers with male passengers drove on average about 5 mph faster than when they had a female passenger, (Simons-Morton, Lerner, & Singer, 2005) • 25% of high school drivers exceeded the speed limit by at least 15 mph when carrying a male passenger; significantly more than when carrying a female passenger, (Simons-Morton, Lerner, & Singer, 2005) • Novice and experienced drivers responded similarly when estimating travel speeds of free-flowing traffic; therefore, on-road differences in speed perception may be due to differences in cognitive or driving skill (Fildes, Fletcher, & Corrigan, 1987)
Vehicle control: Turning	• Drivers under the age of 25 were overrepresented in crashes involving cross intersection turns where the driver was turning onto the major road, compared to expected crash rates, (Clarke, Forsyth, & Wright, 2005) • Young drivers (ages 16-17) were 3.7 times more likely than more experienced drivers (30-49) to be involved in left turn collisions, (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 75) • Young drivers (ages 16-20) are overrepresented in nighttime left turn crashes relative to daytime left turn crashes (Kirk, & Stamatiadis, 2001)
Vehicle control: Car following	• High school teenagers maintained significantly shorter headways (less than 2 seconds) from a lead vehicle compared to adults, (Simons-Morton, Lerner, & Singer, 2005) • As headway increased from 2-3 to 4-5 seconds, high school teenagers showed a sharper increase in mean speed than general adult traffic, (Simons-Morton, Lerner, & Singer, 2005) • Over half of crashes attributable to deficiencies in maintaining space were caused by failures in following distance for teen drivers (ages 16-19), (McKnight & McKnight, 2003)

Behavior	Novice/Teen Considerations
	• Novice drivers (ages 16-18) maintained headway of 1.3 seconds behind a lead car while older drivers (ages 45-54) kept a larger 2.2-second headway. The authors point out that the “safe” following distance chosen by the teen drivers leaves little room for error or distraction (e.g., using cell phone), (Greenberg, Tijerina, Curry, Artz, Cathey, Kockhar, Kozak, Blommer, & Grant, 2003) • Young driver behavior was characterized by closer following distances and higher speeds than middle age and older drivers, (Boyce & Geller, 2002, in McKnight & McKnight, 2003)
Vehicle control: Emergency maneuver/ error recovery	• Novice drivers (age 16) were more likely to be in a fatal car crash involving driver error (e.g., running off the road, following improperly, and failing to yield the right away) than more experienced drivers (ages 20-49), (Williams, Ferguson, & Wells, 2005) • Driver error was a factor in 77% of all fatal crashes involving novice drivers (age 16) in 2003, (Williams, Ferguson, & Wells, 2005) • Drivers under age 20 are 6 times more likely to have a rollover crash than drivers age 20 and older), (Kweon & Kockelman, 2003) • 42% of all novice driver (age 16) fatal crashes were rollover crashes and they were 1.36 times more likely than older drivers (25-49) to be involved in these types of crashes, (Gonzales, Dickinson, DiGuiseppi, & Lowenstein, 2005) • Teen drivers (ages 17-19) were twice as likely as older drivers (ages 20-25) to be at fault in crashes involving “overbraking” or “oversteering,” (Ulmer, Williams, & Pruesser, 1997) • Novice drivers (age 16) were 1.5 times more likely to be involved in run-off-road crashes than older drivers, (Gonzales, Dickinson, DiGuiseppi, & Lowenstein, 2005) • in 86% of cases where novice drivers (age 16) lose vehicle control and crash, they ultimately end up running off the road, (Braitman, Kirley, McCartt, & Chaudhary, 2007) • 36% of all novice driver (age 16) crashes were due to losing control or sliding, (Braitman, Kirley, McCartt, & Chaudhary, 2007) • Young drivers (ages 16-24) are 1.42 times more likely to be in a fatal crash involving loss of vehicle control than are older drivers (ages 25-64), (Zhang, Fraser, Lindsay, Clarke, & Mao, 1998) • The vast majority of single vehicle crashes involving novice drivers (age 16) involved leaving the roadway, overturning and/or striking a fixed object, or spinning or overturning on main travel lanes, (Williams, Preusser, Ulmer,& Weinstein, 1995) • In the first few months of driving, young drivers are overrepresented in fatal rollover crashes resulting from a loss of control, suggesting that they are deficient in vehicle control skills and that they can not accommodate the vehicle control demands of some driving situations, (Lee, 2007) • More than half of all teen driver (ages 16-19) crashes attributed to emergency maneuvers were caused by swerving, (McKnight & McKnight, 2003)
Vehicle control: Passing and overtaking	• Young drivers (ages 16-24) were about 1.5 times more likely than older drivers (ages 25 and up) to get in a fatal crash due to improper lane changes, (Zhang, Fraser, Lindsay, Clarke, & Mao, 1998) • Novice drivers (ages 16-17) were 4.4 times more likely to be involved in fatal passing collisions than older drivers (ages 30-49), (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 75) • Young drivers (ages 16-22) were overrepresented in crashes where they lost control after an overtaking maneuver compared to other age groups (ages 23-81), (Clarke, Ward, & Jones, 1998) • Young drivers (ages 16-22) involved in overtaking crashes were most likely to lose control after returning to the nearside following an overtaking maneuver. The majority of these crashes involved misjudgment and excess speed, (Clarke, Ward, & Jones, 1998) • Novice drivers (age 16) are responsible for causing significantly more overtaking crashes than more experienced young drivers (ages 17-20) (Kirk & Stamatiadis, 2001)

Behavior	Novice/Teen Considerations
Vehicle control: Backing/ parking	• Novice teen drivers are overrepresented in backing crashes, (S. Klauer, Personal Communication, June, 2007)
Risky/aggressive acts: Seat belt use	• Teen drivers (ages 16-19) are significantly less likely to be buckled up on rural roadways than on urban roadways when involved in fatal accidents, (McCartt & Northrup, 2004) • Among drivers in fatal crashes between 1995 and 2000, seat belt use for 16 year-old drivers was significantly higher than for 17 year-olds, (McCartt & Northrup, 2004) • Of the teen drivers (ages 16-19) involved in fatal crashes with 3 or more passengers only 18% of those killed were wearing seat belts, (Williams & Shabanova, 2002) • At elevated blood alcohol concentration levels, teen drivers' (ages 16-19) rate of seat belt use decreases by more than half, (Williams & Shabanova, 2002) • Teen drivers (ages 16-19) with blood alcohol concentration levels over .10 had lower seat belt use rates than those who were not impaired in fatal car crashes, (McCartt & Northrup, 2004) • More child passengers were appropriately restrained with teen drivers (ages 16-19) than with older drivers (ages 20 and up), (Chen, Elliott, Durbin, & Winston, 2005) • Teen drivers (ages 16-19) are more likely to buckle up with older passengers (older than 30) than when driving alone, (Williams & Shabanova, 2002) • Teen drivers (ages 16-19) are less likely to buckle up with young adult passengers (ages 20-24) than when driving alone, (Williams & Shabanova, 2002) • Teen driver (ages 16-19) seat belt use in fatal crashes was reduced with passengers under the age of 30 and increased with passengers over 30, (McCartt & Northrup, 2004) • Teen passengers (high school students) had lower seat belt use rates in cars driven by other teenagers than in cars driven by adults, (Williams, McCartt, & Geary, 2003) • Teen focus group participants (ages 16-18) reported that they were less likely to use a seat belt when riding with their parents than with other teens because they felt safer and trusted their parents as drivers, (Westat Seat belt reminder focus group, August 2005) • Teens (ages 18-19) were more likely than their parents to wear their seatbelts and female teens were more likely to wear their seat belts than male teens, (McKay, Cohen, & Larkin, 2003) • 65% of high school drivers reported that they consistently wore a seat belt as a driver and a passenger, (Children's Hospital of Philadelphia & State Farm, 2007) • Teen drivers' (ages 16-19) seat belt use in fatal crashes was lowest between 9 PM and 6 AM, (Williams & Shabanova, 2002) • Younger drivers (ages 16-22) had significantly lower rates of seat belt use when using a cell phone than when not using a cellular phone, (Eby, Kostyniuk, & Vivoda, 2003) • Male high school drivers had lower seat belt use rates than adult male drivers in the morning and at football games, (Williams, McCartt, & Geary, 2003)
Risky/aggressive acts: Speeding	• Teen drivers (ages 16-19) were 28% more likely to be in a fatal crash on slippery rural roads when speeding, (Marmor & Marmor, 2006) • Speeding was a factor in 76% of novice driver (ages 16) run-off-road crashes, (Braitman, Kirley, McCartt, & Chaudhary, 2007) • Novice drivers (age 16) involved in fatal crashes were 2 times more likely to be charged with speeding and 4 times more likely to be charged with a reckless traffic offense than other drivers (data from Colorado, 1995-2001), (Gonzales, Dickinson, DiGuiseppi,

Behavior	Novice/Teen Considerations
	& Lowenstein, 2005, Table 3) • Speeding is a contributing factor in 39% of fatal crashes among novice teen drivers (age 16) and 34% of fatal crashes among 17-19 year olds, but only 24% of fatal crashes among drivers ages 20-49, (Beginning teenage drivers) • Teen drivers (ages 16-19) that were speeding were 8.3 times more likely to collide with a fixed object and 6.6 times more likely to be involved in a rear-end collision than being involved in an angular collision, (Neyens & Boyle, 2007) • 66% of novice drivers' (ages 16-17) first post licensure citation was speeding, (McCartt, Shabanova, & Leaf, 2003) • Novice teen drivers (age 16) were almost twice as likely to be speeding at the time of a fatal crash than older drivers (ages 25-49), (Gonzales, Dickenson, DiGuiseppi, & Lowenstein, 2005) • In 2005, speeding was a factor in 32% of all fatal crashes involving drivers ages 15-20, (NHTSA, Traffic Safety Facts (Speeding), 2005) • In 2003, speeding was a factor in 38% of all fatal crashes involving novice teen drivers (age 16), (Williams, Ferguson, & Wells, 2005) • Teens (ages 18-19) reported driving significantly faster than their parents, (McKay, Cohen, & Larkin, 2003)
Risky/aggressive acts: Compliance with right of way	• Among young drivers (ages 16-19), more than half of crashes involving a failure to yield at an intersection were attributed to deficiencies in visual search to the side of the vehicle, (McKnight & McKnight, 2003) • Young drivers (ages 16-17) were overrepresented in accidents where they failed to yield compared to more experienced young drivers (ages 21-24), (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 95) • 23% of crashes among novice teen drivers (age 16) involved a failure to yield the right-of-way, (Braitman, Kirley, McCartt, & Chaudhary, 2007) • Novice teen drivers (age 16) were almost 3 times more likely to be charged with failure to yield right of way in a crash than older drivers (ages 25-49), (Ulmer, Williams, & Pruesser, 1997)
Risky/aggressive acts: Hard braking	• Novice drivers (age 17) took significantly longer to respond to a lead vehicle braking event than experienced drivers (Averaged 32 years), (Chisholm, Caird, Lockhart,Teteris, & Smiley, 2006) • Young drivers (ages 18-21) had significantly longer accelerator release times in response to braking events when distracted by a radio tuning type activity than drivers who were not distracted (.33 seconds longer), (Donmez, Boyle, Lee, & Scott, 2005) • Abrupt braking was one of the top three causes of incidents, near-crashes, and crashes for novice drivers (age 16) (McGehee, Raby, Carney, Lee, & Reyes, 2007).
Risky/aggressive acts: Tailgating	• A significantly smaller proportion of younger drivers (ages 16-19) were involved in crashes due to following too closely compared to other crash types, (McKnight & McKnight, 2003) • More than half of novice driver (age 16) crashes due to errors in evaluation of other vehicles or the environment involved following too closely, (Braitman, Kirley, McCartt, & Chaudhary, 2007) • Young drivers (ages 16-24) were just as likely as older drivers (ages 25-64) to be in a fatal crash attributed to following too closely, (Lam, 2003), (Zhang, Fraser, Lindsay, Clarke, & Mao, 1998) • A simulator study conducted in Australia found that young drivers (ages 18-21) maintained shorter following distances than older drivers (ages 30-51) and were less likely to adapt short starting headways to more appropriate distances, (Mitsopoulos-Rubens, Triggs, & Regan, 2007)
Risky/aggressive acts:	• Young drivers (ages 16-22) are underrepresented in overtaking crashes where they cut in compared to older drivers (ages 36-42),

Behavior	Novice/Teen Considerations
Dangerous overtaking	(Clarke, Ward, & Jones, 1998) • About half of novice drivers (age 16) reported that they switch lanes to weave through slower traffic, (Simons-Morton, Hartos, Leaf, & Preusser, 2006)
Risky/aggressive acts: Failure to obey traffic control devices	• In 1993, 33% of fatal multiple-vehicle crashes involving a young drivers (age 16) were caused when a driver violated a traffic control at an intersection, (Williams, Preusser, Ulmer,& Weinstein, 1995)
Risky/aggressive acts: Intentional risk taking, seeking conflicts	• Young drivers (ages 17-25) were more frequently involved in crashes due to voluntary risky behaviors than lack of driving skills, (Clarke, Ward, Bartle, & Truman, 2006 in Hedlund, Shults, & Compton, 2006) • Young California drivers who had experienced alcohol impairment, sleepiness, and excess speed when driving rated these behaviors as less risky than those who had not experienced these behaviors when driving, (Elliot, Shope, Sarkar & Andreas, 2004 in Hedlund, Shults, & Compton, 2006) • Teen drivers (ages 18-19) are more likely to report using a cell phone “routinely” when driving than their parents, (McKay, Cohen, & Larkin, 2003) • 46.9% of teen drivers (18-19) reported adjusting their radio or CD player more than 5 times in a 30 minute period compared to only 6.8% of their parents, (McKay, Cohen, & Larkin, 2003) • 9 out of 10 high school students reported that it was common to see teens driving while talking on a cell phone, (Children’s Hospital of Philadelphia & State Farm, 2007) • 48% of high school students reported that they talked on a cell phone at least sometimes while driving, (Children’s Hospital of Philadelphia & State Farm, 2007) • Young drivers have higher crash rates because they are more willing to take risks such as following other vehicles more closely and driving faster, (Lee, 2007) • Young drivers (ages 16-20) were overrepresented in crashes during high-school rush hours most likely due to students showing off and racing, (Rhodes, Brown, & Edison, 2005) • Male passengers were most likely to influence male or female drivers to drive negatively (i.e., risky or anti-socially), (Mitsopoulos & Regan, 2001)
In-vehicle activity: Communication and entertainment devices	• When cognitively distracted at an intersection, teen drivers (ages 16-19) experienced a 7-fold increase in the likelihood of being involved in an angular collision and a 6 fold increase for a rear-end collision compared to colliding with a fixed object, (Neyens & Boyle, 2007) • Young drivers (ages 16-24) were 1.5 times more likely to be in a fatal collision due to inattention than older drivers (ages 25-64), (Zhang, Fraser, Lindsay, Clarke, & Mao, 1998) • Young drivers (ages 18-20) were involved in more crashes due to inattention than all other age groups (ages 21-55+), (NHTSA, 2006, 100 car study) • Teen drivers (ages 16-19) are 11.5 times more likely to be in a rear-end collision when using a cell phone than colliding with a fixed object, (Neyens & Boyle, 2007) • Teen drivers (ages 16-19) involved in collisions were more likely to use a cell-phone while driving than collision-free teen drivers, (Mayhew, Simpson, & Pak, 2003) • 4 out of 9 teen drivers (ages 17-18) in a focus group had been involved in a crash while using in-vehicle technology, (Lerner & Balliro, 2005)

Behavior	Novice/Teen Considerations
	• Novice drivers (age 16) violated and took longer to respond to an amber light more than older drivers when distracted by a phone or passenger, (Chrysler & Williams, 2005) • Novice drivers (age 16) were closer to colliding and collided with a hidden car more often than other drivers, (Chrysler & Williams, 2005) • Teen drivers (ages 16-18) failed to detect 53.8% of swerving events while dialing a cell phone; significantly more than while performing other secondary tasks, (Greenberg et al., 2003) • Novice drivers (age 17) had longer perception-reaction times than experienced drivers (more than 10 years of experience) while performing cell phone tasks, and made more glances inside the vehicle and fewer glances to the rear view mirror, (Chisholm, Caird, Lockhart, Teteris, & Smiley, 2006) • Novice drivers (age 17) had more crashes than experienced drivers (more than 10 years of experience) when using a cell phone during simulated driving, (Chisholm, Caird, Lockhart,Teteris, & Smiley, 2006) • In general, in-vehicle devices (“infotainment”) increase the reaction time to lead vehicle braking events by approximately 300 ms, (Alm & Nilsson, 1994,1995; Horrey & Wickens, 2006, in Lee, 2007) • 29% of young drivers looked away from the road for more than 3 seconds when interacting with in-vehicle devices (radio, cassette player, cell phone) whereas none of the experienced drivers did so, (Wikman, Nieminen, & Summala, 1998, in Lee 2007) • When retrieving a voice mail from a hand held cell phone, novice drivers (ages 16-18) committed 3.9 lane violations per hour where as adult drivers (ages 25-66) committed only 2.5 lane violations per hour, (Greenberg, Tijerina, Curry, Artz, Cathey, Kockhar, Kozak, Blommer, & Grant, 2003) • Teen drivers did not show decrements in lane deviation when answering a cell phone or taking off of a bottle cap, however, they did experience an increase in subjective mental workload, (Slick, Cady, & Tran, 2005) • A simulator study conducted in Australia found that novice teen drivers spend more than 400 percent more time looking away from the road while text messaging than while not text messaging. While texting, drivers were slower to detect and respond to traffic signs and emerging events (e.g., lead car turning, pedestrian crossing) and had more difficulty in lanekeeping. Decrements were somewhat larger when sending messages rather than receiving, (Hosking, Young, & Regan, 2006) • A small national sample of 75 teens (ages 16-17) found that 62 percent reported driving while talking on a cell phone and 36 percent reported driving while sending or reading text messages, (Windsor, 2008) • A small national sample of 75 teens (ages 16-17) found that 82 percent of respondents owned a cell phone, but only 25 percent owned a hands-free device, (Windsor, 2008)
In-vehicle activity: Passenger interaction	• Passengers under the influence of alcohol may encourage drivers to speed and commit traffic violations, and tolerate more risky driving behavior, (Ulleberg, 2005) • Young adult passengers (age 16-24) are more likely to talk to a driver than passengers of other age groups, (Mitsopoulos & Regan, 2001) • Passengers influence whether the driver engages in risky or antisocial driving behaviors. Male passengers were most likely to influence drivers to drive negatively, (Mitsopoulos & Regan, 2001) • High school drivers reported that dangerous driving behaviors such as driving after drinking alcohol or using drugs, speeding, swerving, crossing the center line, purposely skidding, and running a red light were strongly associated with the presence of peers, (Mayhew, Simposon, Singhal, & Desmond, 2006, pp 14) • 48% of high school students reported seeing passengers influencing a teen driver to speed at least sometimes, (Children’s

Behavior	Novice/Teen Considerations
	Hospital of Philadelphia and State Farm, 2007)
In-vehicle activity: Handling/reading things	• 59 to 73% of novice teen drivers (age 16) reported that they read, ate, talked on a cell phone, put on makeup, physically interacted with passengers, or other such activities while driving, (Simons-Morton, Hartos, Leaf, & Preusser, 2006)
In-vehicle activity: Eating/drinking	• 59-73% of novice teen drivers (age 16) reported that they read, ate, talked on a cell phone, put on makeup, physically interacted with passengers, or other such activities while driving, (Simons-Morton, Hartos, Leaf, & Preusser, 2006)
In-vehicle activity: Smoking	• High school students reported cigarette smoking as the most commonly used substance among teen drivers, (Children's Hospital of Philadelphia & State Farm, 2007)
In-vehicle activity: Dancing/singing	• 79% of high school survey respondents reported that they saw passengers or the driver dancing or singing in a teen driver's car at least sometimes, (Children's Hospital of Philadelphia & State Farm, 2007)
Hazard recognition, risk perception, situation awareness: Recognizing hazards and potential hazards	• Novice drivers (up to 9 months of licensure) failed to notice a pedestrian crossing the road unexpectedly more often than more experienced drivers (average licensure of 27 years), (Sagberg & Bjornskau, 2006) • Only 38.2% of novice drivers (ages 16-17) recognized a risk in a simulated driving scenario compared to 73.6% of experienced drivers (ages 40-50) based upon eye fixations. Additionally, novice drivers recognized significantly fewer risks than experienced drivers even when a potential risk foreshadowing element was present, (Garay-Vega & Fisher, 2005) • Novice drivers (ages 16-17) engaged in behaviors indicative of recognizing potential risks in a simulated road scenario significantly less than young drivers (ages 19-29) and older drivers (ages 60-75), (Pradhan, Hammel, DeRamus, Pollatsek, Noyce, & Fisher, 2005) • Experienced drivers (at least 28,500 miles driven) recognized hazards faster than inexperienced drivers (less than 6,200 miles driven) and unlicensed drivers, (Summala, 1987, in Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 44) • Inexperienced drivers (1-3 years experience) detected fewer hazards and were slower to respond to hazards than more experienced drivers, (McKenna & Crick, 1991, in Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 44) • In a video event detection study conducted in Israel, novice teen drivers (ages 17-18, mean licensure 2.7 months) were slower than young adults (ages 22-30) and older drivers (ages 65-72) to recognize developing hazards, though they were as quick as adults in recognizing imminent hazards. Young drivers tended to look straight ahead rather than scan potential hazard locations, (Borowski, Shinar, & Oron-Gilad, 2007)
Hazard recognition, risk perception, situation awareness: Visual search	• A significant proportion of accidents in teen drivers (ages 16-19) was due to lack of visual search before left turns, (McKnight & McKnight, 2003) • Inexperienced drivers took an average of 0.25 second longer to detect peripheral targets, suggesting that they have not automated many driving skills and lack the spare attentional capacity to respond quickly to these targets, (Patten, Kircher, Ostlund, Nilsson, & Svenson, 2006 in Lee, 2007) • "Risky" young drivers (ages 18-21) made 12.5 times as many 3-second or longer glances at a distracting in-vehicle task than non-risky young drivers, (Donmez, Boyle, Lee, & Scott, 2005) • Teen drivers (mean age 17) looked away from the road significantly more than adult drivers when completing an in-vehicle task, (Olsen, Lee, & Simons-Morton, 2007) • Novice drivers (0.2 years of experience) tended to glance far ahead down the roadway more often than experienced drivers (9 years of experience) suggesting that experienced drivers were able to use peripheral vision to monitor the roadway allowing longer fixations away from the road, (Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003) • Novice drivers (Averaged 10 hours of driver training) spent a greater time looking away from the road than experienced drivers (7

Behavior	Novice/Teen Considerations
	years of licensure), (Lansdown, 2002) • Experienced drivers are able to adapt their visual search strategy to the type of road and the traffic conditions to a greater degree than inexperienced drivers, (Falkmer & Gregersen, 2005) • Novice drivers have longer fixation durations during high demand situations, suggesting that they are more susceptible to attentional capture than more experienced drivers. Furthermore, novice drivers lack the flexibility to change their search strategies to changing visual demands associated with different roadways, (Crundall & Underwood, 1998, in Lee, 2007) • Novice drivers do not use appropriate visual cues to anticipate the trajectory of their vehicle in curves, (Cavallo, Brun-Die, Laya, & Neboit, 1988, in Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 64) • Novice drivers (age 16) glance off the road significantly longer when engaged in more difficult in-vehicle tasks than adult drivers (mean age 43), (Olsen, Lee, & Simons-Morton, 2006)
Hazard recognition, risk perception, situation awareness: Gauge/mirror use	• Novice drivers (mean age 17) glanced significantly less at the rear view mirror than adult drivers (mean age 43), (Olsen, Lee, & Simons-Morton, 2007) • Novice drivers' (mean of 10 hours of training) glances to the in-car entertainment system and the instrument panel had durations significantly longer than expert drivers' glances (mean of 7 years of licensure), (Lansdown, 2002) • Inexperienced drivers (learner's permit) spend twice as much time fixated on in-vehicle objects as experienced drivers (greater than 62,500 miles of driving) and the majority of these fixations were on the dashboard, (Falkmer & Gregersen, 2005) • Experienced drivers (greater than 62,500 miles of driving) increased the number of fixations to the dashboard when driving on a rural route, while inexperienced drivers (learner's permit) showed no difference in fixation patterns between rural and urban roadways, (Falkmer & Gregersen, 2005) • Novice drivers (age 16) made significantly fewer glances to the rear view mirror, left mirror, and window than experienced drivers (mean age 43) when engaged in an in-vehicle task (Lee, Olsen, & Simons-Morton, 2006)
Hazard recognition, risk perception, situation awareness: Risk appreciation	• Teens' (ages 16-18) self-imposed limits for using electronic devices when driving were less restrictive compared to more experienced drivers, (Olsen, Lerner, Perel, & Simons-Morton, 2005) • Teens (ages 16-18) reported that they would be more willing to use a PDA when driving than older drivers (ages 18 and above), (Olsen, Lerner, Perel, & Simons-Morton, 2005) • 25% of teen drivers perceived distracting tasks such as cell phones, personal communication devices, navigation systems, passengers, and food as less risky and were more willing to engage in these tasks when driving than older drivers, (Lerner & Boyd, 2005 in Hedlund, Shults, & Compton, 2006)
Driver status: Drowsy	• Young drivers (ages 16-24) were 1.74 times more likely to be in a fatal crash due to fatigue and 1.59 times more likely to fall asleep while driving than older drivers (25-64), (Zhang, Fraser, Lindsay, Clarke, & Mao, 1998) • Novice drivers (ages 16-17) were 2.79 times more likely to be injured in a crash while suffering from fatigue than while not suffering from fatigue, (Lam, 2003) • Young drivers (ages 18-22) without nighttime driving experience were significantly more worried about being in a crash due to drowsiness than those with nighttime driving experience, (Lucidi, Russo, Mallia, Devoto, Lauriola, & Violani, 2006) • 48.4% of young drivers (ages 18-22) reported that they would continue driving while drowsy, but attempt to compensate by opening a window or drinking coffee, (Lucidi, Russo, Mallia, Devoto, Lauriola, & Violani, 2006) • Teen drivers (ages 15-18) were more likely to be involved in a fatigue related accident during the early hours of the day (midnight to 4 am) than older drivers (ages 19-44), (Groeger, 2006)

Behavior	Novice/Teen Considerations
	• The effects of sleeplessness can lead to a reduction in the capacity to process information, reductions in sustained attention, reduced accuracy in motor control, and increased reaction time, (Groeger, 2006) • Drivers who have not slept within the past 24 hours are as impaired as drivers with normal sleep that have a blood alcohol concentration above .08%, (Lamond & Dawson, 1999; Maruff, Falleti, Collie, Darby, & McStephen, 2005, in Groeger, 2006) • There is a significant increase in risk associated with drivers who identify themselves as sleepy and who report 5 hours or less sleep in the previous 24 hours, (Connor, Norton, Ameratunga, Robinson, Civil, Dunn, Bailey, & Jackson, 2002, In Lucidi, Russo, Mallia, Devoto, Lauriola, & Violani, 2006) • 75% of high school students reported seeing teens driving tired at least some of the time, (Children's Hospital of Philadelphia & State Farm, 2007)
Driver status: Impaired	• Newly licensed young drivers (age 16) in Australia were overrepresented in fatal and serious-injury alcohol-related crashes compared to drivers with provisional licenses (age 16) and more experienced drivers (ages 18 and up), (Senserrick, Haworth, & Narelle, 2005) • Alcohol is a factor in 16% of fatal crashes involving novice drivers (age 16), 25% of crashes involving drivers ages 17-19, and 45% of adult drivers (ages 20-49), (Beginning teenage drivers). • Alcohol is 76% less likely to be a factor in fatal crashes involving novice drivers (age 16) than experienced drivers (ages 25-49), (Gonzales, Dickinson, DiGuiseppi, & Lowenstein, 2005) • Young drivers (ages 16-24) were 2.57 times more likely to be in a fatal crash due to illicit drug impairment than older drivers (ages 25-64), (Zhang, Fraser, Lindsay, Clarke, & Mao, 1998) • Young drivers (ages 15-20) who binge drink, drink in cars, and drink in restaurants are more likely to drive while alcohol-impaired, (Walker, Waiters, Grube, & Chen, 2005) • Teen drivers (ages 18-19) who scored high on a drink driving behavior survey were in 3 times as many at-fault crashes as non-drinkers, (Horwood & Fergusson, 2000) • Alcohol-impaired driving among heavy-drinking young drivers (ages 18-21) was related to a 2.6 fold increase in at-fault accidents and unrelated to accidents where the driver was not to blame, (Horwood & Fergusson, 2000) • Young drivers (ages 18-21) who drink and drive are more likely to engage in risky or illegal driving behaviors in general, (Horwood & Fergusson, 2000) • As blood alcohol concentration level increases, teen drivers' (ages 16-19) seat belt use decreases by more than half, (Williams & Shabanova, 2002) • Novice drivers (age 16) were less likely to be alcohol-impaired at the time of a fatal crash than more experienced drivers (ages 25-49), (Gonzales, Dickenson, DiGuiseppi, & Lowenstein, 2005) • Novice drivers (ages 16-17) have a higher incidence rate per 1000 person years of crashes than older drivers (18-25) but have a much lower incidence rate of alcohol involved crashes, (Ferrante, Rosman, & Marom, 2001) • Novice drivers (ages 16-17) with one arrest for drink driving were twice as likely to be involved in an alcohol related crash, and 3 times as likely if arrested multiple times, (Ferrante, Rosman, & Marom, 2001) • In fatal crashes. teen drivers (ages 16-19) with blood alcohol concentrations over .10 had lower seat belt use rates than those who were not impaired, (McCartt & Northrup, 2004)
Driver status: Physiological arousal	• In a study of normal drivers (mean age 31), an obstacle avoidance maneuver resulted in larger pulse rate deviation than a lane change or over taking maneuver, (Lin & Cai, 2006)

Appendix A2: Novice driver research findings: Driving situations

Situation	Novice/Teen Considerations
Passenger presence: Age, gender, and number	• 20 percent of *all* passenger fatalities occur in vehicles driven by teenage drivers, (Fatality facts 2006: Teenagers) • Presence of passengers can increase the likelihood of rollovers for young drivers (ages 15-20), (McKay, 2005) • Highest driver fatality rate per 10 million trips for teen drivers (ages 16-17) was when they were riding with a passenger between midnight and 6 AM, relative to other times of the day, (Chen, Baker, Braver, & Li, 2000) • Crash risk for teen drivers (ages 16-17) increases exponentially as number of passengers increases, with 3 or more passengers quadrupling the crash risk, (Williams, 2003) • Teen drivers (ages 16-19) were twice as likely to be in a crash with passengers than without passengers and this risk increased as the number of passengers increased, (Doherty, Andrey, & MacGregor, 1998) • Novices drivers (age 16) who were involved in fatal crashes were 4 times more likely to have at least 2 passengers in their car than while driving alone, (Gonzales, Dickinson, DiGuiseppi, & Lowenstein, 2005) • 1/3 of novice drivers (age 16) involved in fatal crashes had 3 or more occupants, which is double the frequency of older drivers (ages 25-49), (Lerner, 2001) • Crash rate for novice drivers (ages 16-17) with 3 or more passengers was nearly double the rate when carrying 2 passengers, (Williams, 2001) • In 1995, more than half of novice driver (ages 16-17) fatalities occurred while transporting teenage passengers, (Williams, 2001) • In 2006, 62% of teenage passenger (ages 13-19) deaths occurred in vehicles driven by teen drivers, (Fatality Facts 2006: Teenagers) • 31% of fatal crashes involving novice drivers (age 16) included 3 or more occupants compared to 24% of fatal crashes for 17-19 year-olds and 17% of fatal crashes involving adult drivers (ages 20-49), (Beginning teenage drivers) • The relative risk of driver fatality increases with each additional passenger for novice drivers (ages 16-17), (Chen, Baker, Braver, & Li, 2000) • Novice drivers (age 16) are 2.28 times more likely to crash alone and 4.72 times more likely with a passenger, relative to older drivers (ages 30-59), (Preusser, Ferguson, & Williams, 1998) • 44% of all novice teen drivers (age 16) involved in fatal crashes had a teenage passenger, (Williams, Ferguson, & Wells, 2005) • Novice drivers (ages 16-17) were twice as likely to be injured in a crash when carrying two or more passengers than when driving alone, (Lam, 2003) • Young drivers' (ages 16-20) risk of an at-fault crash is higher when carrying a teen passenger, and young drivers are less likely to be at fault in a crash when carrying an adult or child passenger, (Padlo, Aultman-Hall, & Stamatiadis, 2005) • Relative to driving alone, teen drivers (ages 16-19) with passengers were 3 times more likely to be involved in a fatal crash at night and 5 times more likely during the day, (Doherty, Andrey, & MacGregor, 1998) • Novice drivers' (age 16) likelihood of speeding, committing driver errors, and having single-vehicle crashes increase with each additional teenage passenger, (Williams, Ferguson, & Wells, 2005) • Relative to driving alone, here is an increased risk of a crash for novice drivers (ages 16-17) carrying male passengers, especially 3 or more male passengers, (Rice, Peek-ASA, & Kraus, 2003)

Situation	Novice/Teen Considerations
	• The rate of novice driver (ages 16-17) deaths per 1000 crashes doubled when there were 2 or more male passengers, (Chen, Baker, Braver, & Li, 2000) • Novice drivers (ages 16-17) are less likely to crash if they are carrying a mature passenger (age 30 and up) than if they are alone, (Rice, Peek-ASA, & Kraus, 2003) • For children riding with younger teen drivers (under age 17), there was a 43% reduction in serious injury compared to only a 24% reduction in older teen drivers (ages 18-19), (Chen, Elliot, Durbin, & Winston, 2005) • Younger passengers (16-24) were more likely to influence negative driving behaviors than younger (5-15) and older (15-55+) passengers, (Mitsopoulos & Regan, 2001) • Young drivers have higher crash rates because they are sensitive to peer influences in adopting inappropriate norms, (Lee, 2007) • Teenagers can be extremely safe drivers and take few deliberate risks when learning to drive with their parents or another adult, (Williams, Preusser, Ferguson, & Ulmer, 1997 in Preusser, Ferguson, & Williams, 1998) • High school drivers increased their headway when carrying female passengers compared to carrying male passengers or when driving alone, Simons-Morton, Lerner, & Singer, 2005 • Male passengers were most likely to influence male or female drivers to drive negatively (i.e., risky or anti-socially), (Mitsopoulos & Regan, 2001) • 40 percent of male drivers reported that they drove slower and committed fewer violations when carrying a female passenger, (Ulleberg, 2005) • Male drivers (general population) with male passengers waited significantly less time for a left turning gap at an intersection than male drivers without passengers and female drivers with same sex passengers, (Jackson & Gray, 1976) • Mean speed was greater and gap distance was less for both male and female drivers when a young male passenger was present than without a passenger, (McKenna, Waylen, & Burkes, 1998, in Simons-Morton, Lerner, & Singer, 2005) • Passenger presence has a protective effect on crash potential with all driver/passenger age combinations except young drivers (ages 16-24) with young passengers, (Lee & Abdel-Aty, 2008)
Environmental conditions: Weather	• Young drivers (age 16) were not overrepresented in crashes during rainy weather. Rainy weather was only a problem in curve accidents, (Lerner et al., 1999) • Novice drivers (ages 16-17) with full licensure were as likely to be injured in a crash in wet weather as dry weather, (Lam, 2003) • Young drivers (ages 16-24) were less likely than older drivers (ages 25-64) drivers to be in a fatal crash during adverse weather, but more likely during dry weather, (Zhang, Fraser, Lindsay, Clarke, & Mao, 1998) • 51% of younger drivers' (age 16) run-off-road crashes occurred during slippery conditions, (Braitman, Kirley, McCartt, & Chaudhary, 2007) • Novice drivers (ages 16-17) had a significantly larger proportion of crashes than more mature young drivers (ages 18-19) due to failure to adjust to wet roads, (McKnight & McKnight, 2003) • Young drivers' (ages 16-19) crash rate per 100,000 person years was 5 times higher on slippery roads than older drivers (ages 30-64), (Marmor & Marmor, 2006) • Young drivers (ages 18-21) were overrepresented in crashes where slippery conditions were a factor, (Lapotti, Keskinen, Hatakka, Hernetkoski, et al., 2006) • Odds of a fatal crash on slippery rural roads were 1.28 times higher for teen drivers (ages 16-19) than on urban roads, (Marmor &

Situation	Novice/Teen Considerations
	Marmor, 2006)
Environmental conditions: Lighting	• Young drivers (ages 16-17) were overrepresented in crashes during daylight and clear/cloudy weather conditions compared to older drivers (30-49), (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 87) • Crashes involving young drivers (18-21) are more likely to result in a fatality than those involving older drivers, especially for young males at night, (Lapotti, Keskinen, Hatakka, Hernetkoski, et al., 2006) • Teen drivers (ages 16-17) were nearly 3 times more likely to die per 100 million miles in a crash at night than during the day, (Williams, 2003, Fig. 9) • An analysis of the U.S. Department of Transportation's Fatality Analysis Reporting System and the National Household Travel Survey found that, "The rate of nighttime fatal passenger vehicle crash involvements per 100 million miles traveled in 2001-02 was almost 6 times higher for male drivers ages 16-19 than for male drivers ages 30-59. The corresponding comparison for females yields 3 times the rate.", (Fatality Facts 2006: Teenagers) • Fewer than 5% of fatal or injury-involved crashes among novice California drivers (ages 16-17) occurred between the hours of midnight and 5 am, (Masten & Hagge, 2004) • Young drivers (ages 16-24) were 2.2 times more likely than older drivers to crash between midnight and 4 am than older drivers (ages 25-64), (Zhang, Fraser, Lindsay, Clarke, & Mao, 1998) • Teen male drivers (ages 16-19) are 5.3 times more likely to be in a fatal crash at night than during the day (Doherty, Andrey, & MacGregor, 1998)
Trip characteristics: Trip purpose	• Teen drivers (ages 16-17) who own their vehicles engage in more risky driving trips ("dangerous" and "utilitarian") than non vehicle owners, (Williams, Leaf, Simons-Morton, & Hartos, 2006) • On average, 30% of young drivers' (ages 18-21) driving time is spent on leisure trips, (Laapotti et al., 2006) • Young females (ages 18-21) tend to drive proportionally more on errands and less for fun than young male drivers, (Laapotti et al., 2006) • 60% of high school teens reported that they drive at least sometimes to relax and 75% reported that they drive at least sometimes to go shopping or on errands, (Children's Hospital of Philadelphia & State Farm, 2007) • Young male drivers (ages 18-21) were overrepresented in accidents where they were driving "just for fun" compared to females who were overrepresented in accidents where they were "running errands", (Laapotti et al., 2006)
Trip characteristics: Trip time	• 60% of fatal crashes involving young drivers (ages 16-24) occurred Friday through Sunday, (Zhang et al., 1998) • 54% of motor vehicle crashes among teen drivers (ages 16-19) occurred on Friday, Saturday, or Sunday, (Fatality facts 2006: Teenagers) • "Thirty-four percent of teenage motor vehicle crash deaths in 2006 occurred between 6 pm and midnight," (Fatality facts 2006: Teenagers) • In North Carolina, high schools with open lunch policies had significantly higher teen crash rates than schools that required students to stay on campus during lunch hours, (Stone & Runyan, 2005 in Hedlund, Shults, & Compton, 2006) • Teen drivers' (ages 16-18) crash rates were three times higher during the lunch time hours in counties that allowed students to leave campus for lunch compared to crash rates at the same hours in the summer, (IIHS, July 2005) • Younger drivers (under age 25) are more likely than older drivers (ages 26-55) to have a fatal crash on the weekend, (Macdonald, Bowland, & Hancock, 1994) • Young drivers (ages 16-19) were twice as likely to experience crashes involving property damage and injury on Friday and

Situation	Novice/Teen Considerations
	Saturday than on weekdays, (Doherty, Andrey, & MacGregor, 1998) • Compared to older drivers (ages 30-49), young drivers (ages 16-24) were overrepresented in crashes during the evening hours, (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 96) • The largest number of crashes occurred when teen drivers (ages 16-18) were leaving school, with the second highest number of crashes occurring during the hour in which teens were driving to school, (IIHS, July 2005) • Teen drivers (ages 16-17) crash rates peak around 2 or 3 pm, (Williams, 2003, Fig. 12) • Odds of a fatal crash on slippery roads for teen drivers (ages 16-19) are higher in the morning (5-9 am) than the afternoon (10 am -3 pm) , (Marmor & Marmor, 2006) • From 2001-2003, teen driver (ages 16-17) crashes peaked between the end of school (3 and 4 PM) and the beginning of school (7 AM hour), (IIHS, Status Report, 2005, pp. 4) • 36.6 % of young male driver (ages 17-25) crashes between 4 and 6 AM involved excess speed which was twice the rate of crashes involving excess speed for young male drivers in general, (Clarke, Ward, Bartle, & Truman, 2006) • Teen drivers (ages 16-17) were almost twice as likely to be injured in a crash where they were going over the speed limit, (Lam, 2003) • Novice drivers' (age 17) driving pattens change once they are no longer accompanied by an adult in the car. When accompanied by an adult, most of the driving occurred during the day, but when driving solo most of the driving occurrs later at night and early in the morning, (Lotan & Toledo, 2007) • In Israel, 31.5% of novice drivers (age 17) drove alone at night (10 PM – 6 AM), and 36.1% drove alone during the weekends (Fridays-Saturdays in Israel), (Lotan & Toledo, 2007) • 50% of crashes involving teen drivers (ages 16-19) occurred between 3 PM and midnight, (IIHS, Fatality Facts 2005) • Male teen drivers (ages 16-19) were 5.3 times more likely to be in fatal crash at night than during the day, (Doherty, Andrey, & MacGregor, 1998)
Trip characteristics: Vehicle type and size	• Teen drivers (ages 17-19) who drove performance cars were found to be more involved in deliberate speeding and recklessness that peaked during hours of darkness, (Clarke, Ward, Bartle, & Truman, 2006)
Road characteristics: Road geometry	• Young drivers (ages 17-19) are overrepresented in crashes on curves in rural areas compared to older drivers (20-25), (Clarke, Ward, Bartle, & Truman, 2006) • 23% of novice drivers' (age 16) at-fault accidents were on curved roads, (Braitman, Kirley, McCartt, & Chaudhary, 2007) • 28.57% of all fatal crashes involving young drivers (ages 16-25) were on curved roads and young drivers were 1.16 times more likely to be involved in such crashes than older drivers (ages 25-64), (Zhang, Fraser, Lindsay, Clarke, & Mao, 1998) • A slightly higher proportion of young drivers (ages 16-17) were involved in fatal collisions on hills than older drivers (ages 30-49), (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999). • Young drivers (under age 25) are more likely to be in fatal crashes on slopes than older drivers (ages 25-55), (Macdonald, Bowland, & Hancock, 1994)
Road characteristics: Road surface	• Novice drivers (ages 16-17) were overrepresented in crashes on poorer road surfaces than older drivers (ages 30-49), (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 87) • Novice drivers (ages 16-17) were overrepresented in crashes on roads with poor quality and narrow shoulders compared to older drivers (30-49), (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 87)

Situation	Novice/Teen Considerations
	• A higher proportion of young drivers (ages 16-17) were involved in crashes on narrow roads (19-22 ft width) than older drivers (ages 30-49), (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 87) • A higher proportion of young drivers (ages 16-17) were involved in fatal and non-fatal collisions on 2-lane roads than older drivers (ages 30-49), (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 77,97) • Young drivers (age 16-24) were more likely to be involved in fatal crashes on divided highways than older drivers (ages 25-64), (Zhang, Fraser, Lindsay, Clarke, & Mao, 1998) • Young drivers (under age 25) are more likely to crash on 2-way undivided highways than older drivers (ages 25-55), (Macdonald, Bowland, & Hancock, 1994) • A higher proportion of young drivers (ages 16-17) were involved in collisions 2-way undivided highways than older drivers (30-49), (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 77)
Road characteristics: Road type	• Teen drivers (ages 16-17) were 3 times more likely to be involved in fatal rural road collisions than older drivers (30-49), (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 76) • Young drivers (ages 18-21) are overrepresented in accidents occurring in built up areas, (Lapotti et al., 2006) • Young drivers (under age 25) are more likely to be in fatal crashes in rural areas during the day than older drivers (ages 25-55) and are less likely to be involved in fatal crashes in urban areas during the day, (Macdonald, Bowland, & Hancock, 1994) • A higher proportion of young drivers (ages 16-17) were involved in crashes with low traffic volume (under 500 vehicles per day) than older drivers (ages 30-49), (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 87) • 67% of teen (ages 17-19) crashes on rural curves were single-vehicle crashes, (Clarke, Ward, Bartle, & Truman, 2006)
Road characteristics: Intersection	• 45% of crashes involving teen drivers (age 16 years) occurred at intersections, (Braitman, Kirley, McCartt, & Chaudhary, 2007) • Novice drivers (ages 16-17) were underrepresented in crashes in dark, non-intersection locations, but overrepresented in crashes at urban intersections compared to more experienced young drivers (ages 18-24), (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 91) • Young drivers (under age 25) are overrepresented in crashes at unsignalized intersections compared to older drivers (over age 60) who are more often involved in crashes at signalized intersections, (Clarke, Forsyth, & Wright, 1999) • Novice drivers (age 16) ran and took longer to respond to an amber traffic signal than older drivers, (Chrysler & Williams, 2005) • Relative to older drivers (mean age 43), novice drivers (age 16) were more likely to continue through an intersection when a traffic signal 200 or 185 feet away turned amber, both with and without a concurrent cell phone task, (Olsen, Simons-Morton, Lee, & Neale, 2005) • 49-59% of young drivers (age 16) reported that they went through a stop sign without completely stopping, (Simons-Morton, Hartos, Leaf, & Preusser, 2006) • 51.6% of teen drivers (ages 18-19) reported that they sometimes sped up to run a yellow light, compared to 35.6% of their parents, (Williams, 2002, in Shope, 2006) • Novice drivers (age 16) are involved in significantly more intersection crashes when turning left than older teen drivers (ages 17-20), especially at night (Kirk & Stamatiadis, 2001)
Road characteristics: Railroad grade crossing	

Situation	Novice/Teen Considerations
Problem scenarios	• Young drivers (ages 16-17) were overrepresented in rural curve collisions during rainy weather compared to young adult drivers (ages 18-24), (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 90) • Young drivers (ages 16-17) have more problems with sharper and shorter rural curves than young adult drivers (ages 18-24), (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 89) • Novice drivers (ages 16-17) were overrepresented in fatal crashes at wider 41-50 ft intersections than 30-49 year olds. These intersections were most likely busy 2 lane intersections with 12 ft lanes, curbs, no turning lanes, and parallel parking on both sides of the roadway, (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 91) • Relative to older drivers (ages 30-49), young drivers (ages 16-17) were overrepresented in crashes at low functional-class, stop sign-controlled intersections in areas of higher activity, (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 92) • Relative to older drivers (ages 30-49), young drivers (ages 16-17) were overrepresented in crashes at poorly lit intersections at night, (Lerner, Tornow, Freedman, Llaneras, Rabinovich, Steinberg, 1999, p 96) • For at-fault novice drivers (age 16) the following factors contributed to run-off-road crashes: speeding, “lost control or slid,” and “slippery roadway,” (Braitman, Kirley, McCartt, & Chaudhary, 2007)

Appendix A3: Novice driver research findings: Problem driver characteristics

Characteristic	Novice/Teen Considerations
Personality: Risk taking/sensation seeking	• In a sample of young Australian drivers (age 22), it was found that the personality characteristic of rebellion against authority predicted speeding and the characteristic of sensation seeking predicted driving after drinking, (Fernandes & Job, 2003 in Hedlund, Shults, & Compton, 2006) • Young California drivers who had experienced alcohol impairment, sleepiness, and excess speed when driving rated these behaviors as less risky than those who had not participated in these behaviors when driving, (Elliot, Shope, Sarkar & Andreas, 2004 in Hedlund, Shults, & Compton, 2006)
Personality: ADHD	• 81% of teen driver (ages 16-19) crashes attributed to deficiencies in attention were due to problems in maintaining attention, (McKnight & McKnight, 2003)
Personality: Aggression	• According to self report, teen drivers (ages 18-19) were more likely to commit aggressive actions (shout, gesture, or blow the horn “sometimes”) than their parents, (McKay, Cohen, & Larkin, 2003)
Driver gender	• An analysis of the U.S. Department of Transportation's Fatality Analysis Reporting System and the National Household Travel Survey found that, “The rate of fatal passenger vehicle crash involvements per 100 million miles traveled in 2001-02 was highest at ages 16-17 for male drivers and at age 16 for female drivers,” Fatality facts 2006: Teenagers). • Young females (ages 16-19) were more likely than young male drivers to be involved in crashes attributed to failure to yield when turning left across an intersection, (McKnight & McKnight, 2003) • Young female drivers (ages 18-21) were overrepresented in fatal slippery road crashes, relative to male drivers, (Lapotti et al., 2006) • Male teen drivers (ages 16-19) were 5.3 times more likely to be in fatal crashes at night than during the day, (Doherty, Andrey, & MacGregor, 1998) • Young male drivers (ages 17-20) were more than twice as likely as young females to crash due to excess speed, (Young, Regan, Mitsopoulos, & Haworth, 2003) • Young male drivers (ages 16-19) were significantly overrepresented in crashes involving speeds that were too fast for conditions, (McKnight & McKnight, 2003) • Female teen drivers (ages 16-19) were twice as likely as teen males to be involved in fatal crashes due to avoiding, swerving, or sliding, (Marmor & Marmor, 2006) • Teen male drivers (ages 16-19) were overrepresented in fatigue-related crashes compared to teen female drivers, (McKnight & McKnight, 2003) • Young male drivers (ages 16-19) were overrepresented in alcohol-related crashes, (McKnight & McKnight, 2003) • Teen male drivers (ages 16-19) have a crash rate 2-3 times higher when driving alone than older male drivers (ages 20 and up), (Williams, 2003) • Novice male drivers are more likely to be involved in a crash with injuries than females, (Rice, Peek-Asa, & Kraus, 2003) • Overall, young male drivers (ages 17-25) were more likely than young female drivers to be involved in crashes while not wearing a seat belt, (Young, Regan, Mitsopoulos, & Haworth, 2003) • Young male drivers (ages 18-21) were overrepresented in crashes where they were driving “just for fun” compared to females who were overrepresented in crashes where they were “running errands”, (Lapotti et al., 2006)

Characteristic	Novice/Teen Considerations
	• From 1994 to 2004, driver fatalities in young males (ages 16-19) rose 1% while driver fatalities for young women rose 15%, (National Research Council Workshop Report, 2006) • 81% of young drivers (ages 16-25) in fatal crashes were male, (Zhang, Fraser, Lindsay, Clarke, & Mao, 1998) • 64% of novice drivers (age 16) involved in fatal crashes between 1994 and 2004 were male, (NHTSA, 2004) • 2 of 3 fatal crashes involving novice drivers (ages 16-17) in 1993 involved male drivers, (Williams, Preusser, Ulmer,& Weinstein, 1995) • About 2 out of every 3 teenager drivers (ages 16-19) killed in motor vehicle crashes in 2005 were males, (Fatality facts: Teenagers) • Young male drivers (ages 18-20) were the most risky drivers with the highest crash and traffic citation rates, suggesting that males fail more often at the lower hierarchical levels of driving behavior (e.g., risk appreciation, self-control), (Laapotti, Keskinen, Hatakka, & Katila, 2001) • Crash rates for young female drivers (ages 18-20) did not significantly decrease with experience compared to young males signifying that female drivers fail more often at the lower hierarchical levels of driving behavior (e.g., vehicle maneuvering; vehicle control, speed control), (Laapotti, Keskinen, Hatakka, & Katila, 2001) • Male novice drivers (up to 9 months of licensure) responded significantly slower to hazards in the roadway when performing a secondary task than when not performing a secondary task compared to male experienced drivers and female novice drivers, (Sagberg & Bjornskau, 2006) • Risky driving increases as substance use levels increase more significantly for female high school students than male high school students. However, males had a higher overall level of risky driving, (Elliot, Shope, Raghunathan, & Waller, 2006 in Hedlund, Shults, & Compton, 2006) • Male teen drivers (ages 16-19) in fatal car crashes had lower seat belt use rates than female drivers in fatal car crashes, (McCartt & Northrup, 2004)
Psychosocial maturity	• Psychosocial maturity is associated with lower levels of high-risk driving and driving under the influence of drugs or alcohol, (Bingham, Shope, Zakrajsek, & Raghunathan, 2008)
Driver experience	• After 2 years of licensure, young drivers showed a 69% decline in nighttime crashes, a 62% decline in evening crashes, a 42% decline in daytime crashes, a 70% decline in run-off-road crashes, a 51% decline in all other crash types, and a 60% decline in all crashes. Most of this benefit appears to be achieved within 7 months of licensure, and appears to be due to experience rather than age, (Mayhew, Simpson, & Pak, 2003) • High school drivers' crash rate per 100 licensed drivers and per 10,000 miles decreased throughout the first months of licensure, (McCartt, Shabanova, & Leaf, 2003) • In Israeli, the number of injury crashes among novice drivers declined every month since licensure, (Lotan & Toledo, 2007)

Appendix A4: Novice driver behavior references

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Appendix B: Parent focus group discussion path

Note: Teen focus group path paralleled parent focus group path, but rephrased questions to teen audience.

Introductions and rules (20 minutes)

- Moderator introduces self and aides
    a. The purpose of this focus group is for us to learn more about how parents monitor their teenage drivers while they are new drivers
    b. This work is being done for the National Highway Traffic Safety Administration, which is part of the U.S. Department of Transportation. Our company, Westat, is conducting these focus groups on their behalf
    c. Focus groups have certain rules or etiquette that we follow
        i. How many of you have taken part in a focus group?
        ii. Need to hear about <u>your</u> feelings. We are not here to reach consensus, but to hear and discuss a range of views. There are no right or wrong answers.
        iii. Cross talk among group, not to/from moderator; moderator guides the discussion to cover the topics we need to hear about
        iv. Give everyone the opportunity to speak – it is important to hear from everyone
        v. Inform of being videotaped for offline analysis; participation is voluntary
        vi. Refreshments, rest rooms, breaks
- We hope that you will feel free to be completely honest in this discussion. Your responses will NOT be shared with your teenagers and you won't be identified in any report that we write about these focus groups.
- Please respect the privacy of the other people in this group by not discussing with anyone what is said here.
- Round of introductions of participants (first names) - What are the best things and worst things about your son or daughter becoming a driver?

Parental control (20 minutes)

- What major concerns do parents have about your teenagers learning to drive?
- How do you keep track of your driving behavior now?
- What rules or controls do you impose on your son or daughter's driving? What rules do your friends' impose on their teenage drivers?

In-vehicle technology (40 minutes)

- Introduce concept of technological tools for intervention, feedback, and monitoring with one or two examples of each. What type of device would you most want? Which devices do you find acceptable?
- If you were to design a device, what would it do? (Probe with examples of behaviors that could be monitored – location - GPS, video, speed, seatbelt use, etc.)
- At what point would you want to know about speeding? (how fast)
- (What concerns would you have – what wouldn't you want to know?)

- How would you prefer to receive the information? How often? Format (media?, summary vs. detail?)
- What would you do with the information?

Reactions to four hypothetical monitoring systems and features (30 minutes)

- [Describe four potential monitoring systems with different sets of features]
- How well would each potential monitoring system work in the context of your relationship with your son or daughter?

Reactions to use of in-vehicle monitoring device in various programs (30 minutes)

- Would you support teen driver monitoring as part of GDL (graduated drivers' license)? Use in driver's education? Insurance company sponsorship / discounts?
- Is there any other type of incentive or program that would encourage parents and teens to use vehicle monitoring devices?

Wrap-up (15 minutes)

- As a parent, would you want to have a vehicle monitoring device for your teenage driver? Under what circumstances?
- Anything else that they would like to mention about driver monitoring devices?

Appendix C: Workshop participants

Tom Artushin	Ford
David Benedict	Toyota
Stephanie Binder	NHTSA
Steve Blackistone	National Transportation Safety Board
John Brock	Windwalker Corporation
Peter Burns	Transport Canada
Bill Combs	National Safety Council
Richard Compton	NHTSA
Linda Cosgrove	NHTSA
Tom Dingus	Virginia Tech Transportation Institute
Max Donath	University of Minnesota
Patty Ellison Potter	NHTSA
Rob Foss	University of North Carolina
Donna Gompert	Road Safety
Allen Greenberg	FHWA
John Harvey	Oregon DOT
Jim Jenness	Westat
Charlie Klauer	Virginia Tech Transportation Institute
Andrew Krajewski	Maryland Motor Vehicle Administration
Neil Lerner	Westat
Michael Manser	University of Minnesota
Tom Manuel	American Association of Motor Vehicle Administrators
Daniel Mayhew	Traffic Injury Research Foundation
Anne McCartt	Insurance Institute for Highway Safety
Scott McClellan	inthinc
Daniel McGehee	University of Iowa
Justin McNaull	AAA

continued on next page

Bill Morrison	Montgomery County Police Department
John Nepomuceno	State Farm Insurance
Steve Norling-Christensen	Farmers Insurance
Scott Osberg	AAA Foundation for Traffic Safety
Mike Perel	NHTSA
Ian Reagan	NHTSA
Allen Robinson	American Driver and Traffic Safety Education Association
Bill Scheel	American Family Insurance
Dan Selke	Mercedes-Benz USA
Jean Shope	University of Michigan Transportation Research Institute
Bruce Simons-Morton	National Institute of Child Health and Human Development
Jerry Singer	Westat
Matthew Smith	Deplhi
John Svensson	The Driving School Association of the Americas
Hiroshi Tsuda	Nissan
Nic Ward	Montana State University
Jennifer Warren	NHTSA
Rusty Weiss	DriveCam
Penny Wells	SADD
Flaura Winston	Children's Hospital of Philadelphia
Jim Wright	NHTSA

Appendix D: Workshop presentations

Presentation **Page**

An Exploration of Vehicle-based Monitoring of Novice Teen Drivers

Stephanie Binder and Mike Perel
Human Factors/Engineering Integration Division, NHTSA
May 15, 2008

The Crash Problem

- Leading cause of death for 16-19 yo
- Crash risk is exceptionally high for first 6-12 months of solo driving, but is high for the first two years of driving
- High risk situations include: nighttime driving, teen passengers, distraction
- Two-thirds of teens in fatal crashes were not wearing their belts

In the News

DOT 69-08
Tuesday, May 13, 2008
Contact: Brian Turmail
Tel.: (202) 366-4570

Fewer People Injured in Highway Crashes Every Year

But cautions that too many teens still getting injured in crashes, Announces new teen driving safety measures

SEVERNA PARK, Md. – The number of people injured in crashes on our nation's highways has declined every year since 1995, Transportation Secretary Mary E. Peters announced today, noting that there were 4.8 percent fewer injuries in 2006 (2,575,000) than in 2005. The trend also extends to teenaged drivers, who achieved a more than 6 percent decline from 2005 to 2006.

Still, the new data released today … indicates that teen injuries make up more than 16 percent of overall crash-related injuries, even though they represent only 8 percent of the driving public

Countermeasures

- Traditional: Licensing, enforcement, education, parental involvement
- Potential: Behavioral modification using in-vehicle monitoring systems
  - Vehicle adaptations
  - In-vehicle feedback
  - Reporting

Program Motivation

- Data sensed, recorded, and analyzed from a monitoring technology can be used to:
  - Provide safety feedback while driving by presenting information on unsafe behaviors
  - Issue summary of unsafe driving behaviors
  - Prevent unsafe driving (belt use required)
  - Provide information to parents, enforcement
  - Assure adherence to graduated driver's licensing program and expand possible restrictions
  - Allow incentives for safer driving

Program Objectives

- This program addresses the following:
  - What can be done?
    - Behaviors & situations to monitor
    - Technology that can be applied
    - Programs for effective implementation
  - What appears promising/effective?
  - What are the needs of users: teens, parents, others?
  - What research are needed?

Program Components

- Information search
  - Behaviors and situations
  - Technologies for sensing and communicating
  - User interfaces
  - Programmatic efforts
  - Parent and teen focus groups
- New data on teen driver behavior (ex., co-sponsoring 40-Teen project)
- Expert stakeholder perspectives
- Research and programmatic needs

Program Team

- Prime contractor: Westat
- Subcontractors
  - Virginia Tech Transportation Institute
  - University of Minnesota
  - University of Montana

Tasks

- **Three tasks:**
  1. Determine Behaviors to Monitor
  2. Determine Best Approaches
  3. Develop Research Plan

Task 1

- **Determine Behaviors to Monitor**
  – **Objective**: To determine unsafe driving behaviors that should be monitored and the criteria needed for using them in a monitoring technology
  – **Approach**: Naturalistic instrumented vehicle methodology
    - **Leveraging NIH study at Virginia Tech**

Task 2

- **Determine Best Approaches**
  – **Objective:** To identify and compare the alternative requirements for key components tailored to deployment options
  – **Approach:** Analyses to identify the potential components of an effective and acceptable technology; conduct a focus group with parents to further explore implementation options
    - Behaviors to monitor, interface approaches, enabling technologies, and user needs

Task 3

- **Develop Research Plans**
  – **Objective:** To identify the determine the required research to determine the requirements for effective, acceptable vehicle-based teen monitoring systems
  – **Approach:** Today's workshop (among other approaches)

Program Status

- Task 1 and 3 underway, Task 2 complete
- The workshop will supplement Task 3
- Final report available late 2008, including:
  – Proceedings from today
  – Preliminary Task 1 findings, summary of Tasks 2 and 3

Questions?

- Contact information:
  – Stephanie Binder: Stephanie.Binder@dot.gov
  – Mike Perel: Mike.Perel@dot.gov

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AN EXPLORATION OF VEHICLE-BASED MONITORING OF NOVICE TEEN DRIVERS

PROJECT BACKGROUND

Neil Lerner, Westat

VARIATION IN CRASH RISK

- Although novice teen driving risk is generally high, there is huge variation with:
  - Driver actions
    - Speeding
    - Lane tracking
    - Visual search
  - Driver status
    - Distraction
    - Fatigue
    - Impairment
    - Experience
  - Driving situation
    - Night
    - Roadway
    - Passengers

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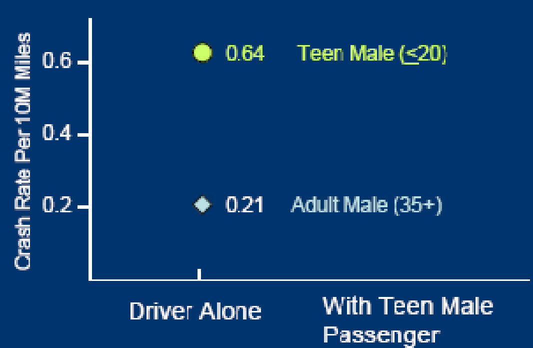
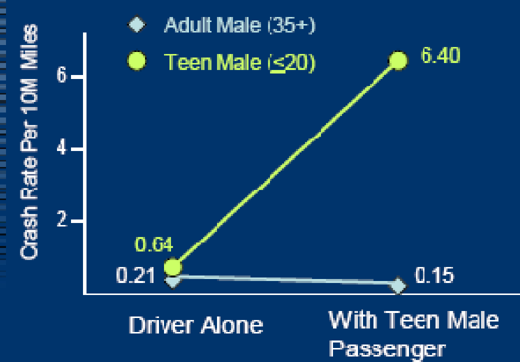
ESTIMATED FATAL CRASH RATE FOR MALE DRIVERS

(NICHD and Westat data, unpublished)



Westat 3

ESTIMATED FATAL CRASH RATE FOR MALE DRIVERS



Westat 4

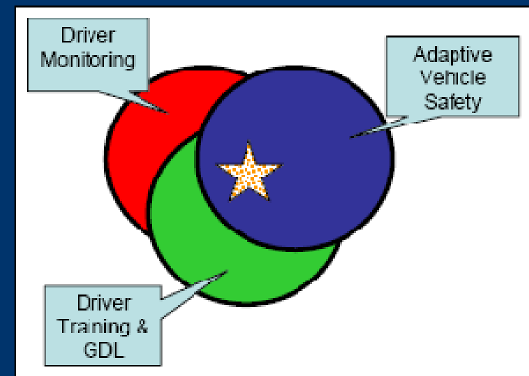
NOVICE DRIVER PROBLEMS AND MONITORING TECHNOLOGY

Driver/Vehicle Monitoring

- Reported success stories
  - Ambulances
  - Commercial fleets
  - Smart vehicle R&D
  - Teen products
- Monitoring capabilities
  - Sensing
  - Recording
  - Communicating

Westat 5

CONVERGENCE OF CURRENT DRIVING SAFETY ACTIVITIES



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QUESTIONS ABOUT MONITORING TECHNOLOGY

- Evidence already seems to be that monitoring can help, but
- What is most effective?
  - Immediate improvements
  - Greatest improvements
  - Most lasting improvements
- What is the critical aspect?
  - Learning vs. motivational
  - Just knowing you are being monitored
  - Sanctions
  - Rewards

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QUESTIONS ABOUT MONITORING TECHNOLOGY (contd.)

- Implications of emerging technology
  - Sensing and communications
  - Vehicle as a platform
- Other considerations
  - What is most efficient?
  - What is practical/impractical?
  - What is acceptable?
    - Public acceptance
    - Political acceptance
    - Consumer acceptance
  - What is the minimum that works?
  - Issues of privacy, legality, culpability, ethics

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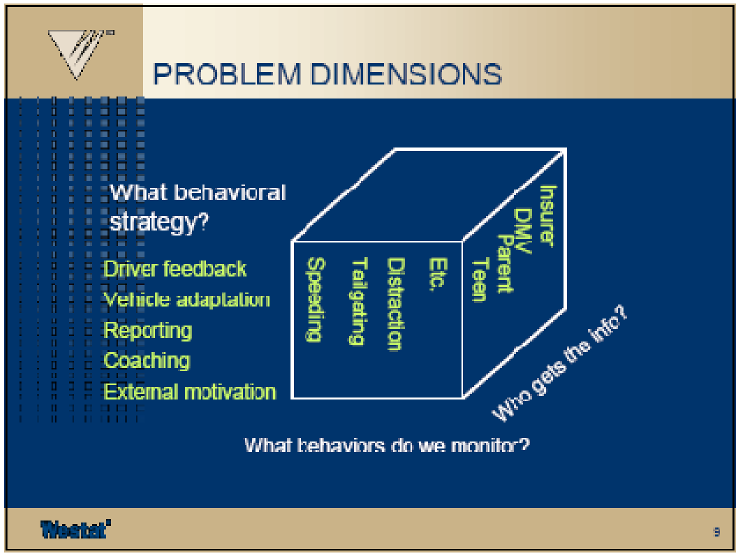
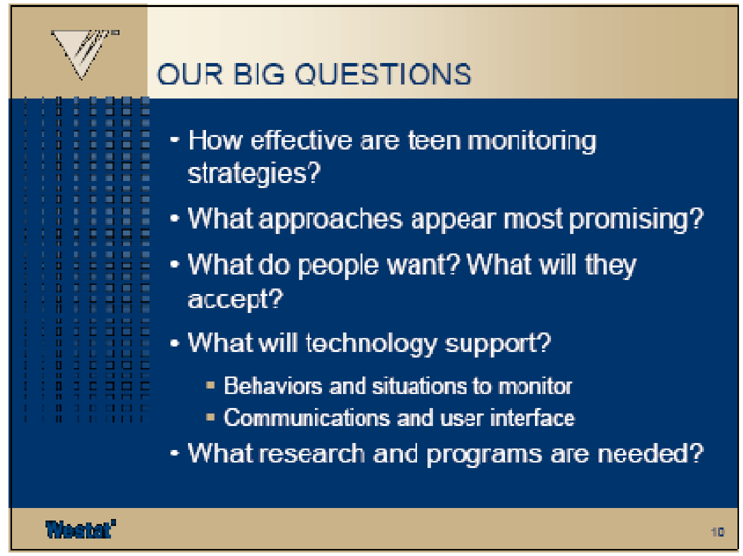

PROBLEM DIMENSIONS
What behavioral strategy?
Driver feedback
Vehicle adaptation
Reporting
Coaching
External motivation
Speeding
Tailgating
Distraction
Etc.
Teen
Parent
DMV
Insurer
Who gets the info?
What behaviors do we monitor?
Westat
9


OUR BIG QUESTIONS
• How effective are teen monitoring strategies?
• What approaches appear most promising?
• What do people want? What will they accept?
• What will technology support?
▪ Behaviors and situations to monitor
▪ Communications and user interface
• What research and programs are needed?
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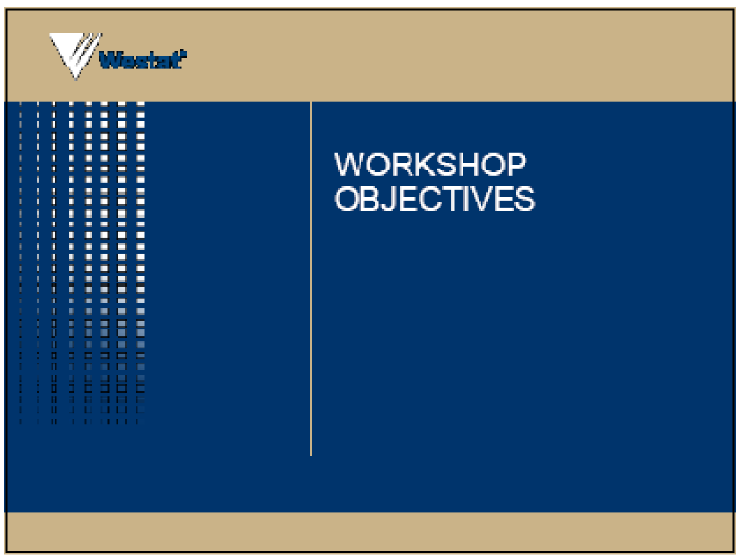
10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WORKSHOP OBJECTIVES


WORKSHOP MAKEUP
• Who is here today?
▪ NHTSA
▪ Contractor team
▪ Stakeholder communities
• Other Federal agencies (U.S. and Canada)
• States, State-related organizations
• Automotive industry
• Commercial monitoring technology
• Insurance industry
• Driver education and training
• Enforcement, licensing
• Researchers: driving safety, adolescence, technology
•Westat
•Univ. of Minnesota
•Virginia Tech (VTTI)
•Montana State
Westat

WORKSHOP OBJECTIVES

- Want to bring broad range of stakeholder perspectives into deliberation and decision-making
- Recommendations
  - Promising strategies
  - Key issues
  - Research needs
  - Priorities
  - Suggested next steps

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WORKSHOP PROCEDURE

- Morning and Lunch
  - Project background and findings
  - Presentations with opportunity for discussion
- Afternoon
  - Group collaboration and recommendations
    - Breakout groups develop suggestions
    - Group review and recommendations

Westat 14

MORNING TOPICS

- Teen Driver Monitoring: What and How?
  - Behaviors and situations that may be monitored
  - Technologies to support monitoring
    - Sensing
    - Communications
  - Group discussion
- Program Strategies
  - Five general categories of strategy
  - Parental and teen focus group findings

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LUNCH PRESENTATION

- 40-Teen Naturalistic Driving Study
  - Study is in progress at VTTI
    - Data collection is ongoing
    - Analysis underway
  - Method and emerging findings
  - Implications for teen monitoring
  - Limited time for questions & discussion

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AFTERNOON GROUP ACTIVITY
• Instructions for breakout groups
• You are assigned to one of five groups
▪ Driver feedback
▪ Vehicle adaptation
▪ Reporting
▪ Coaching
▪ External motivation
• Breakout group reports
• Full group discussion
• Recommendations: topics, priorities, next steps
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17

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CANDIDATE BEHAVIORS AND SITUATIONS FOR POTENTIAL MONITORING

N. Lerner, J. Jenness, J. Singer, D. Kidd

PROJECT COMPONENTS

- Information Search
  - Behaviors and situations
  - Technologies for sensing and communicating
  - User interfaces
  - Programmatic efforts
  - Parent and teen focus groups
- New Data on Teen Driver Behavior
  - Co-Sponsorship of 40-Teen Naturalistic Driving Study
- Expert Stakeholder Perspectives
- Research and Programmatic Needs

Westat® 2

WHAT TEEN DRIVER BEHAVIOR SHOULD BE MONITORED?

- Many teen driver behaviors may relate to risk
- Those commonly used:
  - Speeding
  - Lateral and longitudinal acceleration and deceleration
  - Seat belt use
- Are these the only behaviors we need?
- Are they the best set to monitor?

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WHAT TO MONITOR

- Key behaviors to monitor may relate to strategy for using monitoring
  - Feedback to driver
  - Vehicle adaptation
  - Monitoring for third parties
- Monitoring the *situation* as well as behavior
  - Context determines degree of risk, appropriateness of behavior

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PROJECT ACTIVITY TO IDENTIFY CANDIDATES

- Search of research literature, crash studies, training, monitoring devices
- 40-teen study complements this phase
- Handouts include a listing of potential behaviors and situations
  - Some have clear evidence of relation to risk, heightened teen crash rates
  - Others minimal data
- Set aside the issue of *how* to monitor for now – what would we like to monitor?

Westat 5

DRIVER BEHAVIORS

- Major Categories of Driver Behavior
  - Vehicle control
  - Risky/aggressive driving acts
  - In-vehicle activity
  - Hazard recognition/risk perception/situation awareness
  - Driver status
  - Prohibited tripmaking

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DRIVING SITUATIONS

- Major Categories of Driving Situations
  - Passenger presence
  - Environmental conditions
  - Trip characteristics
  - Roadway characteristics

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PROBLEM DRIVER CHARACTERISTICS

- Major Categories of Driver Characteristics
  - Personality
    - Risk taking/sensation seeking
    - ADHD
    - Aggression
  - Driver gender
- Driver Characteristics Not a Major Focus in This Project

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SPECIFIC DRIVING BEHAVIORS TO CONSIDER

BEHAVIOR: VEHICLE CONTROL

- Vehicle Control Behaviors
  - Lane keeping
  - Curve negotiation
  - Speed perception/speed choice
  - Turning
  - Car following
  - Gap acceptance
  - Emergency maneuver/error recovery
  - Passing/overtaking
  - Backing/parking

Westat 10

BEHAVIOR: RISKY/AGGRESSIVE DRIVING ACTS

- Risky and Aggressive Actions
  - Belt use
  - Speeding
  - Compliance with right-of-way
  - Obeying traffic control devices
  - Hard braking
  - Tailgating
  - Dangerous overtaking
  - Intentional risk taking/setting up conflicts

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BEHAVIOR: IN-VEHICLE ACTIVITY

- Risky In-Vehicle Activities
  - Use of communications and entertainment devices
    - Cell phones
    - Text messaging
    - Portable media players
    - Emerging products (internet, video)
  - Use of in-vehicle displays and controls
  - Passenger interaction
  - Reaching for, handling things
  - Singing, dancing
  - Reading, eating, drinking, smoking, etc.

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BEHAVIOR: HAZARD RECOGNITION, RISK PERCEPTION

- Difficulties in Recognizing and Managing Risks
  - Recognizing hazards and hazard potential
  - Visual search
    - Eyes off road
    - Long glances
    - Inefficient search
  - Gauge/mirror use
  - Risk appreciation

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BEHAVIOR: DRIVER STATUS

- Safety-Relevant Driver Status
  - Drowsy
  - Impaired
  - Workload
  - Physiological arousal, emotion

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BEHAVIOR: PROHIBITED TRIPMAKING

- Trips Specifically Precluded by Parents or Authorities
  - Prohibited times
    - School hours
    - Curfew hours
  - Prohibited locations
    - Type of road
    - Specific locale
    - Radius

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SPECIFIC DRIVING SITUATIONS TO CONSIDER

SITUATION: PASSENGER PRESENCE

- Influence of Passengers
  - Number of passengers
  - Age of passengers
  - Gender of passengers
  - Peer relationships

SITUATION: ENVIRONMENTAL CONDITIONS

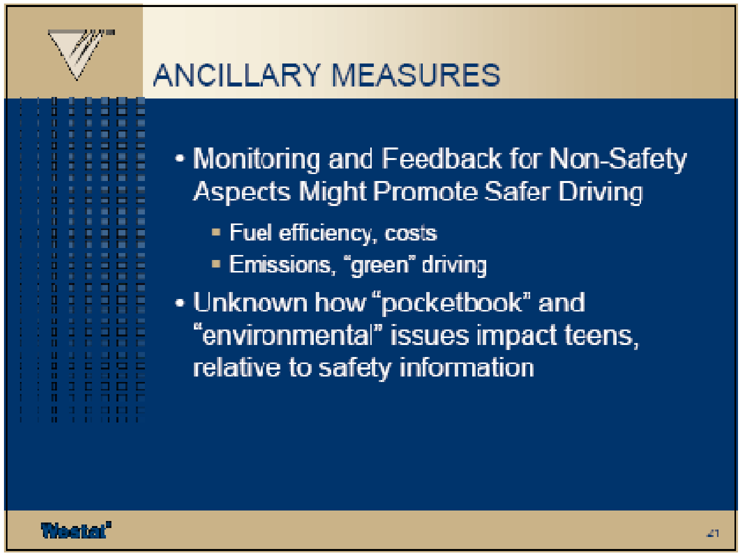
- Challenging Environmental Conditions
  - Weather
    - Rain
    - Snow
    - Fog
    - Road surface
  - Lighting
    - Night

SITUATION: TRIP CHARACTERISTICS

- Risk-related Trip Characteristics
  - Trip purpose
  - Trip time
    - Time of day: before/after school, lunch hour, night
    - Day of week: weekends
  - Vehicle type and size
    - SUVs
    - Performance cars

SITUATION: ROADWAY CHARACTERISTICS

- Roadway Features
  - Road geometry
    - Curves
    - Undivided road
  - Road surface
    - Width, material
    - Shoulder quality
  - Locale: local roads, rural roads
  - Intersection
    - Signalized: dilemma zone
    - Unsignalized: gap judgment, right of way
  - Highway-railroad crossing


ANCILLARY MEASURES
• Monitoring and Feedback for Non-Safety Aspects Might Promote Safer Driving
▪ Fuel efficiency, costs
▪ Emissions, “green” driving
• Unknown how “pocketbook” and “environmental” issues impact teens, relative to safety information

Associated Technologies

*Nic Ward,
Max Donath,
Rich Hoglund,
Mike Manser
University of Minnesota

Now at Montana State University (WTI)

ITS INSTITUTE Intelligent Transportation Systems
UNIVERSITY OF MINNESOTA

Topics

- Introduction
- System Functions
- System Examples
- Enabling Technology
  - Measurement
  - Communication
  - Interfacing

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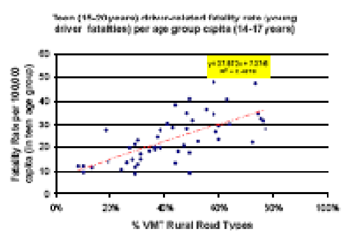
The Problem

Age	Driver Fatalities	Fatalities as % of Total	Miles Traveled	Miles Traveled as % of Total*	Rate (Fatalities per 100 M VMT)
16-19	2,463	11.4	81,691,870,115	3.5	3.0
70+	2,869	13.1	116,084,984,569	5.3	2.5
20+	19238	88.6	2,088,819,553,138	96.3	0.9

Source: FARS, 2004; NHTS,2001



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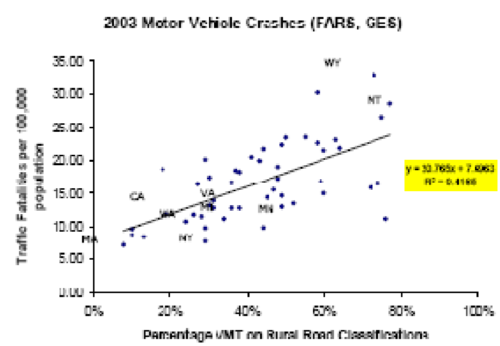
Rural Safety



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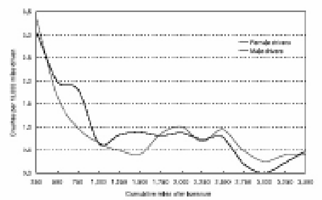
Crash Factors



Source: Mayhew et al., 2003

Percentage of fatal crashes by characteristic, 2004

Driver Age:	16	17-19	20-49
Driver error	78	69	55
Speeding	39	33	23
Single vehicle	52	45	39
3+ occupants	29	24	18
Drivers killed with .08+ BAC	13	25	44

Sources - FARS, NHTSA 2004

Source: IIHS, 2006

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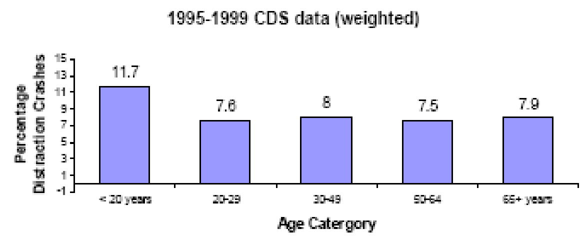
Distraction



Source: Stutts et al., 2001

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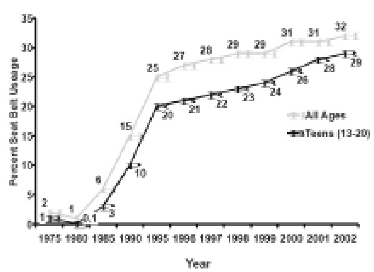
Seat Belts



Source: NHTSA DOT HS 809 899

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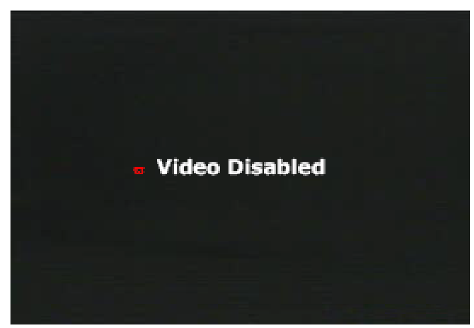
The Solution?



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Technology Support

- **Feedback (coaching) Function**
  - *Drivers may not be aware of risks.* Real-time warnings can alert the driver in case of poor driving behavior or potential risks.
- **Adaptation Function**
  - *Some unsafe actions (risks) may be habitual.* Forces actions in a safe sequence prior to vehicle operation, or prohibits vehicle operation while an undesired behavior persists.
- **Reporting (coaching) Function**
  - *Some drivers may purposely take risks because they feel anonymous.* Vehicle parameters can be saved for inspection by parents (or other authorities).

Disclaimer

The following systems are presented only as **examples** of available technology and demonstrated functions.

This presentation **does not** imply any endorsement or promotion of a specific system or individual technology by the authors or anyone we ever met.

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System Examples

	Behavior			Condition		
	Error	Speed	Lane	Night	Belt	Distr.
Feedback	❶		LSS		❸	DAS
Adapt		ISA			AIL	
Report	❷		GPS	❹		

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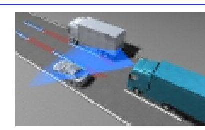
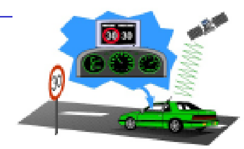
Intelligent Transportation Systems



Lane Support System (LSS)



Intelligent Speed Adaptation (ISA)

Driver Attention System (DAS)

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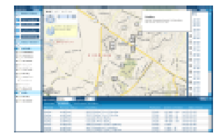
System Examples:
❶ Behavior Feedback

	Road Angel EVO (www.roadangel.com)
Goal	Provide a driving companion to keep drivers safe by monitoring speed and various road hazards
Functions	**Monitors speeding violations and warns the driver of upcoming road hazards**, including red light cameras, accident black spots, school zones, speed cameras and railway crossings.
Data	Speed, location, road hazards, and distance traveled.
Strategy	**Feedback via auditory voice generated warnings and a visual display.**
Interface	1.(Feedback) The system provides auditory and visual feedback to the driver when speed limits are violated and road hazards are presents.
Evidence	None provided.

System Examples:
❷ Behavior Report

	Brickhouse Security Trim TracXS (www.brickhousesecurity.com)
Goal	Offer parents peace of mind by monitoring speed and location.
Functions	**Monitors location and speeding violations.**
Data	Speed, nearest address, stop location, and date/time.
Strategy	**Reporting via secure online tracking interface.**
Interface	1.(Reporting) Parents can track teen online in real-time. System will email or text message parent if teen speeds or is outside geofence area.
Evidence	Brickhouse lists many reviews and testimonials on the website.

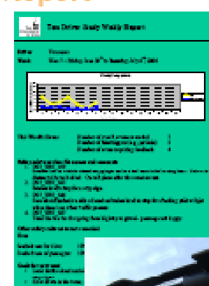


System Examples:
❸ Condition Feedback

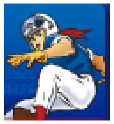
	Road Safety RS-1000 (www.roadsafety.com)
Goal	Improve teenage driving behavior by monitoring speeding, excessive acceleration, and seatbelt status.
Functions	Monitors speeding violations, **driver seatbelt use (option)**, excessive acceleration/deceleration.
Data	Speed, location, seatbelt status, acceleration/deceleration, lateral accelerations, decibel level, and distance traveled.
Strategy	Feedback via auditory beeps. Reporting via PC data transfer.
Interface	1.(Feedback) **The system provides auditory feedback** to the driver when speed and acceleration limits are violated or **if the driver seatbelt is not fastened.** 2.(Reporting) Data is downloaded to computer where driving reports are created and reviewed by parents.
Evidence	Road Safety claims large reduction in insurance premiums upon installation; however, no specifics are provided.

System Examples:
❹ Condition Report

	DriveCam DriveCam (www.drivecam.com)
Goal	Provide driving performance measuring tool by monitoring driving behavior with a video recorder.
Functions	Monitors what's happening inside and outside the vehicle when a driving incident has been detected.
Data	Video footage to diagnose **driver state (Distraction)** and action. Footage of the interior also includes sound.
Strategy	Visual feedback via an LED. Reporting via uploading footage to a PC for review.
Interface	1. (Feedback) An LED flashes when a driving incident has been detected. 2. (Reporting) **Parents can review video footage to monitor driving behavior**
Evidence	DriveCam claims the device reduces at fault accidents by 44%.



Enabling Technology


Who?


What?

Where?


Communicate


Interface

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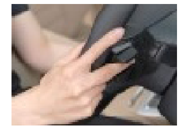
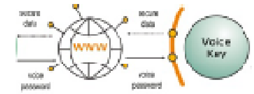
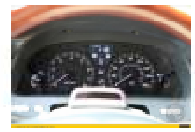
Measurement Who?


Biometric



Voice


Face


Passengers?

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Measurement What and Where?


Vehicle Status
OBDII BT


Driver Status
(Transdermal)


Vehicle Location
GPS

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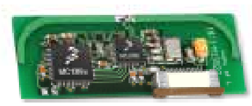
Communicate


Bluetooth


802.11


Zigbee


Cellular

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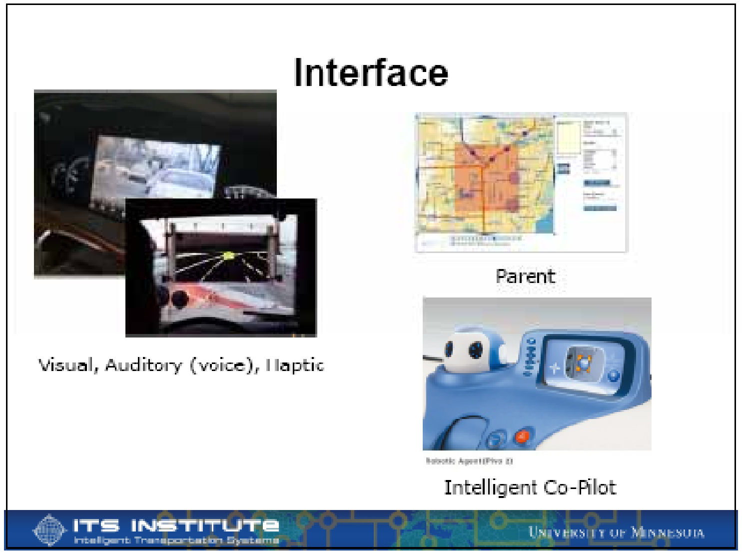
Interface
Parent
Visual, Auditory (voice), Haptic
Intelligent Co-Pilot
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PARENT AND TEEN FOCUS GROUPS ON TEEN DRIVER MONITORING

J. Jenness, N. Lerner, J. Singer, E. Hein, S. Levi

Project Components

- Information Search
  - Behaviors and situations
  - Technologies for sensing and communicating
  - User interfaces
  - Programmatic efforts
  - Parent and teen focus groups
- New Data on Teen Driver Behavior
  - Co-Sponsorship of 40-Teen Naturalistic Driving Study
- Expert Stakeholder Perspectives
- Research and Programmatic Needs

Purpose

- Assess parents' and teens' acceptance of various electronic monitoring strategies for teen drivers
- For workshop discussions today – consider how parents and teens may accept and use various technologies and strategies

Focus Groups

- Two focus groups of parents
- Two focus groups of teen drivers
- Parent/Teen pairs were recruited through a newspaper ad and PTA contacts in Montgomery County, MD
- Included Parent/Teen pairs where teen was oldest child, and pairs where teen was a younger child
- Each session lasted 2 ½ hours

Discussion Topics

- Parental concerns and controls
- Use of in-vehicle technology for monitoring teenage drivers
- Reaction to four hypothetical systems
- Use of technology in programs

Westat 5

Parents' major concerns about their teenager driving

PARENTS:

- Distraction (cell phones, texting, passengers, external distractions – need to stay focused on the driving task)
- Inexperience with emergency maneuvers (deer, slipping off edge of road, skids)
- Overconfidence excessive speed for conditions, following distance too close

Westat 6

What are teens' concerns?

TEENS:

- Often speed to get home before curfew
- Concerned about their own personal safety (not only related to driving)
- Vehicle being stolen or damaged
- Say that parents are concerned about financial costs associated with driving (vehicle, fuel, insurance, tickets)

Westat 7

Westat

Four hypothetical systems for monitoring teenage drivers

System 1: Event-based video recorder

- Records video clips of driver's face and view in front of the vehicle
- Video and audio recording is triggered by unsafe events – hard braking, hard turns, hard acceleration (no speeding). These recordings are saved on the device.
- Parent must download the data from device (USB port).

Westat 9

System 1: Event-based video recorder (continued)

- The device records anyone who drives the vehicle and triggers events.
- Optional service available – data is downloaded automatically and videos are reviewed by professional driving coach. Families receive a DVD each month with videos and narration by a coach.

Westat 10

System 1: Event-based video recorder

PARENTS:

- Some concern that the device might be a distraction
- Mixed reaction to usefulness of video and audio recordings of driver
- Some concern about data being used by police, lawyers
- Device could create good driving habits
- Groups differed on reaction to professional review/coaching

Westat 11

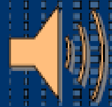
System 1: Event-based video recorder

TEENS:

- Good to see who was at fault in crash
- Video enough, don't want audio!
- OK if triggering thresholds for events are set to reasonable levels (speeding, hard maneuvers)
- Coaching feature is not necessary, and probably expensive

Westat 12

System 2: In-vehicle driver feedback system



- Provides feedback (sounds) to the driver whenever unsafe events occur
- Monitors seatbelt use, speeding over the posted speed limit, hard turns, hard braking
- Parents may download a list of stored events from the device (wireless connection to home computer)

Westat

13

System 2: In-vehicle driver feedback system

PARENTS:

- Liked the immediate feedback to the driver (especially for speeding)
- Positively perceived as a teaching system
- Beeping for hard braking & turns might be distracting during evasive maneuvers (track these for parent but don't beep)
- Some preferred downloading data via USB port rather than wireless

Westat

14

System 2: In-vehicle driver feedback system

TEENS:

- Might want to have beeping at X mph above speed limit to help them avoid getting a speeding ticket
- Seatbelt notifications would be pointless because we wear them all the time
- Beeping or voice could be annoying. Might turn up music or try to disconnect
- Might be too complicated for parents to download data

Westat

15

System 3: Real-time vehicle tracking system

- Device monitors vehicle location and speed, and unsafe maneuvers
- Parents can see current location and speed of vehicle on a website map
- Website also shows where unsafe events have occurred (speeding, hard turns, hard accelerations, hard braking, no seatbelt use)

Westat

15

System 3: Real-time vehicle tracking system (continued)

- Device can contact parent (phone, text message, or Email) when unsafe events occur
- Parent may set location boundaries and be alerted when vehicle crosses boundary (geofencing)
- Smart keys for vehicle to control which drivers are monitored

Westat 17

System 3: Real-time vehicle tracking system

PARENTS:

- Mixed response – Some liked the number of features, ability to locate in real time if necessary
- "This is going to further erode trust" "An 'I gottcha' system rather than a teaching system."
- Concern that teens would start riding with others rather than driving own car

Westat 18

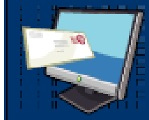
System 3: Real-time vehicle tracking system

TEENS:

- "A stalking system!" – don't like it
- Shows lack of trust – big issue
- Only good if your car is stolen
- Geofencing   parents would like it, but not us. Could park away from boundary and walk!
- Smart key - Switch keys to fool system?

Westat 19

System 4: Driving summary reporting system



- "Black box" in vehicle records speeding over posted limit, hard acceleration, hard braking, hard turns, seat belt use.
- Driver is identified by fingerprint recognition system
- Summary reports of driving activity and events are sent to the family each week (email or postal system).

Westat 20

System 4: Driving summary reporting system (continued)

- Family can also download summary reports from a website (no map view)
- Vehicle location information for events is given by the street name and nearest cross street.

Westat 21

System 4: Driving summary reporting system

PARENTS:

- Liked the idea of being able to see historical data, trends over time
- Concerns about data security – some would prefer that information is NOT available on a website.

Westat 22

System 4: Driving summary reporting system

TEENS:

- Parents would use it if they had a mistrust issue
- Too elaborate and probably too expensive

Westat 23

Which system would work best in your family?

PARENTS:

- Diverse opinions about which if any they would like to use
- Majority in group 1 liked #3 (real time tracking) best, only one parent in group 2 liked #3 best
- Some would like interlocks for alcohol, and to restrict cell phone use by driver in motion

Westat 24

Which system would work best in your family?

TEENS:

- Some felt all 4 systems were too extreme
- Some thought that an alcohol interlock would be acceptable
- Said parents would not want to make the effort to get data – minimal phone notifications might be best
- Vehicle location might be useful so you do not have to phone parent. Also good for stolen car

Westat 25

Using these technologies in programs?

PARENTS:

- Positive about use in GDL
- If most everyone had it, it would be more acceptable
- Mandatory use would reduce cost per unit and possibly encourage new legal protections
- Mixed reaction to use by insurance companies
- Would limit the period of time that they use it

Westat 26

Using these technologies in programs?

TEENS:

- Not useful for driver's ed
- Should not be mandatory in GDL for everyone, only for teens who have a lot of traffic violations
- Positive about insurance company incentives (but some concern about paying more based on poor driving performance)

Westat 27

Other incentive ideas?

- Lengthen GDL restriction period, but provide opportunity to move through faster with device.
- Gold star on teen's license indicating verified good driver – may help if stopped by Police
- Credit or preference in college admissions process
- Gasoline discount!

Westat 28

Conclusions and Implications

- Families differ widely in their acceptance and anticipated use of technologies
  - They need to have choices about getting features that will work for them
  - They would like to turn on and turn off features as needed (i.e. if teen gives them reason to)

Westat 29

Conclusions and Implications

- Privacy concerns with data on Internet
  - Some families prefer delivery of data through postal system or manual downloads
  - Families would like some legal protections for keeping their own data private

Westat 30

Conclusions and Implications

- Families would be more likely to use monitoring technology if "everyone was doing it"
  - Use of technology may be increased through programs
  - Local programs may be especially effective
  - Mandatory use may be acceptable

Westat 31

Conclusions and Implications

- Incorporation of monitoring technology into GDL process or into insurance incentive programs may have good acceptance if data use / data privacy concerns are addressed

Westat 32

40 Teen Naturalistic Driving Study and Electronic Teen Co-Pilot

Charlie Klauer

Collaborators/Sponsors:

VTTI – Tom Dingus, Suzie Lee

NICHD – Bruce Simons-Morton and Marie-Claude Ouimet

NHTSA – Mike Perel and Stephanie Binder

WESTAT – Neil Lerner

Problem Statement

- 1 in 5 Teenagers will be involved in a crash during the first 6 months after licensure.
- Crash risk decreases dramatically across the first 18 months of driving.
- The reasons for this initial heightened crash risk are unknown, but researchers hypothesize it may be due to risk factors such as:
  - inexperience
  - greater risk taking
  - presence of other teenage passengers
  - time of day
  - alcohol use

Experimental Design

- Instrument 42 private vehicles with highly capable data collection systems
  - Collect continuous data beginning within 2 weeks of licensure and continuing for 18 months
    - 22 teens are primary driver of vehicle
    - 20 teens share vehicle with parents
  - Video, video snapshots, driving performance data, and questionnaire data

Current Status

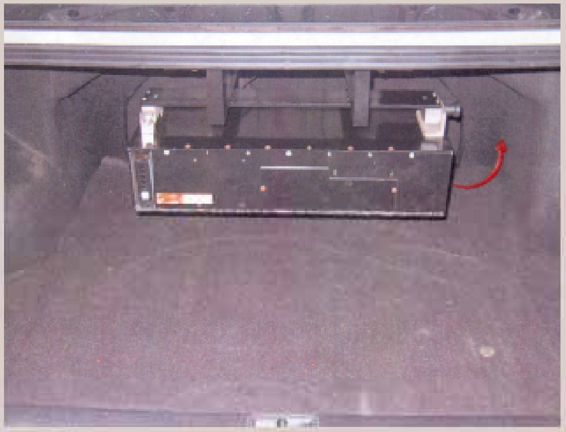
- 18 out of 42 vehicles still on the road
- Approximately 86% of data collected
- Data collection will be complete in October
- Data reduction has been underway for several months

40 Teen Data Collection System

- Four channels of continuous digital, compressed video
- 2 Camera snap shots
  - Blurred cabin snapshot (number and age of passengers)
  - Rear seat snapshot for seatbelt use
- One front radar sensor
- Machine vision-based lane tracker
- Many other sensors: GPS, acceleration, yaw rate, controls, etc.
- Swappable hard drives
- Tie into vehicle network to obtain other sensor information

40 Teen Continuous Video

40 Teen Video View with In-cabin Snapshots



Primary Research Questions

- Assess teen driving performance over time.
  - Will reduce three different driving scenarios over 18 months of driving to assess driving performance differences
    - Intersections
    - Merge ramps
    - Straight road segments
- Assess the relationship between risk factors (such as distraction, passengers present, & nighttime driving) and actual crash/near-crash risk.
  - Identify crashes and near-crashes
  - Sampled baseline data will be used to calculate relative risk

Electronic Co-Pilot Add-On (NHTSA)

- What driving performance variables are most highly associated with crash risk; thus should be monitored and part of an e-report card?
- Determine the criteria required to effectively monitor teen driving using an electronic co-pilot system.

Four Phases of Data Reduction

- General Reduction per trip file
  - Driver ID, # Passengers, Seatbelt use, General age of Passengers, Gender of Passengers
- Scenario Reduction
  - Merge Ramp
  - Intersection
  - Straight Road Segment
- Event Reduction
  - All crashes and near-crashes
- Baseline driving
  - Random sample of driving. Use to calculate odds ratios/relative risk

General Goals of Reduction

- Exposure assessment: Assess driver id and presence of specific risk factors (e.g., passengers)
- Scenario/Event/Baseline driving
  - Assess occurrence of driving errors (e.g., appropriate speed, accel, following distance)
  - Driver behavior (e.g. ,secondary task, drowsiness)
  - CES-type variables
  - Eye glance/scanning

Merge Analysis

- Used GPS and identified every time vehicles passed merge location.
- Error analysis
  - Appropriate turn signal use, mirror/blindspot check, gap judgment, speed selection, etc

Intersection Scenario

- Used GPS data to identify everytime vehicles crossed a priori selected intersections.
- Error analysis:
  - Broken into SCP, right turn, LTAP
  - mirror/blind spot check, turn signal use, appropriate speed, gap judgment

Straight Road Segment

- GPS data to identify when drivers were on a priori selected road segments.
- Error analysis looking at speed selection, following distance, lane change behavior, driver behavior, etc.

Event Analysis

- Find crashes, minor collisions, and near-crashes
  - Self-report
  - Critical Incident Button
  - Reported property damage by data downloaders
  - Scanning the kinematic data using established 'triggered' values

Potential Kinematic Triggers, based upon the 40 Teen DAS

- Longitudinal Acceleration/Deceleration
- Lateral Acceleration
- Yaw Rate
- Forward Time-to-Collision
- Forward Range
- Velocity
- Network information: turn signal, brake, throttle, etc.
- Combinations of the above

Appendix E: An exploration of vehicle-based monitoring of novice teenage drivers: Draft final report*

October, 2008

Sheila G. Klauer, Suzanne E. Lee, and Thomas A. Dingus
Virginia Tech Transportation Institute

Submitted to the National Highway Traffic Safety Administration

**Note: This appendix contains the body of the draft final report, with the exception of the executive summary, which was integrated into the body of the main report as Section 5. The report has also been minimally reformatted for consistency with the rest of this document. The unedited draft final report has also been submitted to NHTSA as a stand-alone document.*

ABSTRACT

The Naturalistic Teenage Driving Study database was used for these analyses to begin to fill in the research gaps in teen driving research related to 1) assessing the prevalence of teen driver engagement in risky driving behaviors and 2) understanding which behaviors are associated with an increase in a teen driver's crash/near-crash risk. The purpose of these analyses was to assess whether an electronic co-pilot for teen drivers could be effective in reducing crash/near-crash risk. Forty-two teen drivers were grouped into high risk (N= 23) and low risk (N=19) groups based upon their involvement in crashes and near-crashes during the first six months of driving. Results suggested that the high risk teen drivers engaged in secondary tasks, high risk secondary tasks, and speeding behaviors significantly more frequently than did the low risk drivers. Results also suggested that the high risk teens performed extreme levels of longitudinal deceleration during "normal," baseline driving significantly more frequently than did the low risk drivers. In fact, nearly 90 percent of the high-risk drivers but fewer than 50 percent of the low-risk drivers performed braking maneuvers greater than 0.5*g* during baseline driving. Although it was rare for teen drivers to be unbelted, when they were unbelted, they were more than seven times more likely to also have unbelted teen passengers than were the adult drivers. Because these results are based on continuous, naturalistic observation of drivers over 18 months, the results provide the first window into what teen drivers are actually doing as they drive. The implications of these results imply that teen driver monitoring can potentially reduce teen involvement in crashes and near-crashes. Teen drivers are clearly engaging in risky behaviors, including engaging in secondary tasks and speeding; if we can find ways to reduce the prevalence of these behaviors, then we may also see a corresponding reduction in teen driver crashes.

TABLE OF CONTENTS

INTRODUCTION

The crash rate for young drivers is higher than for any other age group, whether the rate is calculated per number of miles driven, per unit of population, or per number of licensed drivers (Goodwin, Foss, Sohn, and Mayhew, 2007). In 2005, 5,699 young drivers between the ages of 16 and 20 were killed in traffic crashes, and an additional 432,000 were injured (NHTSA, 2006). For the same year, the rate of fatalities per 100,000 population of 16 to 20 year olds was 27.35 (as compared to 4.65 for 10 to 15 year olds), and the corresponding injury rate was 2,072 per 100,000 population (about 4 times as high as for 10 to 15 year olds; NHTSA, 2006). When the rates per 100,000 licensed drivers are considered, 16 to 20 year olds have the highest rates of any age group (a rate of 58.12 per 100,000 licensed drivers in fatal crashes and 4,035 per 100,000 licensed drivers in injury crashes in 2005).

Recent instrumented-vehicle studies have demonstrated that driver performance feedback can reduce the occurrence of risky driving behaviors such as hard decelerations and swerving maneuvers. Musicant, Lotan, and Toledo (2007) conducted a study using fleet vehicle drivers. An in-vehicle data recording system (IVDR) was installed to provide driving feedback to 103 drivers concerning episodes of hard braking, swerving, high vehicle speed, and global positioning system (GPS) location data. From these data, risk indices were calculated based upon previous crash records as well as the driving parameters collected by the system (e.g., trip time, vehicle location, and number of hard-braking maneuvers). After baseline data were collected for a period of eight weeks, feedback regarding braking patterns, speed selection, acceleration around corners, and other unsafe driving maneuvers was stored on a driver-accessible website. Results indicated a 38 percent reduction in crashes per 1,000 miles traveled within the first two months of receiving feedback. No recurring increase in crash rate was reported through the first seven months of driving with feedback, thus indicating that the reduction in crash risk remained stable over time. There was no video with this system, so the drivers could not review these episodes in context (e.g., to weed out false alarms or to see when the seemingly unsafe behavior was instead a correct response to an external situation). It is important to note that these drivers were all adults and that it was thus feasible to include a baseline period (i.e., the drivers would be expected to exhibit stable driving behaviors). One final note is that the feedback was provided both immediately and in summary form at a later time.

In a later study using the same system, Toledo, Musicant, and Lotan (2008) examined a different group of 191 drivers. The results showed a significant reduction of 38 percent in overall crash rates, but not in at-fault crash rates. However, the remainder of the fleet (which was neither monitored nor exposed to feedback) showed a 19 percent reduction from the period before exposure to feedback to the period after exposure. There was also a significant correlation between crash rate and the calculated risk index for the monitored drivers. Lotan and Toledo (2005) have also used the same IVDR to study a group of 150 teen drivers. However, the latest reported results do not include the results of providing feedback to these young drivers in terms of reducing risky driving maneuvers. Instead, this preliminary report focused on the number of braking, turning, and lane-change events experienced by the novice drivers and their parents for a small subset of the expected data.

McGehee, Raby, Carney, Lee, & Reyes (2007) used a different type of data collection system with teen drivers. In this study, an in-vehicle feedback system consisting of accelerometers and cameras provided both real-time driving performance feedback to the teen drivers as well as post hoc feedback to both the teens and their parents (the DriveCam™ system). When teens performed hard decelerations or hard swerve maneuvers past a set *g*-force level, a light on the data collection system illuminated and a segment of video and driving performance data was saved in a file. Data were automatically downloaded at the teen's high school parking lot. These segments of video were consolidated on a CD-ROM and mailed weekly to the teens and their parents for review. The results from this study indicated that teens who frequently engaged in these risky driving performance maneuvers reduced the frequency of such maneuvers by 72 percent in the first nine weeks that the feedback device was installed in their vehicles. By the second 9-week period, the risky teens were performing at comparable levels to the teens with low frequency of risky behaviors (McGehee et al., 2007). These levels were then maintained throughout 36 weeks of feedback. The low-frequency teen drivers did not exhibit any reduction, likely due to a floor effect. Teens were only compared to themselves – there was not a control group.

In another report, McGehee, Carney, Raby, Lee, & Reyes (2007) reported on the same group of drivers, but with results covering 40 weeks of feedback and a second baseline (no feedback) period of eight weeks at the end of the study. Except for one high-frequency driver, the results showed that the high-frequency drivers maintained a lower frequency of events during the second baseline period. This indicates that driving habits were successfully changed during the feedback period, and that the changes were durable. It is important to note that for this particular monitoring and feedback system, the downloaded files required significant post-processing before the parents could receive feedback (to weed out false alarms and categorize the events). Such a system would be difficult to implement on a widespread basis due to the significant resources required to perform this post-processing. It should be noted that the sample of teens in this study had been driving for quite a while before the study began, due in large part to the laws in Iowa that allow a teen to receive a school driving license at age 14.5 (solely to drive to and from school events).

Conclusions

The results of the work by Lotan and colleagues and McGehee and colleagues show real promise in reducing crashes and injuries among teen drivers using driver monitoring and feedback. Research is still necessary to both assess the association of performance variables to crash and near-crash involvement and an optimal manner of providing driving performance feedback.

METHOD

Approach

The Naturalistic Teenage Driving Study data is an ideal data set with which to assess the relationship between driving performance variables, such as hard braking, hard turning, etc., to crash and near-crash involvement. The following report presents results using the first four to six months of teen independent driving data on crash and near-crash involvement. Teen driving performance is compared to parent driving to assess what differences exist between experienced drivers and novice teen drivers. Also, crash and near-crash data were used to group the teen drivers and to analyze the differences between the teens involved in crashes and near-crashes and those not involved using the first five to six months of independent driving.

Participants

Forty-two newly licensed drivers (*M* = 16.4 years old) were tested in this study. Participants' vehicles were instrumented within a period of ± 3 weeks of receiving their valid driver's license. Gender was approximately equally divided among teens (49 percent males and 51 percent females). Participants were recruited through driving schools and newspaper advertisements. All participants were licensed to drive in the Commonwealth of Virginia and had at least 20/40 corrected vision. Written parental consent, teen assent, and adult consent were obtained for each participant.

Apparatus

The 40-Teen instrumentation package, designed and developed by staff at the Virginia Tech Transportation Institute (VTTI), consisted of a computer (LINUX-based PC) that received and stored data from a network of sensors in the vehicle. In addition to data collected directly from the vehicle network, sensors included:

- An accelerometer box that obtained longitudinal, lateral, and yaw kinematic information
- A radar-based headway detection system to provide information on leading vehicles
- An incident box to allow drivers to flag incidents
- A video-based lane tracking system
- Four channels of continuous video to validate any sensor-based findings

As illustrated in Figure 6, the video subsystem included four continuous camera views monitoring the driver's face and driver side of the vehicle, the forward view, the rear view, and an over-the-shoulder view of the driver's hands and surrounding areas. Two other cameras provided periodic still shots of the interior vehicle cabin as well as the lap area of the rear passenger seat (Figure 7). The interior cabin view was blurred to protect the anonymity of the passengers, yet still allowed reductionists to assess the number of passengers in the vehicle cabin, as well as the general age and seat belt use of the front seat passenger. The rear-seat lap camera was not blurred as passenger faces were obstructed from view, but still allowed judgment of seat belt use and estimations of age and gender of rear-seat passengers (based on clothing and physical body size). Also included was a GPS unit that collected information on vehicle position.

Figure 6. The Quad-image of the Four Continuous Video Camera Locations. From Upper Left to Right: Driver Face Camera, Forward View, Over-the-shoulder, and Rear-view.

Figure 7. The Quad Image with Two Continuous Video Feeds on the Top Two Locations and Still Frames in the Two Bottom Locations. From Upper Left to Right: Driver Face View, Forward View, Blurred View of the Vehicle Cabin, and Back Seat Passenger Lap View.

Data Reduction

The data reduction process pertinent to the following analyses included three separate tasks: initial data reduction, straight road segment data reduction, and event data reduction. These three processes are discussed in detail below.

Initial data reduction

Trained data reductionists reviewed every trip taken by each instrumented vehicle. A trip, or trip file, is operationally defined as beginning when the vehicle ignition is turned on and ending when the ignition is turned off. Data reductionists opened every trip and recorded the participant identification number for the driver, the number of passengers present, an estimate of the age category and gender of each passenger, and whether each passenger had a seat belt fastened. This information is not available automatically by any vehicle sensor, and thus had to be performed manually. Table 1 provides more details regarding the data that were recorded and the operational definitions for each variable type and level of variable.

Table 1. The Variables Reduced during Data Reduction with Corresponding Operational Definitions

Variable Name	Variable Options	Operational Definitions/Notes
Participant ID	Numerical value	Teens, parents, and siblings who commonly drove the vehicle each had a unique participant ID.
Number of passengers	1	1 passenger (additional to driver)
	2	2 passengers (additional to driver)
	3	3 passengers (additional to driver)
	4	4 passengers (additional to driver)
	5	5 passengers (additional to driver)
	6	6 passengers (additional to driver)
	Unable to determine	
Age of passenger	Infant/Toddler (6 years or younger)	Passenger is restrained in a car/booster seat.
	Child, 7 – 13 years of age	Small child not restrained in a car seat.
	Teen, 14-18 years of age	Younger person, clearly not an adult 18 years or older
	Young adult, (19-24)	Younger adult, post high school/college aged.
	Adult (25+ years of age)	Adult, aged 25 years or older
Time of Day	Daytime	Ambient lighting is present
	Nighttime	No ambient lighting is present
	Unable to determine	Video is not present.

Straight Road Segment Reduction

Trained data reductionists also reviewed and recorded a battery of variables for 22 *a priori* selected straight segments of roadway. These segments did not contain any primary or secondary roadway junctions, though entrances into parking lots were sometimes present. Segments were also chosen to represent one of four types of roadways:

1. Two-lane undivided highway
2. Divided highway
3. Undivided urban/suburban roadway
4. Divided urban/suburban roadway

The selection process for these road segments and road types focused on relatively high-traffic roadways to maximize the frequency of travel for study participants. GPS coordinates for each end of the roadway segment were obtained using mapping software. Each pair of GPS coordinates was then used as a geo-fence: every time a participant vehicle sequentially passed through each of the GPS coordinates (on either end of the road segment), this segment of data was flagged in the data stream and reviewed by a trained reductionist. Once it was verified that the vehicle did, in fact, traverse the appropriate road segment, the reductionist recorded a variety of variables regarding driver behavior and performance on this straight road segment. Of particular interest to this analysis was driver engagement in secondary tasks during these road segments as well as their eye scanning patterns. Eye glance data reduction was completed on those straight road segments where there was a teen passenger present and/or the driver performed a lane change maneuver during the straight road segment.

The reduction of secondary task engagement required the data reductionists to review the video and assess whether the driver engaged in any of the listed secondary tasks while negotiating the road segment. The list of secondary tasks and the operational definitions for each are presented in Appendix A.

While it was assumed that the frequency of teens traveling through any one straight road segment would be highly variable, the degree of variability was still somewhat surprising. In Figure 8, the frequency of all 42 teen drivers traversing each of the 22 road segments is shown. The variability ranges from one road segment being crossed once to another road segment being crossed 417 times, all within the first 6 months of driving. Given this wide variability, the statistical analyses using these data will use frequency counts; however, the accompanying figures will show the percent of road segment crossings per driver.

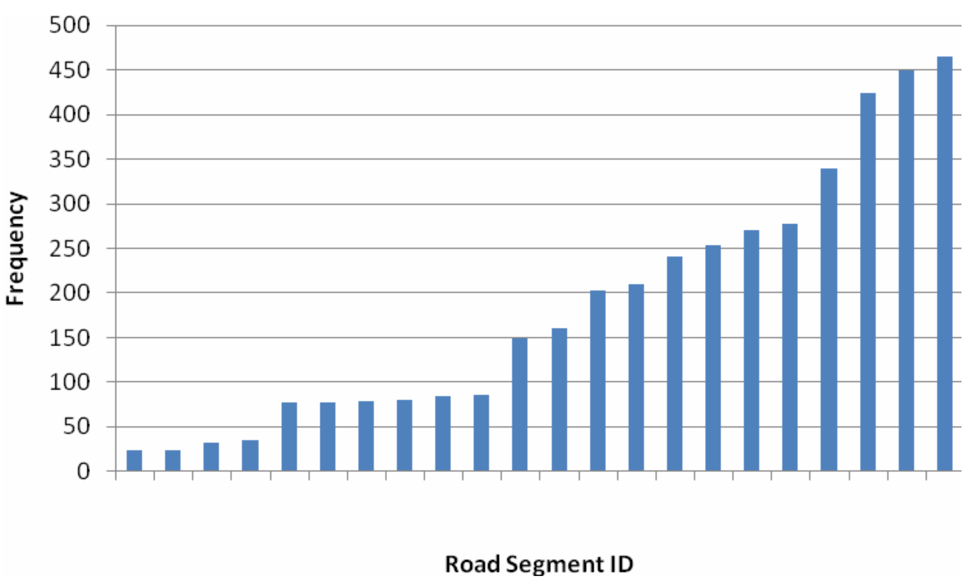


Figure 8. The Frequency of Teen Drivers Crossing *a priori* Selected Road Segments during their First Six Months of Unsupervised Driving

Event Reduction

Trained data reductionists also reviewed the video and the corresponding driving performance data for potential crashes and near-crashes (collectively referred to as *events*). Due to the continuous data collection that resulted in over 6 Terabytes of video and driving performance data, events are identified in the data stream using kinematic data triggers. The values of these kinematic triggers are presented in Table 2.

Table 2. Values of the Triggers used to Identify the Crashes and Near-crashes in the 40 Teen Driving Performance Data

Trigger Name	Value
Longitudinal deceleration	=-0.65g longitudinal deceleration
Lateral acceleration	± 0.75g lateral acceleration
Forward Time-to-Collision	• Forward time-to-collision of 4 seconds coupled with longitudinal deceleration of -0.6g. • Forward time-to-collision of 4 seconds coupled with longitudinal deceleration of -0.5g and less than 100 feet to lead vehicle.
Yaw Rate	Vehicle swerves ±4 degrees per second to ±4 degrees per second within a window of 3.0s
Longitudinal acceleration	=0.5g but returns to =0.1g within 0.2 seconds.
Critical Incident Button	Boolean response.
Speeding Trigger	In excess of 70 mph but not traveling on an interstate.

Once a potential event was identified, data reductionists reviewed the corresponding video and classified the event by severity, as a crash, near-crash, or judgment error. Table 3 provides operational definitions for these three severity levels. A battery of variables was recorded for the events that were categorized as crash or near-crash. Judgment errors are currently not being reduced but may be reduced in a set of future analyses. The types of variables that were recorded for the crashes and near-crashes are shown in Table 4.

Table 3. The Operational Definitions of Each Severity Level

Severity Level	Operational Definition
Crash	Any contact with an object, either moving or fixed, at any speed in which kinetic energy is measurably transferred or dissipated. Includes other vehicles, roadside barriers, objects on or off of the roadway, pedestrians, cyclists, or animals.
Near-crash	Any circumstance that requires a rapid, evasive maneuver by the subject vehicle, or any other vehicle, pedestrian, cyclist, or animal to avoid a crash. A rapid, evasive maneuver is defined as steering, braking, accelerating, or any combination of control inputs that approaches the limits of the vehicle capabilities.
Judgment Error	Any circumstance where the teen driver purposefully or inadvertently created a safety-relevant situation due to either general inexperience or performance error. Examples include those events where the teen drivers engage in 'horseplay' or over-react to surrounding traffic.

Table 4. Areas of Data Reduction, Definition of the Area, and Examples

Area of Data Reduction	Definition	Example
Vehicle Variables	All of the descriptive variables including the vehicle identification number, vehicle type, ownership, and those variables collected specifically for that vehicle, such as vehicle miles traveled (VMT).	Vehicle ID, Vehicle type, owned/shared, and VMT.
Event Variables	Description of the sequence of actions involved in each event, list of contributing factors, and safety or legality of these actions.	Nature of Event/ Crash type, Pre-event maneuver, Precipitating Factors, Corrective action/Evasive maneuver, Contributing Factors, Types of Inattention, Driver impairment, etc.
Environmental Variables	General description of the immediate environment, roadway, and any other vehicle at the moment of the incident, near-crash, or crash. Any of these variables may or may not have contributed to the event, near-crash or crash.	Weather, ambient lighting, road type, traffic density, relation to junction, surface condition, traffic flow, etc.

Driver's State	Description of the instrumented-vehicle driver's physical state.	Hands on wheel, seat belt usage, fault assignment, eye glance.
Driver/Vehicle 2	Description of the vehicle(s) in the general vicinity of the instrumented vehicle and the vehicle's action.	Vehicle 2 body style, maneuver, corrective action attempted, etc.
Narrative	Written description of the entire event.	

Data Reduction Inter- and Intra-Rater Reliability for the Naturalistic Teenage Driving Study

Training procedures were implemented to improve both inter- and intra-rater reliability, given that data reductionists were asked to perform subjective judgments on the video and driving data. Reliability testing was then conducted to measure the resulting inter- and intra-rater reliability.

The entire process for ensuring quality and reliability in the data reduction process is shown in Figure 9. The first step in ensuring high levels of reliability among data reductionists occurs prior to the training of the data reductionist. Researchers work with the lab manager to first write a clear, concise protocol that operationally defines the data reduction process. This is an iterative task that includes the experimenter, data reduction lab manager, and senior level data reductionists reviewing and revising the protocol until it is deemed by all parties to be appropriate to train new reductionists.

Second, data reductionists are trained using the approved protocol. The lab manager provides the initial training on using the approved protocol, and then the lab manager works closely with the data reductionists to assess their levels of understanding and comprehension. All initial data reduction is spot-checked to ensure that the protocol was written appropriately and that the resulting dataset will be satisfactory.

After this initial period, the data reduction manager performed periodic spot checks of the reductionists' work, monitoring event validity judgments as well as recording all database variables. Reductionists also performed 30 minutes of spot-checks of their own or other reductionists' work each week. This was done to ensure accuracy, but also to allow reductionists the opportunity to view other reductionists' work. It was anticipated that this would encourage each reductionist to modify his/her own work and to improve consistency in decision-making techniques across all reductionists. Any issues identified by the spot-checking activities of the reductionist managers and the reductionists were communicated via email and impromptu lab discussion sessions. These communications provided iterative and ongoing reduction training throughout the entire data reduction process.

To determine the success of these techniques, inter- and intra-rater reliability tests were conducted every three months. Reliability tests were developed (each containing 20 events) for which the reductionist was required to make validity judgments. Three of the 20 events were also completely reduced in that the reductionist recorded information for all reduction variables (i.e., event variables, driver state variables, and environmental variables) as opposed to simply marking severity of event. Three of the test events on each test were repeated on the next test to obtain a measure of intra-rater reliability. Using the expert reductionist's evaluations of each epoch as a “gold” standard, the proportion of agreement between the expert and each rater was calculated for each test. Inter-rater tests were completed on the initial reduction for 6, 12, and 18 months of data reduction. The results indicated an intra-rater reliability of 99percent for all three tests. The entire data reduction for six months of straight-road segments was conducted in less than 3 months, thus only one inter-rater test was completed on this segment of data. The average inter-rater reliability score for this reduction task was 92.1 percent. To date, no formal inter-rater test has been completed on the crash/near-crash reduction. Only two reductionists have worked on this task and they have been spot-checking over 50 percent of each other’s work to date. Discrepancies are mediated by a third, senior-level researcher.

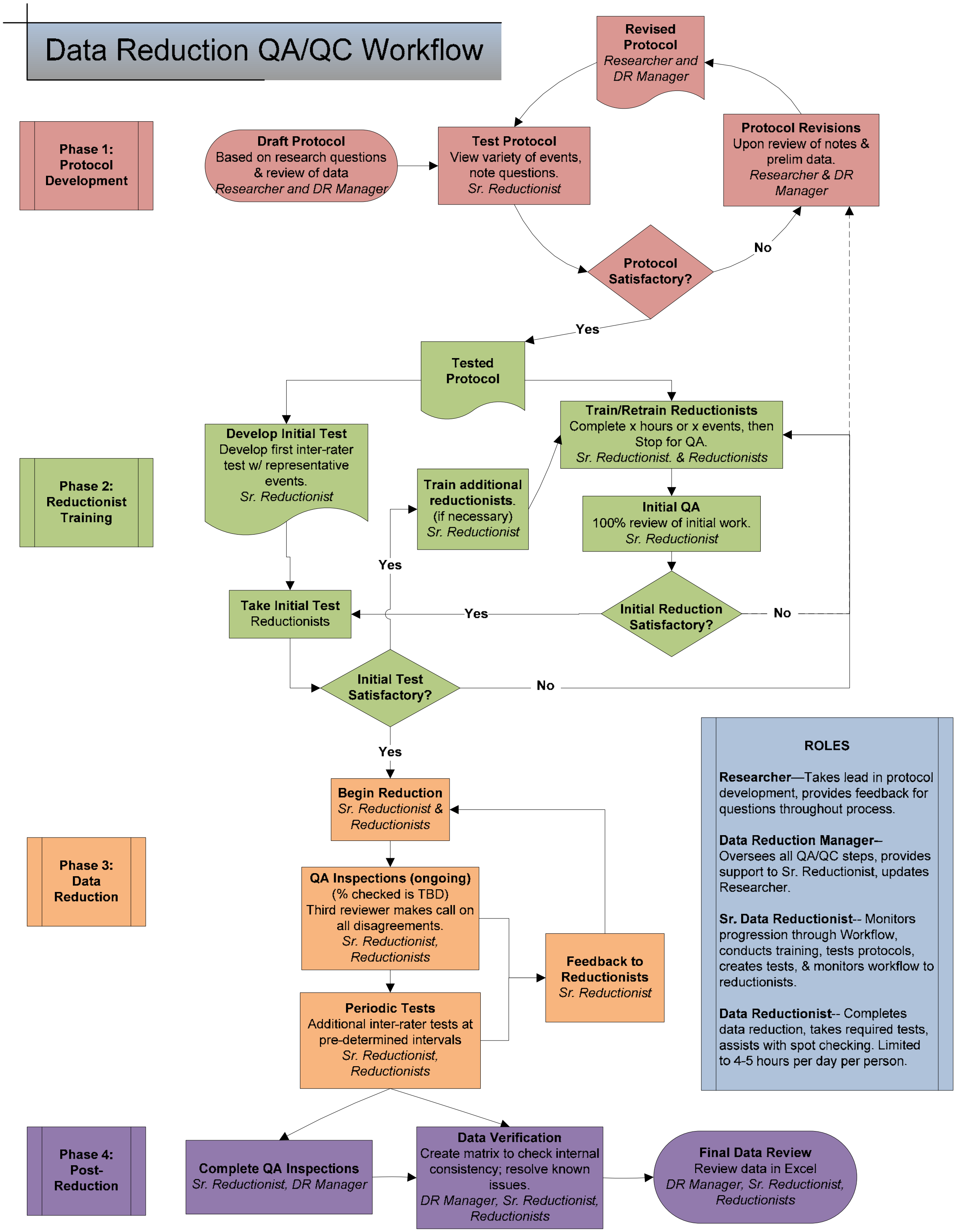


Figure 9. The Quality Assurance and Quality Control Flow Chart for Data Reduction at VTTI

RESULTS

The results are focused on five general research questions:

1. How does teen driving performance differ from adult driving performance?
2. How does teen driving performance differ between teens with high versus low involvement in crash and near-crash events?
3. Which driving performance variables are the best predictors of crash and near-crash event involvement for teens?
4. How do teen risk factors (speeding, presence of teen passengers, etc.) interact with teen driving performance and crash and near-crash event involvement?
5. Using the trigger criteria developed for the Naturalistic Teenage Driving Study, provide an assessment of the effectiveness of the triggers used (i.e., what percentage of triggered events were valid?). What would be the cost/benefit of altering these trigger criteria to be suitable for a teen driver monitoring system?

Analysis

Statistical analyses were conducted using the SAS Statistical Software Package (v 9.1 for Windows). A *p* value of 0.05 was considered to indicate significance, while *p* values of between 0.051 and 0.10 were considered to be indicative of trends. Categorical data were analyzed using contingency tables and Chi Square type tests. For 2x2 contingency tables, either the Fisher's Exact Test or the Mantel-Haenzel (when categorical data were also ordinal) were used, while Chi Square was used for larger contingency tables. Note that the Fisher's Exact Test cannot be used with very large sample sizes. Continuous data were analyzed using the PROC GLM routine (equivalent to PROC ANOVA, but resistant to unequal cell sizes).

Question 1: How does teen driving performance differ from adult driving performance?

To answer this question, the number of crashes and near-crashes for the adult drivers was first compared to the number of crashes and near-crashes for the teen drivers over the first five months of driving. In the first five months of driving, there were 7 crashes and 42 near-crashes for teen drivers and 6 near-crashes for the adult drivers.

However, this does not account for the exposure (miles driven during those five months). To account for exposure, all of those drivers with at least 300 miles driven over the first five months in the study were included in a rate calculation (events per 10,000 VMT). Only four adults were involved in any crashes or near-crashes over the first five months of driving (Figure 10), whereas 23 of the teen drivers were involved in a crash or near-crash over the same time frame (Figure 11). When these data were normalized to 10,000 miles of driving, the number of events was dramatically different for teens and adults. Adults had in a maximum rate of 27.4 crashes/near-crashes per 10,000 mi and the teens had a maximum rate of 50.9 crashes or near-crashes per 10,000 VMT, as illustrated in Figures 10 and 11.

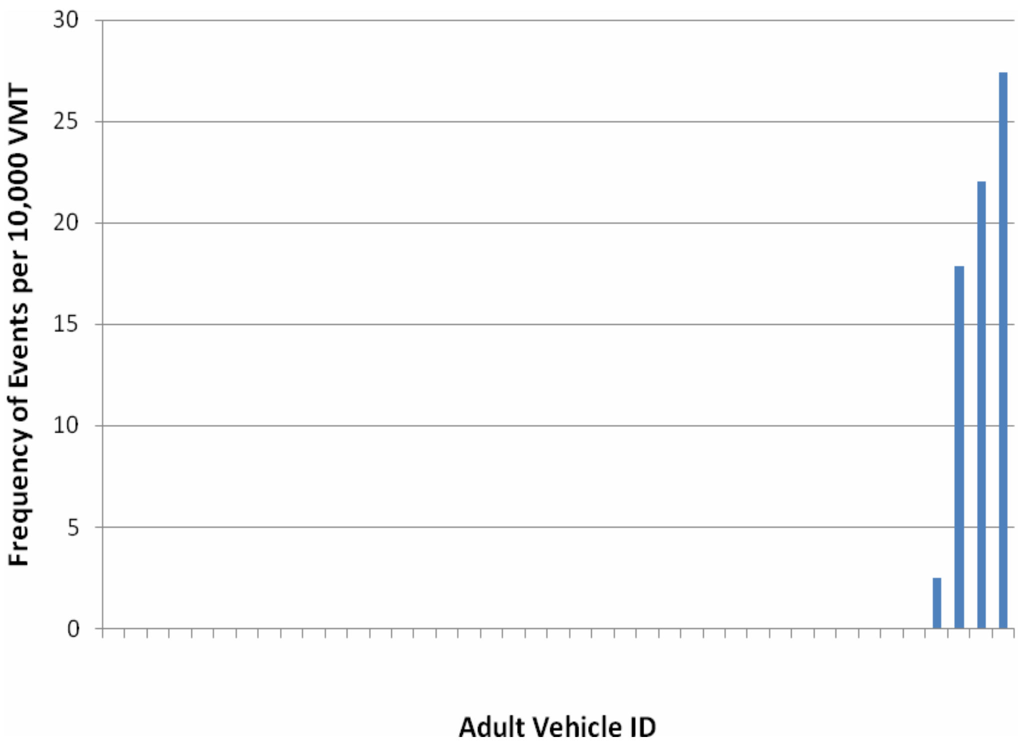


Figure 10. The Number of Events per 10,000 VMT for the Parents of Shared Vehicles

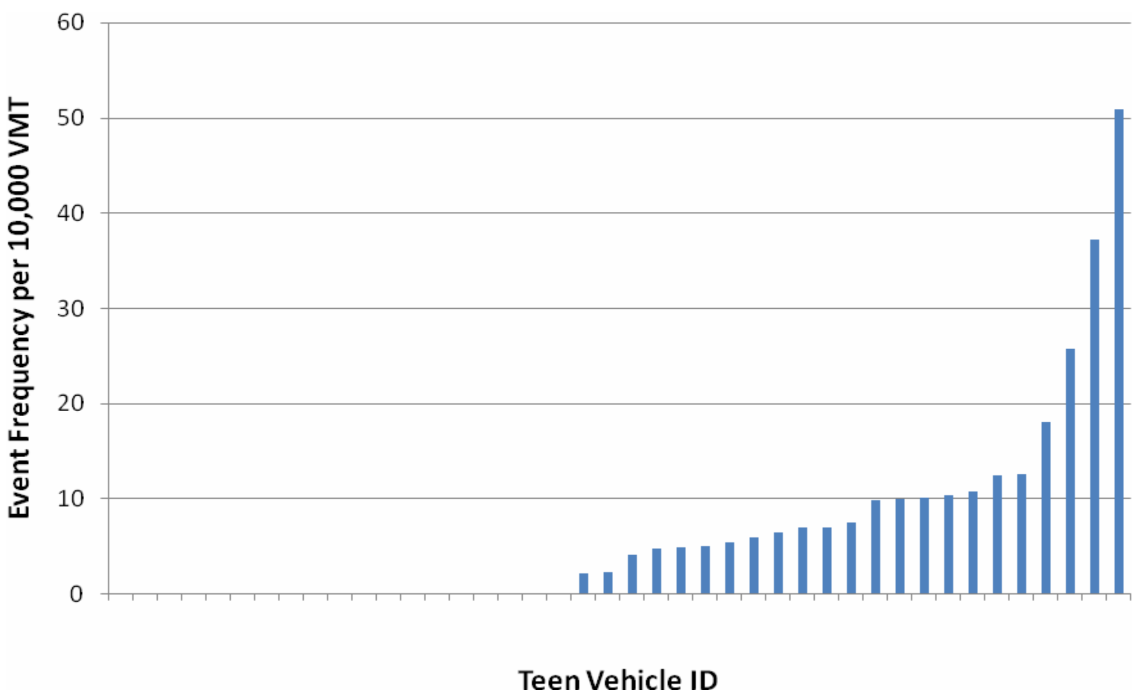


Figure 11. The Number of Events per 10,000 VMT for the Teen Drivers

There were only four parents with crashes or near-crashes and enough mileage to calculate rates for the first five months of driving. The rates for these four drivers were compared to the rates for their corresponding children (the teen drivers). As can be seen in Figure 12, there was almost no correspondence between the parents and teens, with one teen having a substantially higher event rate than his/her parent, and three teens having substantially lower events rates than their parents.

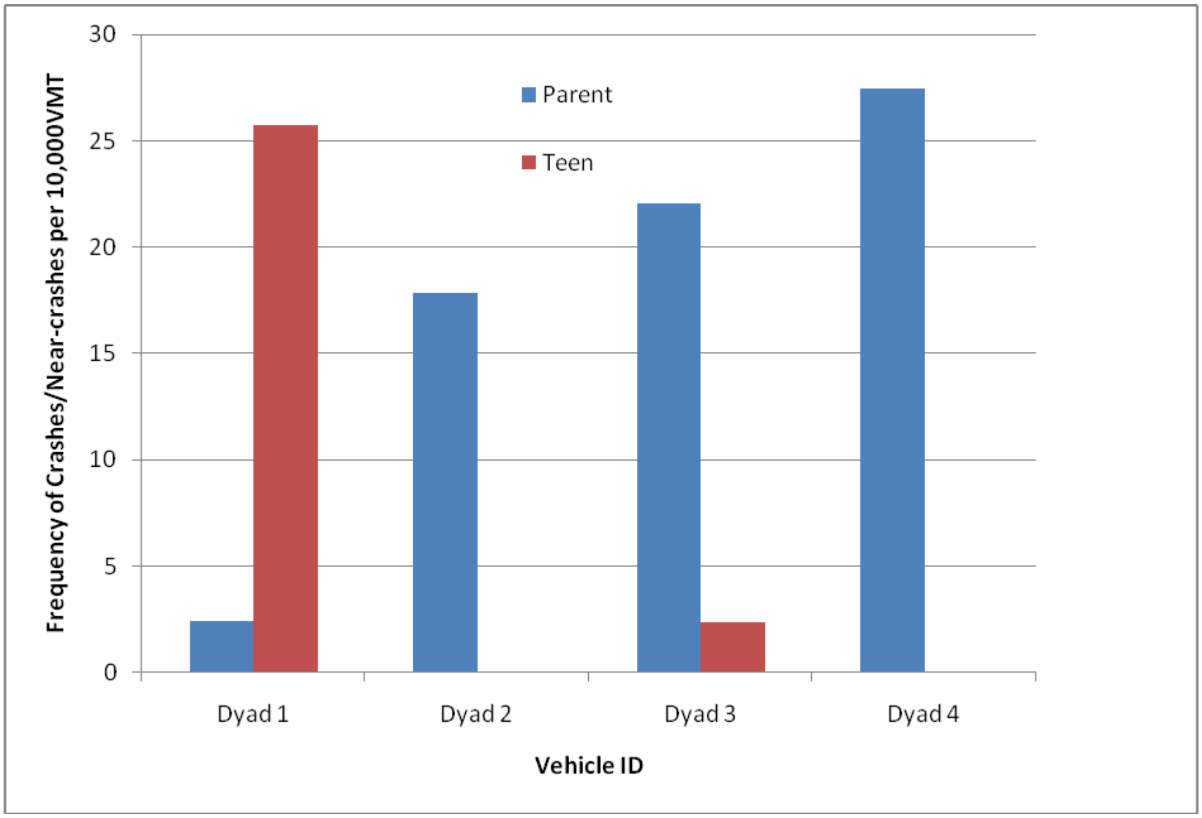


Figure 12. Crash/Near-crash Rates for the Four Parent-teen Dyads where the Parent and Teen had Crashes or Near-crashes

Differences in driving performance between the teen and adult drivers were also compared for the frequency of secondary task engagement during the straight road segment epochs (Figure 13). *At this time, only four months of data have been reduced for the road segments for both parents and teens; therefore only four months of data are reported.* For this analysis, secondary tasks include all of those listed in Appendix A except for "Talking/singing/dancing with obvious passenger." This was excluded from the secondary task analysis because this is a known risk factor and will be discussed separately in this report.

Note that the parents engaged in secondary tasks for a higher percentage of their road segment crossings than did the teen drivers for the first three months, although both teens and adults showed an increasing trend. The upward trend in teen driving secondary task engagement will be interesting to follow across 12 months of data collection, as it appears to be nearing the adult level after just 4 months. A Chi Square test for adults by months was not significant ($p = 0.1108$), indicating that the presence of secondary tasks on straight road segments did not vary significantly over time. However, the same test for teen drivers showed that the upward trend shown in Figure 13 was significant (*p* = 0.0125). When teens were compared to adults, regardless of time, adults had a significantly higher frequency of performing secondary tasks on straight road segments over the entire 4-month span (Fisher's Exact Test, *p* = 0.0025).

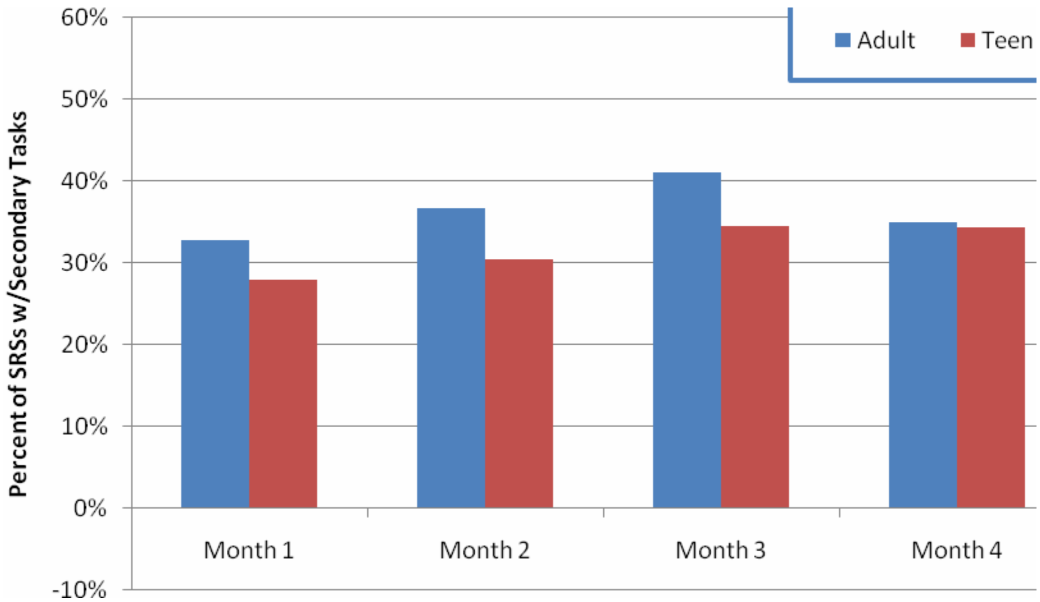


Figure 13. Percentage of Straight Road Segments where Teens or Adults are engaging in a Secondary Task across the First Four Months of Driving

Cell phone use is a secondary task of particular interest to many researchers in the field of novice teen driving. As shown in Figure 14, adult cell phone use on straight road segments varied over the four months without a clear pattern, while teen cell phone use over the same road segments and the same time period increased in a linear fashion. Adults' cell phone use varied significantly over time (Chi Square, *p* = 0.0002), as did the teens' cell phone use over time (*p* = .0025). A Fisher's Exact test comparing teens to adults over this period, but without regard to month, showed a significant difference (*p* = 0.0064) with adults using the cell phone more frequently overall (7.7 percent of the time versus 5.7 percent of the time for teens). However, note that the teens surpassed the adults in Month 4, so examination of trends over the subsequent months will be of great interest.

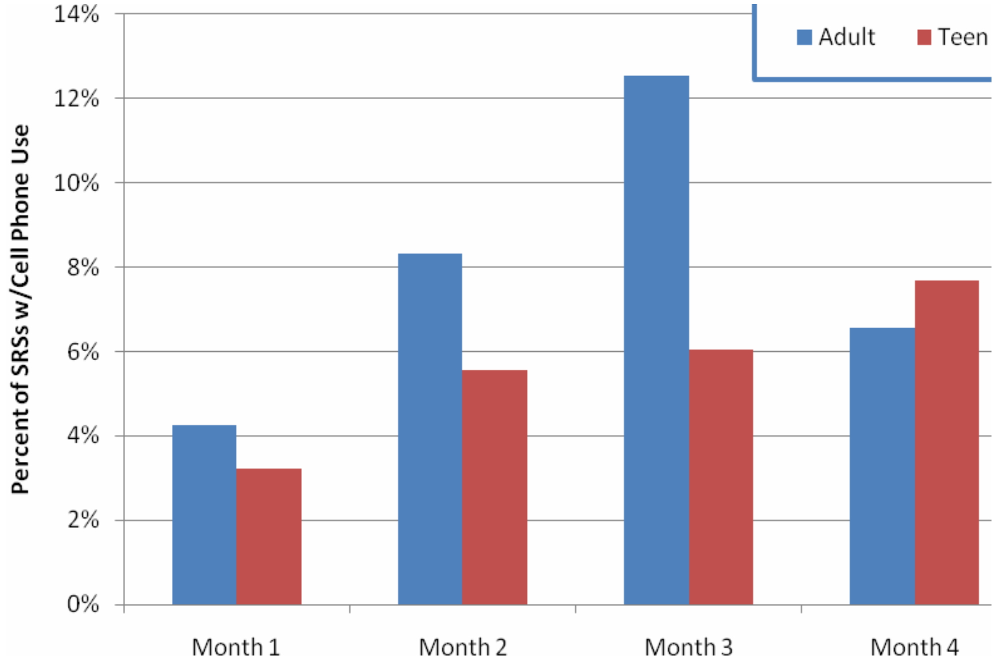


Figure 14. Percentage of Straight Road Segments where Teens or Parents are engaging in a Cell Phone Task across the First Four Months of Driving

An analysis was also conducted comparing parents versus teens on the percentage of road segment crossings where they were traveling at least 5 mph over the speed limit. Figure 15 shows an interesting pattern where the teens are speeding on a greater percentage of road segments as they gain experience over four months of driving. No such trend is apparent for the parents. A Chi Square test for adults by months was not significant ($p = 0.421$), indicating that the presence of speeding on straight road segments did not vary significantly over time. However, the same test for teen drivers was significant ($p = 0.006$), indicating that teens become more likely to speed on straight road segments over time. In comparing teens to adults without regard to time, adults had a significantly higher frequency of speeding on straight road segments over the entire 4-month span (Fisher's Exact Test, $p < 0.0001$).

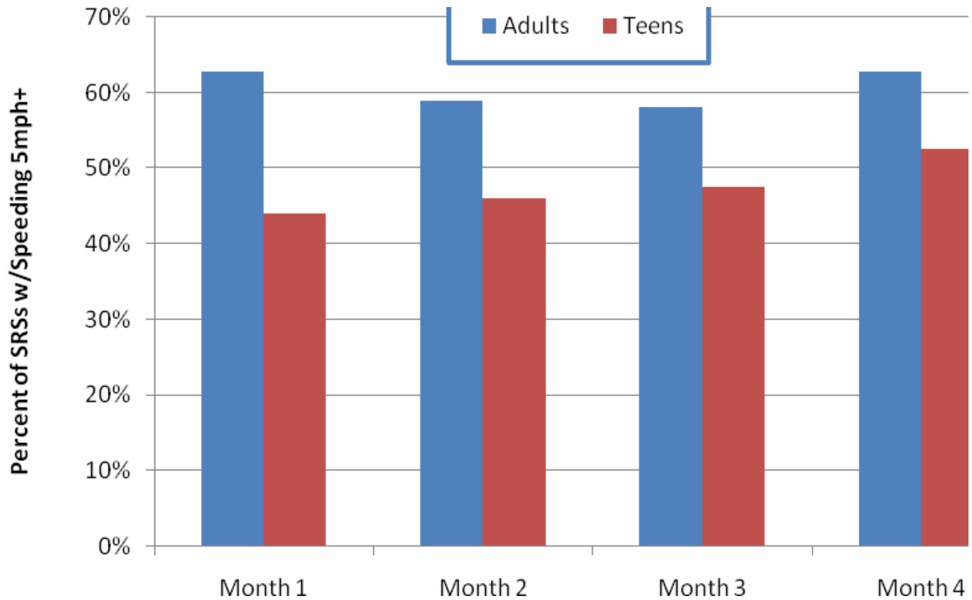


Figure 15. Percentage of Straight Road Segments where Teens or Parents are engaging in Speeding at Least 5mph Above the Speed Limit across Months of Driving

The final set of analyses conducted for this research question compared teen and adult drivers in their frequency of driving under known risk factor conditions for teen drivers, such as driving at night, with teenage passengers, after curfew, on weekends, and without wearing seat belts. These analyses required use of the initial reduction dataset, which at the time this report was written was almost completely reduced. There were thus 101,290 trips considered in these analyses, with up to 19 months of data collection per participant. Primary and secondary parents were grouped in these analyses as adults. Altogether, 27,745 trips were taken by adults, and 73,545 were taken by teens. Recall that about half of the teen participants entered the study expecting to share a family vehicle with their parents, and about half expected to have dedicated use of a vehicle. As shown in Figure 16, those participants who expected to initially share a vehicle drove for about half of the trips in that vehicle over 18 months, with their parents accounting for the other half of the trips. Those with dedicated use of a vehicle at enrollment into the study accounted for 95 percent of the trips subsequently taken in that vehicle. These differences were significant (Chi Square, $p < 0.0001$).

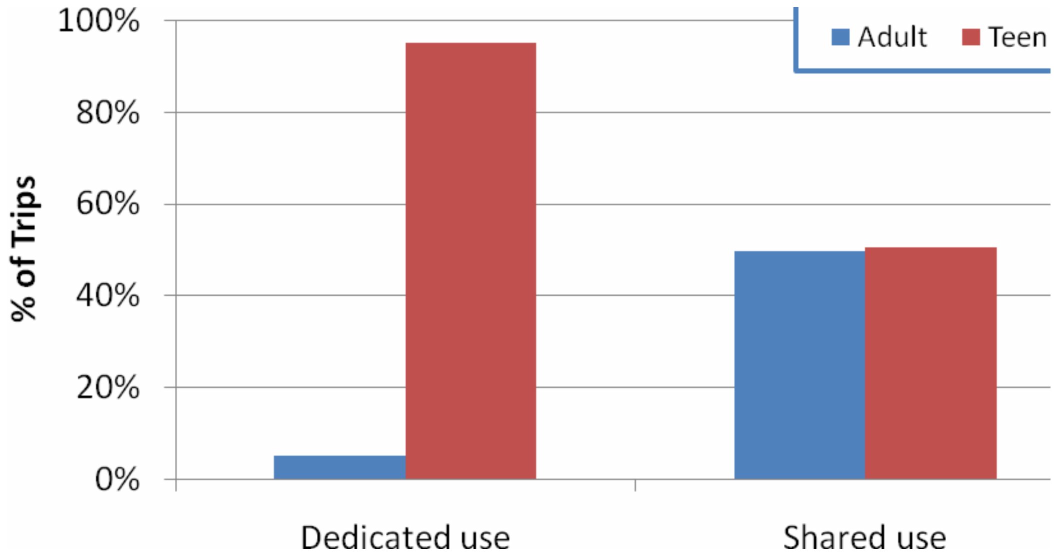


Figure 16. Percent of Trips taken by Teens and Adults across 18 months of Data Collection for those Dyads Initially Identified as having Dedicated Versus Shared Use of a Vehicle

Driving at nighttime was almost twice as prevalent for teen drivers as compared to adults, as shown in Figure 17 (nighttime was determined using video during initial data reduction). However, both teens and adults were more likely to drive during daylight than at nighttime (Chi Square, $p < 0.0001$). Teen drivers in Virginia are also subject to a curfew between the hours of midnight and 4 a.m., except for going to and from work or to and from school-sanctioned events (although there was no way to determine whether either of these conditions were met for a given trip). Curfew was classified based on the date-time stamp place at the beginning of the trip file (this indicates that the trip started during curfew hours). Figure 18 shows that teens are slightly more likely to drive during curfew hours as compared to adults, while both teens and adults were more likely to drive during non-curfew hours than during curfew hours (Chi Square, $p < 0.0001$). Altogether, 1.1 percent of teen trips were taken during the curfew hours, which make up 16.7 percent of the day (4 hours out of 24 hours).

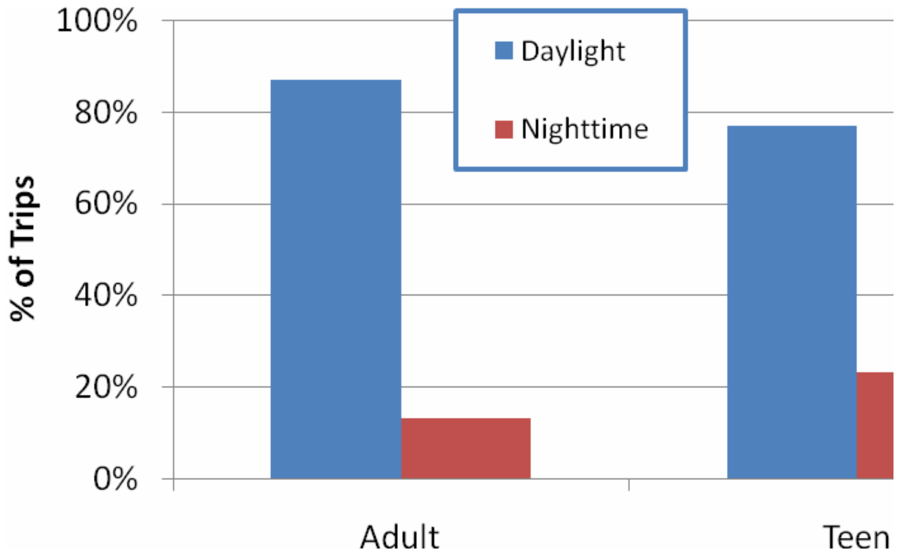


Figure 17. Percentage of Trips Taken at Nighttime and in Daylight for Teens and Adults over 18 Months of Data Collection

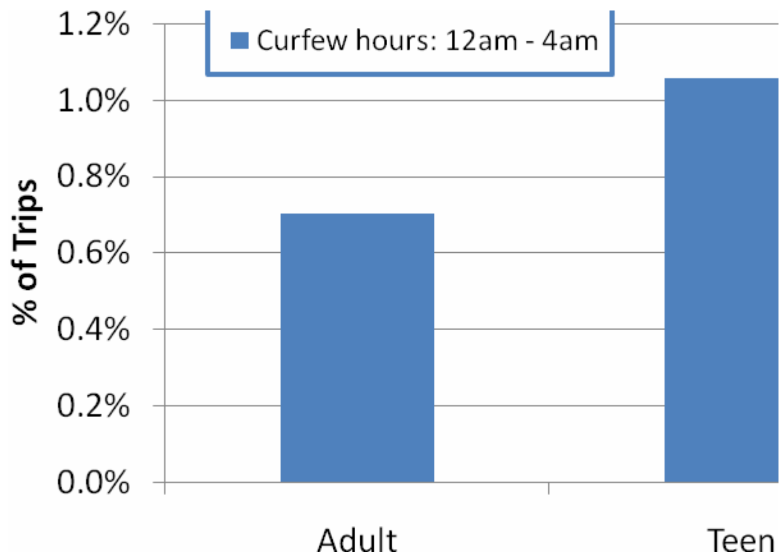


Figure 18. Percentage of Trips Taken during Curfew Hours for Teens and Adults over 18 Months of Data Collection

Another risky driving situation for teen drivers is driving on weekends as compared to weekdays. As shown in Figure 19, adults took a slightly higher proportion of trips on weekends as compared to teens, while both parents and teens were more likely to drive during weekdays (Chi Square, $p < 0.0001$). Another potentially risky driving situation for teens is driving on weekends at nighttime. Figure 20 shows that on weekends, teen drivers are twice as likely as adults to be driving at nighttime, although both teens and adults are more likely to be driving during the daytime on weekends (Chi Square, $p < 0.0001$).

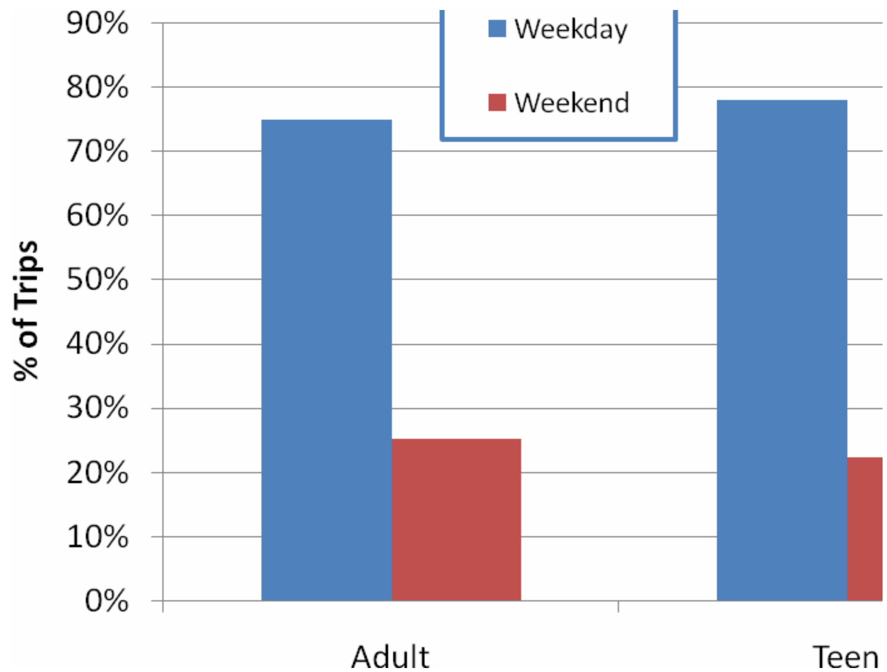


Figure 19. Percentage of Trips taken by Teens and Adults on Weekends Versus Weekdays over 18 Months of Data Collection

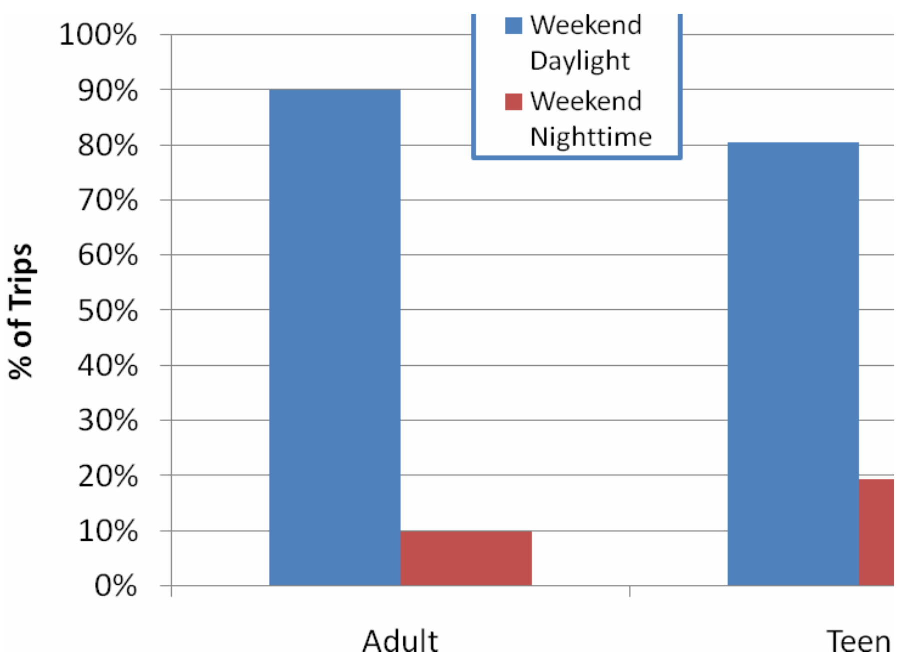


Figure 20. Percentage of Trips Taken by Teens and Adults on Weekends, During Daylight and Nighttime over 18 Months of Data Collection

Driving with teen passengers is another known risk factor for teen drivers. The adults and teens in this study were just as likely to drive with teen passengers (Figure 21). This analysis was not statistically significant, whether examined in terms of: 1) the exact number of teen passengers, 2) no teen passengers versus one or more teen passengers (as in Figure 21), or 3) zero or no teen passengers versus two or more teen passengers. This indicates that the increased risk for teens is not simply due to increased exposure to driving with teen passengers, but is more likely due to activities taking place within the vehicle with these passengers present.

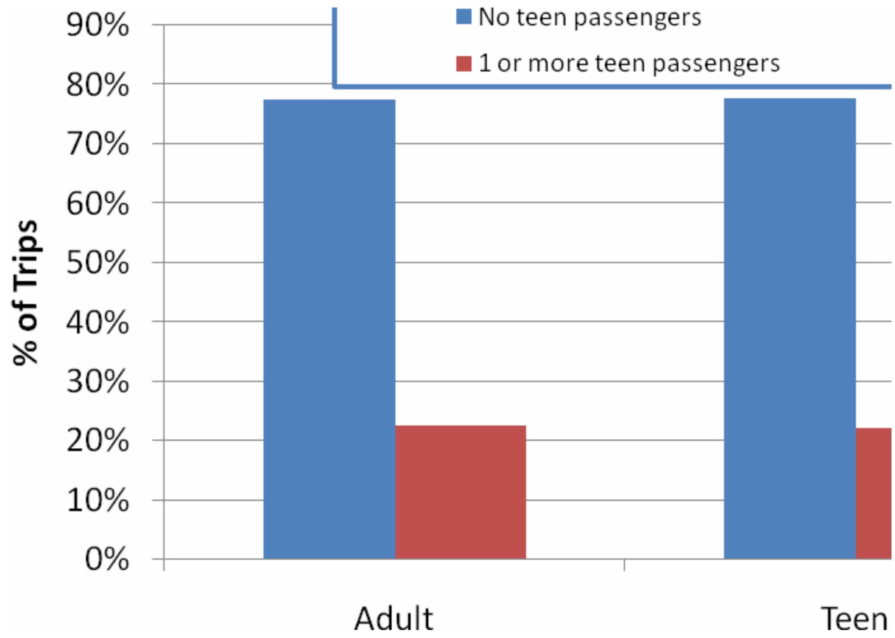


Figure 21. Percentage of Trips taken by Teens and Adults with Teen Passengers over 18 Months of Data Collection

Seat belt use was the final risky driving situation examined between teens and adults. As shown in Figure 22, both teens and adults were more likely than not to be wearing their seat belts (lap and shoulder belts; Chi Square, $p < 0.0001$). Teens were slightly more likely to be observed driving without their seat belts, but overall use was very high for both groups (at least 95 percent for each group). Both teens and adults were also very likely to be observed with all passengers belted (90 percent for teen drivers and 94 percent for adult drivers). This result is shown in Figure 23, which also shows that teens were more than twice as likely as adult drivers to have all passengers unbelted (Chi Square, $p < 0.0001$).

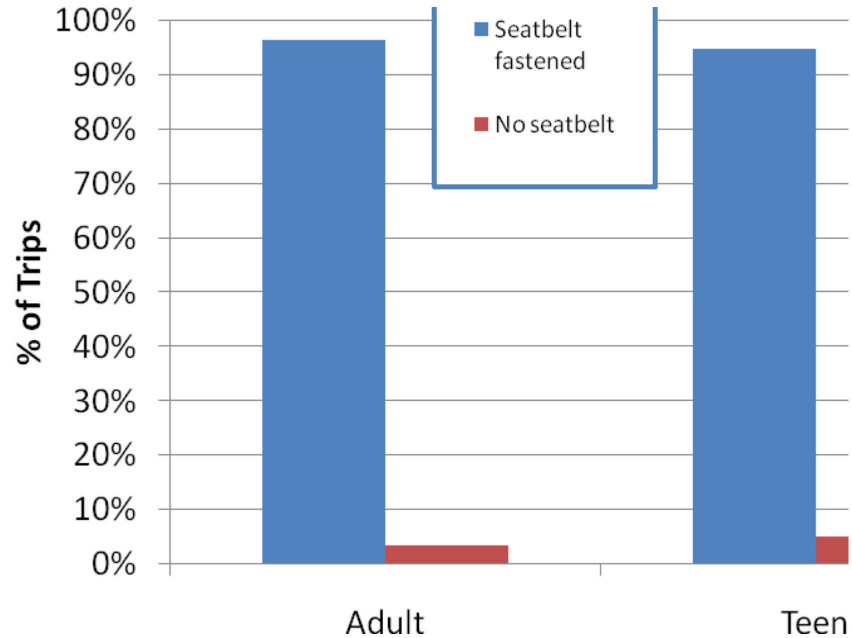


Figure 22. Percentage of Trips taken by Teens and Adults by Seat Belt use over 18 Months of Data Collection

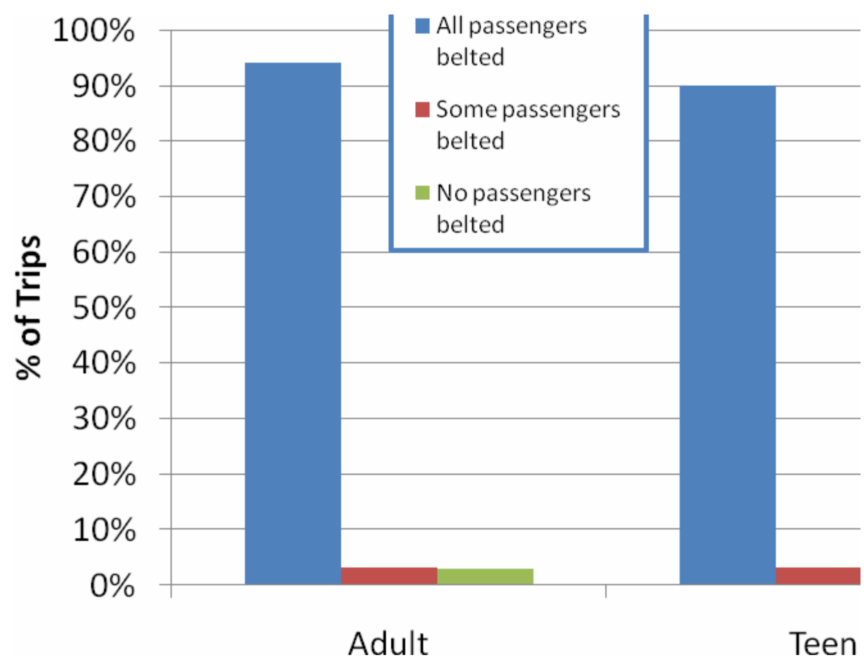


Figure 23. Percentage of Trips taken by Teens and Adults by Passenger Seat Belt Use over 18 Months of Data Collection

The next analysis examined whether the driver's lack of seat belt use was related to passenger seat belt use (however, keep in mind that it was rare for either adult or teen drivers to be unbelted). Figure 24 shows that when an adult driver is not wearing a seat belt, all passengers were belted in more than 80 percent of trips, while when a teen driver was unbelted, all passengers were belted in fewer than 40 percent of trips. In other words, a teen driver who is unbelted and carrying one or more passengers is less than half as likely to have all passengers belted than are adult drivers under the same conditions. Furthermore, a teen driver who is unbelted and carrying one or more passengers is almost five times more likely to have *all passengers unbelted* than is an adult driver under the same conditions (Chi Square, $p < 0.0001$).

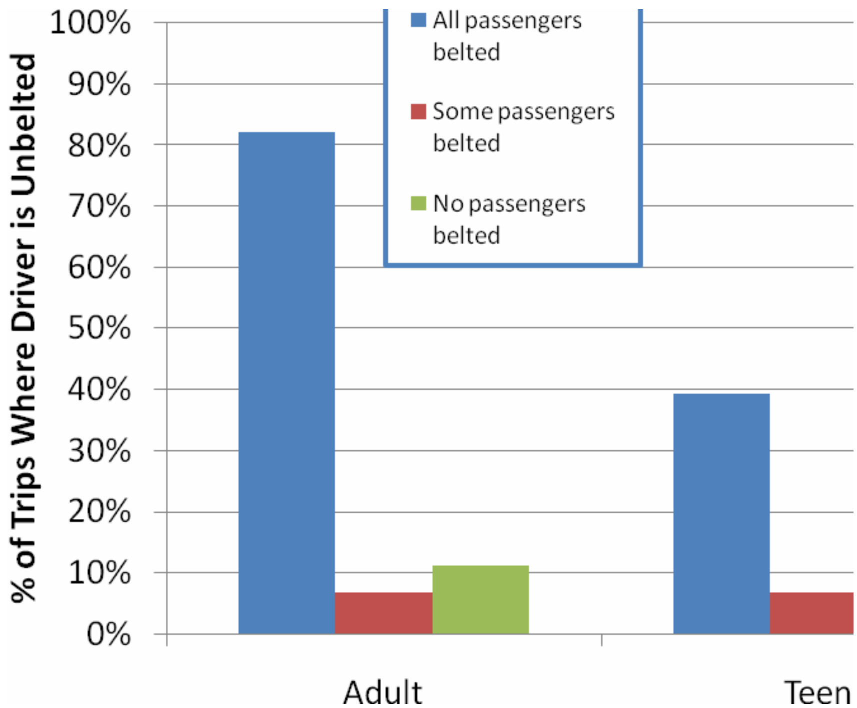


Figure 24. Percentage of Trips taken by Unbelted Teen and Adult Drivers by Passenger Seat Belt use over 18 Months of Data Collection

A final analysis was conducted for the risky situation of unbelted drivers driving with teen passengers. For this rare but highly risky teen driving situation, a teen driver who is unbelted and carrying one or more teen passengers is over seven times more likely to have all passengers unbelted than are adult drivers under the same conditions (Figure 25). Also, a teen driver who is unbelted and carrying one or more teen passengers is less than half as likely to have all passengers belted than are adult drivers under the same conditions (Chi Square, $p < 0.0001$).

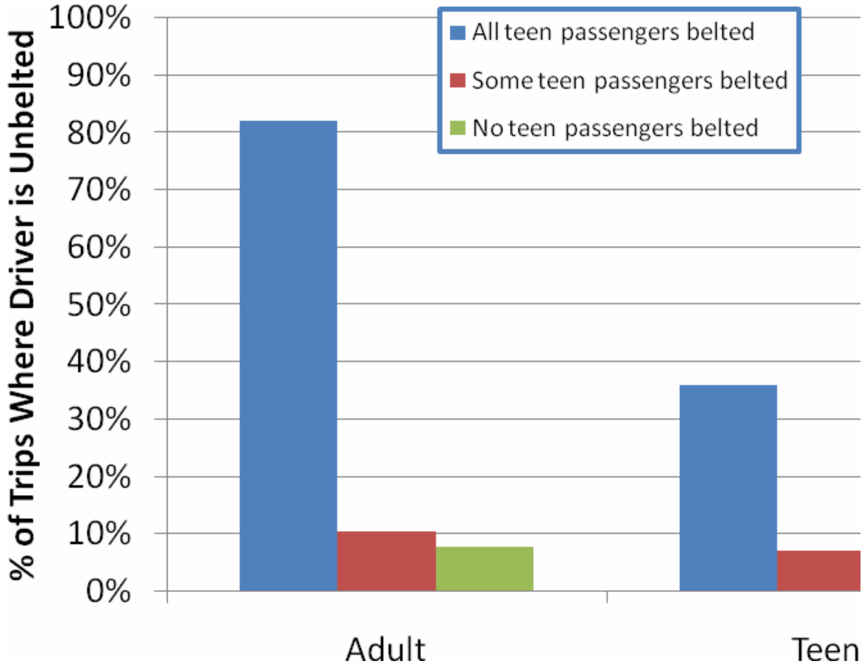


Figure 25. Percentage of Trips taken by Unbelted Teen and Adult Drivers by Teen Passenger Seat Belt use over 18 Months of Data Collection

Question 2. How does teen driving performance differ between teens with high versus low involvement in crash and near-crash events?

Based on the evaluation of crash and near-crash involvement presented in Question 1, teen drivers were placed in one of two categories: 1) those who were involved in crashes and near-crashes in their first six months of driving, and 2) those that were not involved in crashes and near-crashes over the same time period. All of the drivers without any crashes or near-crashes were grouped in the ‘low risk’ group. All of the drivers who were involved in at least one crash or near-crash were grouped in the ‘high risk’ group. These groups were so named given that previous naturalistic driving studies and field operational tests repeatedly have found that 15 to 20 percent of the drivers account for 70-80 percent of the crashes and near-crashes. Therefore, the same drivers are repeatedly involved in a majority of the crashes and near-crashes. Given that most of these analyses are only looking at the first six months of driving data, those drivers who were involved in a crash or near-crash are most likely at higher risk of being involved in more crashes and near-crashes than those drivers who have not. Therefore, those drivers who were involved in at least one crash or near-crash in the first six months of driving were assigned to the higher risk group and those who were not involved in any crash or near-crash in the first six months of driving were assigned to the lower risk group.

The ‘low risk’ group consisted of 19 participants (12 female, 7 male). The ‘high risk’ group consisted of 23 participants (10 female, 13 male). Given that all participants were 16 when they started the study and were within 3 weeks of licensure, their ages are all primarily equivalent.

Three risky driving behaviors were assessed for these two risk groups: secondary task engagement, speeding above the posted speed limit, and total time eyes off the forward roadway. These three driving performance parameters were assessed for the straight road segments that the drivers in these two groups traversed. Because of the high variability in frequency of driving on each of the *a priori* selected road segments, the number of road segment crossings where the driver was engaging in a secondary task or speeding was divided by the total number of times that the driver traversed these road segments. Therefore, a percentage per driver was calculated versus reporting frequency counts since a frequency count would be skewed due to high variability. Percent total time eyes were off the roadway was calculated by assessing the amount of time that drivers were looking away from the forward roadway, not including glances to the rearview mirror or the instrument panel (e.g., driving-related glances) and dividing by the total time that eye glances were recorded. Chi Square analysis and an analysis of variance (ANOVA) were conducted (as appropriate) and the results are described below.

Figure 26 presents the data for engaging in secondary tasks across the first five months of driving. The high-risk drivers (mean = 31.3) had a significantly higher prevalence of secondary task engagement than did the low-risk drivers (mean = 27.7; $\times^2[1,N = 4,497] = 8.94$, $p < 0.05$). A Chi Square analysis was also conducted to determine whether the drivers engaged in secondary tasks more frequently across month of driving as there appears to be an upward trend. Significant differences across month of driving were not found for either driver group.

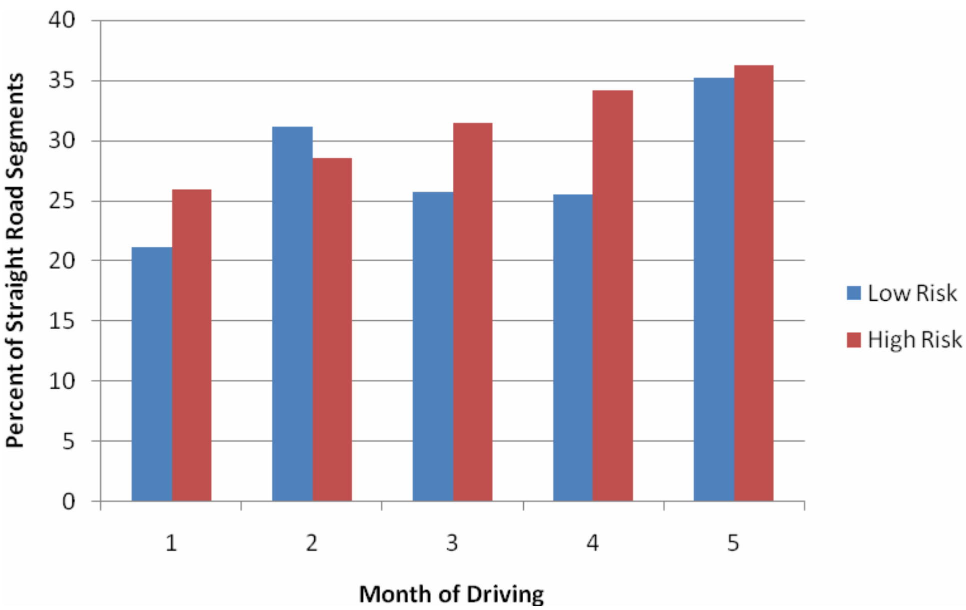


Figure 26. Percent of Sampled Straight Road Segments where Teen Driver is Engaging in a Secondary Task

To further investigate secondary tasks, an analysis of specific task type was conducted to assess whether the 'high risk' group engaged in the most risky secondary tasks more frequently than did the low-risk drivers. Klauer, Dingus, Neale, Sudweeks, & Ramsey (2005) reported that tasks that require multiple eye glances or multiple button presses (also referred to as moderate and complex secondary tasks) increase crash/near-crash risk more so than do tasks that only require one eye glance or button press. The results from that report were used and those tasks that were categorized as moderately or complex were used. Additionally, newer tasks that are known to require multiple button presses/multiple eye glances away from the forward roadway, such as text messaging and iPod use, were also included in the list of secondary tasks. Table 5 lists those secondary tasks that were included in the current analysis.

Table 5. List of High-risk Secondary Tasks

High-risk Secondary Tasks
Moving object in vehicle
Insect in vehicle
Looking at external object
Reading
Applying makeup
Cell phone: Dialing a hand-held device
Cell phone: Text messaging/email/internet
Cell phone: Looking at cell phone display
Inserting/retrieving a CD
Dining: Eating with a utensil
Dining: Eating without a utensil
Reaching for a non-moving object
iPod: Operating iPod
iPod: Viewing iPod
External: Looking at previous crash or highway incident
External: Pedestrian located outside the vehicle
External: Animal located outside the vehicle
External: Object located outside the vehicle
External: Construction zone

The results of the Fisher's Exact Test indicated that there were significant differences in the frequency of engaging in these higher risk secondary tasks between the two driver risk groups ($\times^2$[1, N = 4,404] = 3.78, $p < 0.05$). Figure 27 shows the pattern of percentage of straight road segments where both groups engaged in high-risk secondary tasks across month of driving. The high-risk drivers were engaging more frequently in months 3 through 5, but not in months 1 and 2. Both groups show some increase across the first five months. The Chi Square analysis on differences in engaging in high-risk secondary tasks across month of driving was not significant for either group. Future analyses should assess this trend over more months of driving to determine if differences emerge, thus contributing to the high-risk drivers' potential for being involved in crashes or near-crashes.

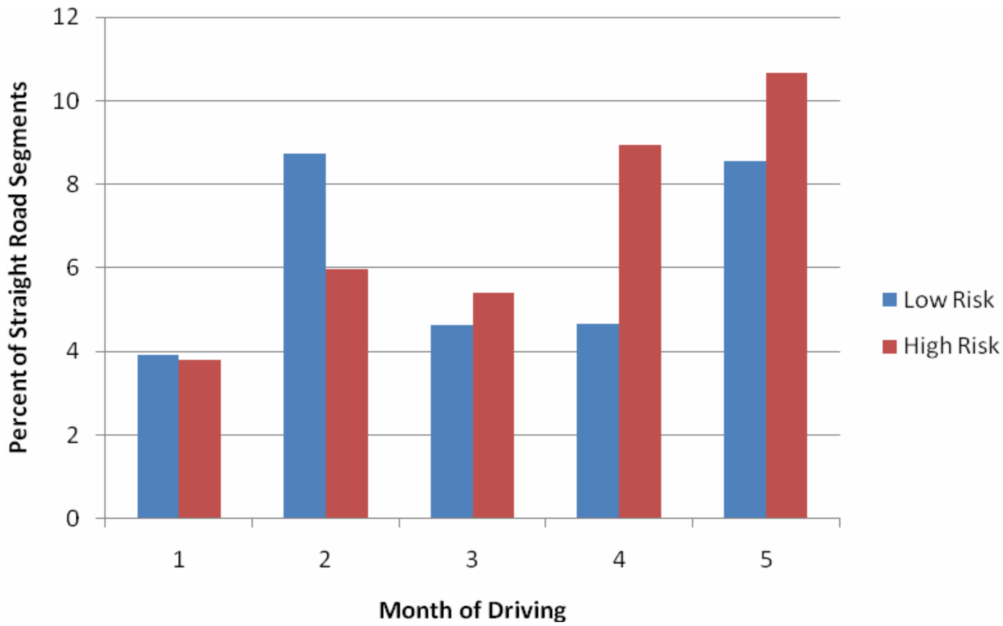


Figure 27. Percent of Straight Road Segments where the High- versus Low-risk Drivers were engaging in Secondary Tasks that have been shown to Increase Crash/near-crash Risk

The percentage of straight road segments where the drivers drove faster than 5 mph over the posted speed limit is shown in Figure 28. Speed was assessed by first assessing the driver's maximum speed on each of the straight road segments and then comparing this maximum speed to the posted speed limit on each segment.

The results indicated that the high-risk drivers were speeding faster than 5 mph significantly more frequently than were the low-risk drivers ($\times^2[1, N = 4{,}404] = 16.36$, $p < 0.05$). The high-risk drivers' speeding behaviors generally increased sporadically across the first five months, whereas the low-risk drivers' speeding showed a clear, linear increase over the same time period. Two additional Chi Square analyses indicated that increase across month of driving for the low-risk drivers was significant ($\times^2[4, N = 2{,}256] = 23.5$, $p < 0.05$); however, there were not significant differences across month of driving for the high-risk drivers.

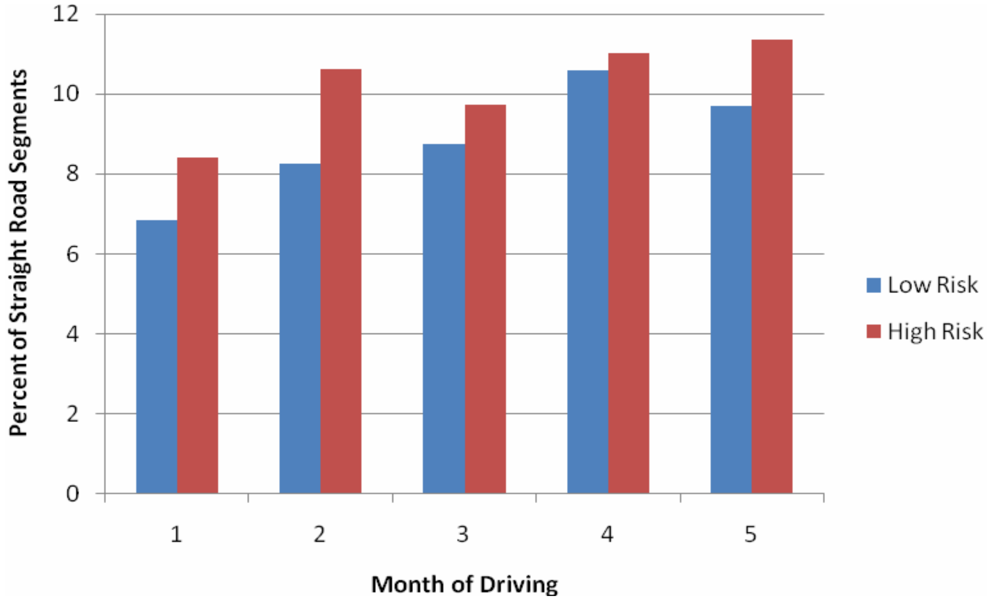


Figure 28. Percent of Straight Road Segments where Teen Driver is Speeding at Least 5 mph Above the Speed Limit

The percentage total time that drivers' eyes were off the forward roadway was calculated for each event and an ANOVA was conducted to assess whether there were differences between the two risk groups. As stated in the method section, limited project resources would not allow for eye glance reduction to be performed on every straight road segment. Rather, eye glance reduction was only performed on those road segments where a teen passenger was present and/or the teen driver performed a lane change. This resulted in 1,110 straight road segments present in the current analysis, and 41 of the 42 total vehicles were sampled.

The ANOVA indicated that the two risk groups were not significantly different from each other ($p = 0.06$). The 'high risk' group's percent total time EOR was 6.1 percent, compared to the 'low risk' group's percent total time EOR of 3.1 percent. The main effect for month of driving or the interaction between month of driving and risk group was also not significant. Due to the exploratory nature of these analyses, Figure 29 is presented to show the relationship of percent time EOR for the two risk groups. The high-risk drivers do appear to look away from the forward roadway more frequently than do the low-risk drivers. This relationship will be reviewed more closely when more data are available for analysis. The low-risk drivers appear to increase their EOR time over months of driving. This trend will also be reviewed across more months of data.

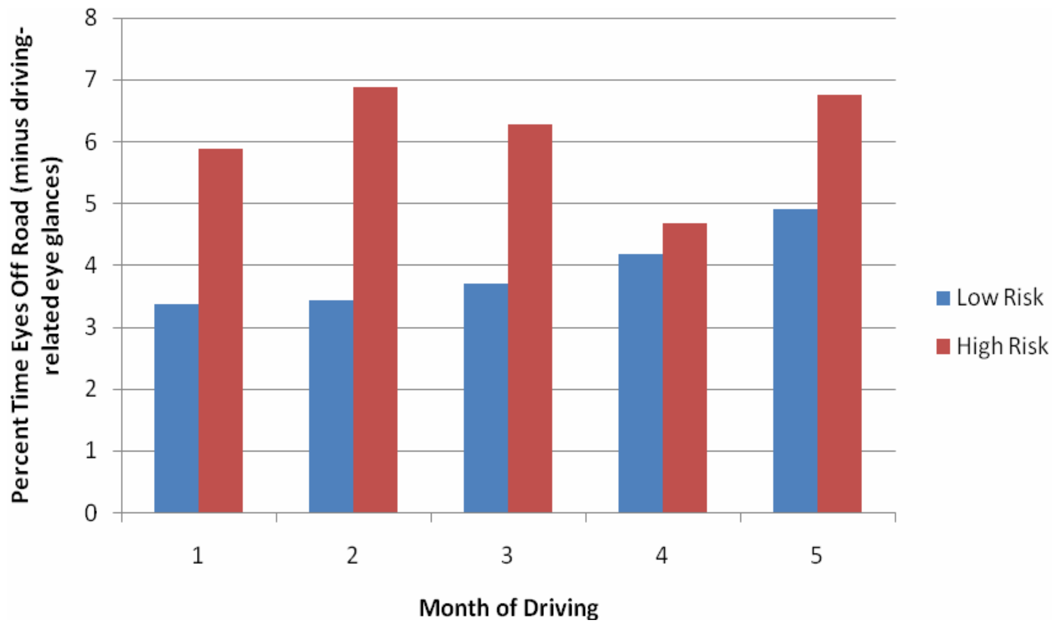


Figure 29. Percent of Time the Teen Drivers' Eyes were Off the Forward Roadway while Traversing Straight Road Segments with Teen Drivers Present or while Performing a Lane Change

Question 3. Which driving performance variables are more predictive of teen crash and near-crash event involvement?

As discussed in the Introduction, there are several teen driving research projects that have attempted to decrease teen drivers' crash risk by providing feedback to these teens regarding their rate of deceleration (i.e., braking), acceleration (i.e., starting the vehicle from a stop), and lateral acceleration (i.e., rate of turning the vehicle). No data have been collected to date that can truly assess whether these types of behaviors are associated with teen driving crash/near-crash risk. This analysis represents the first attempt to directly assess this relationship. For this analysis, a crash was defined as any physical contact with an object where kinetic energy is measurably transferred or dissipated.

Thirty trip files per teen driver per month of driving across the first six months were randomly selected and used for the following analysis. Using filtered acceleration data (longitudinal and lateral), peak decelerations and accelerations were identified across the entire trip. Maximum acceleration values for each peak were identified. The total mileage per trip file reviewed was also collected and summed for the trip files for each driver. The frequency of peak accelerations for the following 8 'bins' (numerical categories) of acceleration was assessed and divided by the VMT per driver.

- 0.40 to 0.449 *g*
- 0.45 to 0.499 *g*
- 0.50 to 0.549 *g*
- 0.55 to 0.599 *g*

- 0.60 to 0.649 *g*
- 0.65. to 0.699 *g*
- 0.70 to 0.749 *g*
- 0.75 to 0.799 *g*
- 0.80 to 8 *g*

A comparison of these acceleration values was conducted for the low-risk and high-risk drivers. Figure 30 shows the frequency of peak longitudinal decelerations per 10,000 miles traveled for each group. As was expected, the frequencies for the higher decelerations decrease rapidly. A Chi Square analysis was conducted on the frequency counts normalized by miles traveled, and indicated that these two groups are significantly different from each other. Upon inspection of the data, these differences probably occur on the 0.55 to 0.5 *g* levels, and not at the more extreme *g*-force levels. The frequency counts (not normalized for VMT) indicate that these braking levels are very infrequent with total frequency counts under 30 counts per bin at 0.6 *g* and above. Thus, with such low power, differences between these two groups would be difficult to assess.

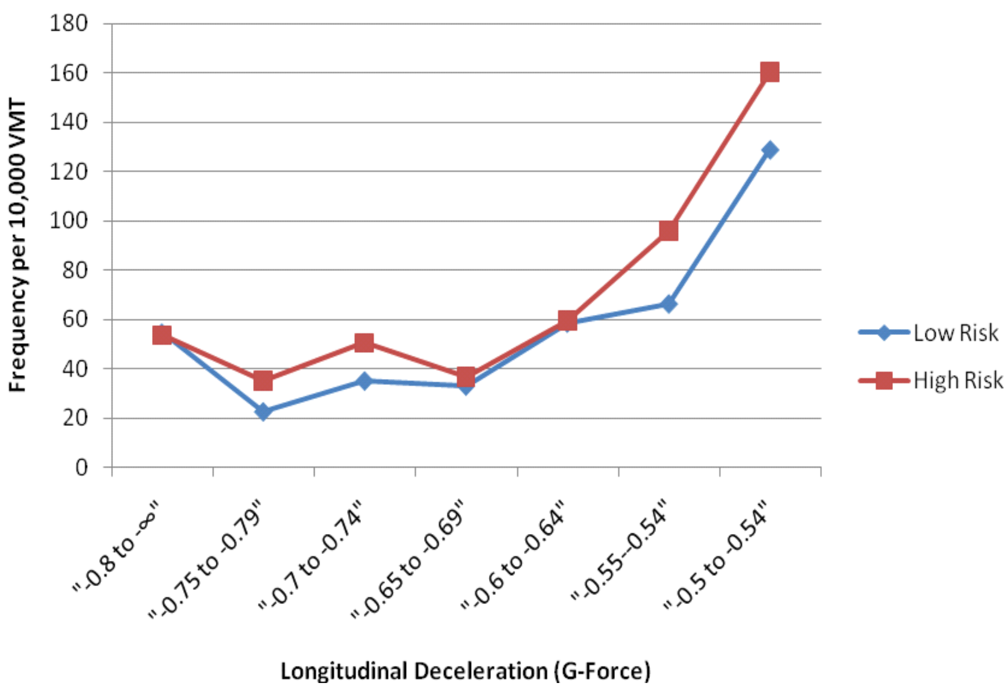


Figure 30. Frequency of Peak Longitudinal Decelerations for Low- and High-risk Drivers per 10,000 VMT

As is shown, the high-risk drivers braked at nearly all deceleration levels significantly more frequently than did the low-risk drivers; however, the patterns were quite similar. Given the low frequency counts at the extreme deceleration levels, the percentage of low-risk drivers was compared to the percentage of high-risk drivers who performed braking maneuvers at these extreme levels of deceleration. In other words, what percentage of low-risk drivers contributed to the figure at the extreme levels of deceleration versus high-risk drivers? The results are shown in Figure 31 and show several interesting comparisons. Note that for the two tails of the deceleration distribution shown here, the two groups are similar. However, in the middle, from 0.65 g to 0.5 g, a higher percentage of high-risk drivers perform these high deceleration levels versus the low-risk drivers. Of most interest, 87 percent of the high-risk drivers performed decelerations of -0.5 g to -0.549 g compared to only 47 percent of the low-risk drivers. A Mantel-Haenzel Chi Square was conducted assessing the maximum deceleration performed by each driver. This analysis showed that the high-risk drivers' maximum deceleration levels are significantly higher than the lower risk drivers maximum deceleration levels (×2[2, N = 42] = 5.43, p = 0.02).

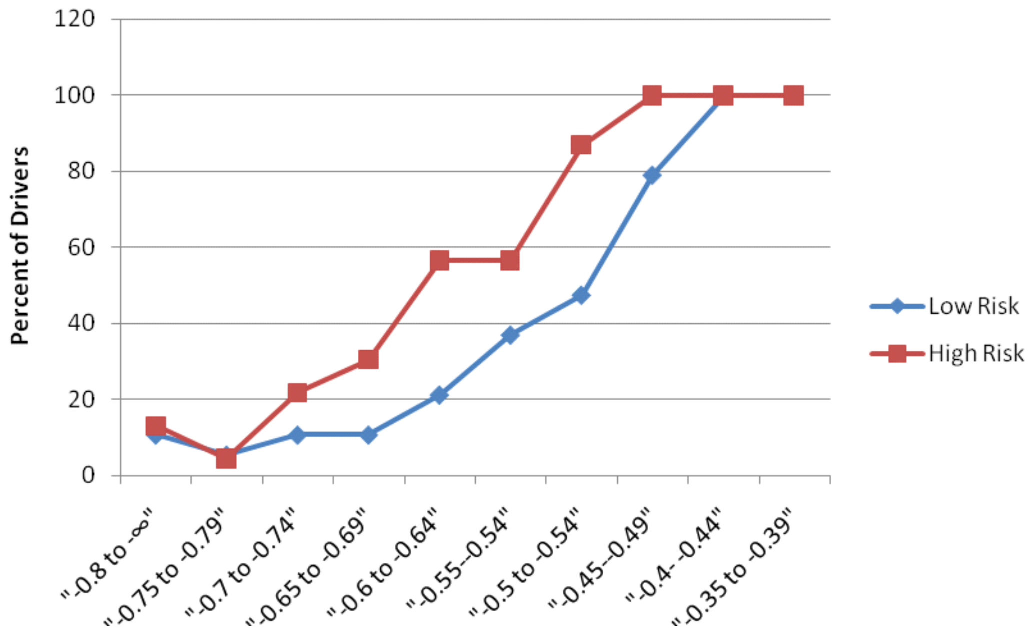


Figure 31. The Percentage of Drivers from each Risk Group who Performed Maximum Decelerations at each Deceleration Level

Similar analyses were conducted using longitudinal acceleration and lateral acceleration data. The longitudinal acceleration per 10,000 VMT is shown in Figure 32. The differences between the low-risk and high-risk drivers in this figure are negligible. An analysis of the percentage of high-risk versus low-risk drivers was conducted and also demonstrated virtually no differences between the two groups.

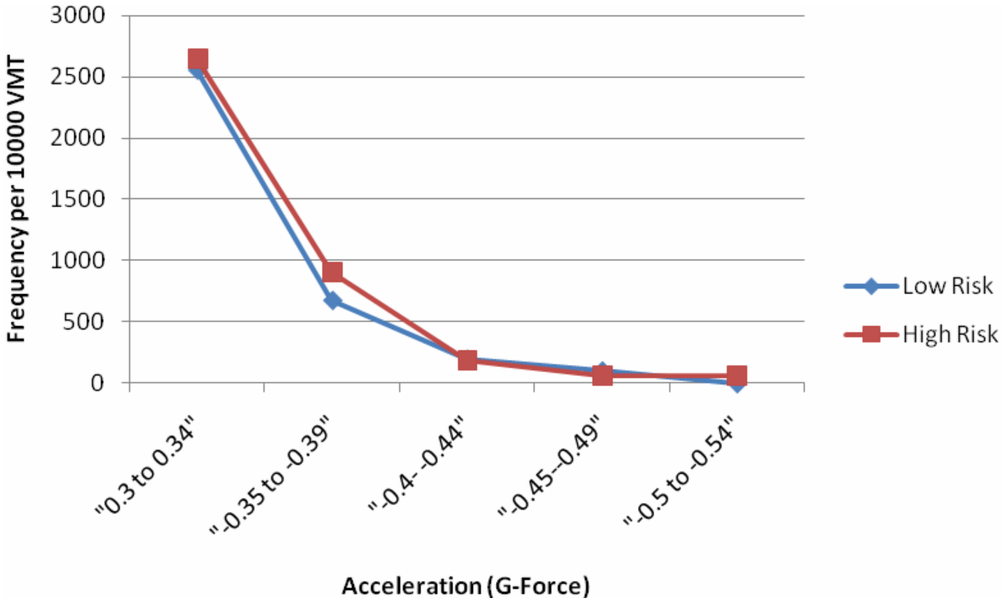


Figure 32. Frequency of Peak Longitudinal Accelerations for Low- and High-risk Drivers per 10,000 VMT

For lateral acceleration, the positive (right turns) and negative acceleration (left turns) data were combined and are shown in Figure 33. A Chi Square was conducted to assess whether the high-risk drivers were more frequently engaging in lateral accelerations to the left or right. The results indicated that the high-risk drivers are more frequently performing high lateral accelerations than the low-risk group ($\times^2$[6, N = 2,281] = 60.2, p < 0.001).

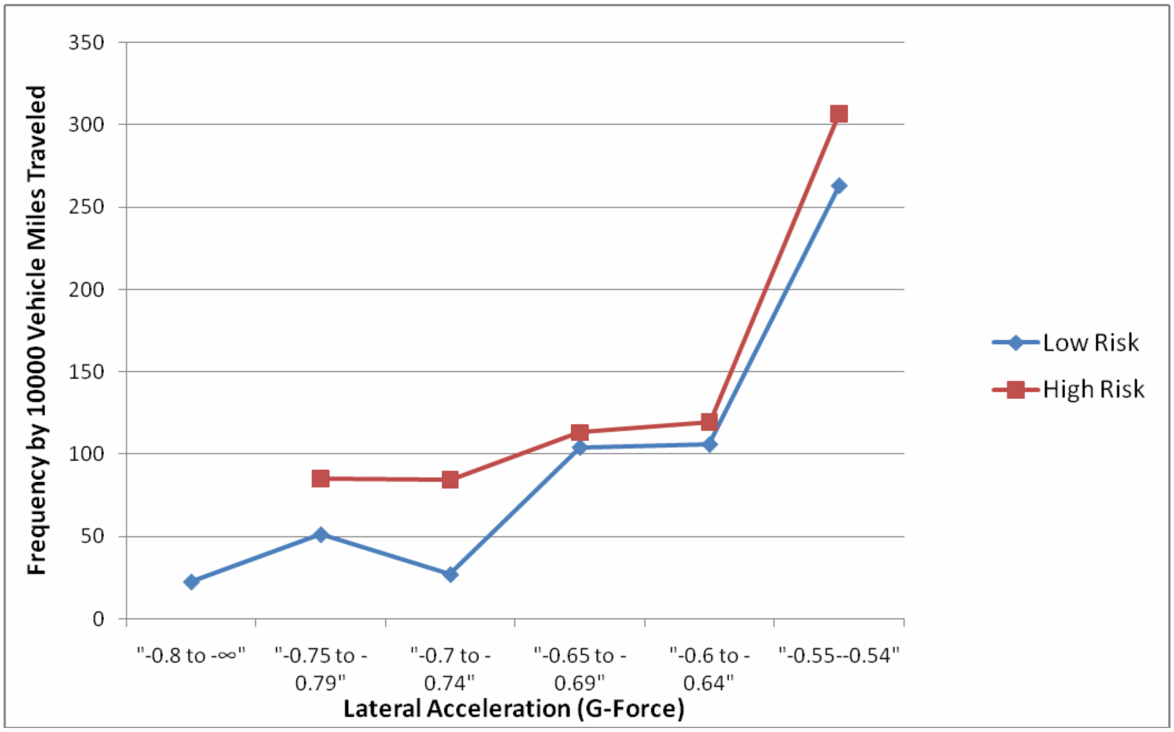


Figure 33. The Frequency of Lateral Accelerations (either positive or negative) that Occurred for High- and Low-risk Drivers per 10,000 VMT

A similar analysis was conducted reviewing the percentage of low-risk and high-risk drivers that contribute to the higher *g*-force levels of lateral acceleration. While a higher percentage of high-risk drivers contribute at levels of 0.65 to 0.55 *g*, these differences were not statistically significant (Figure 34).

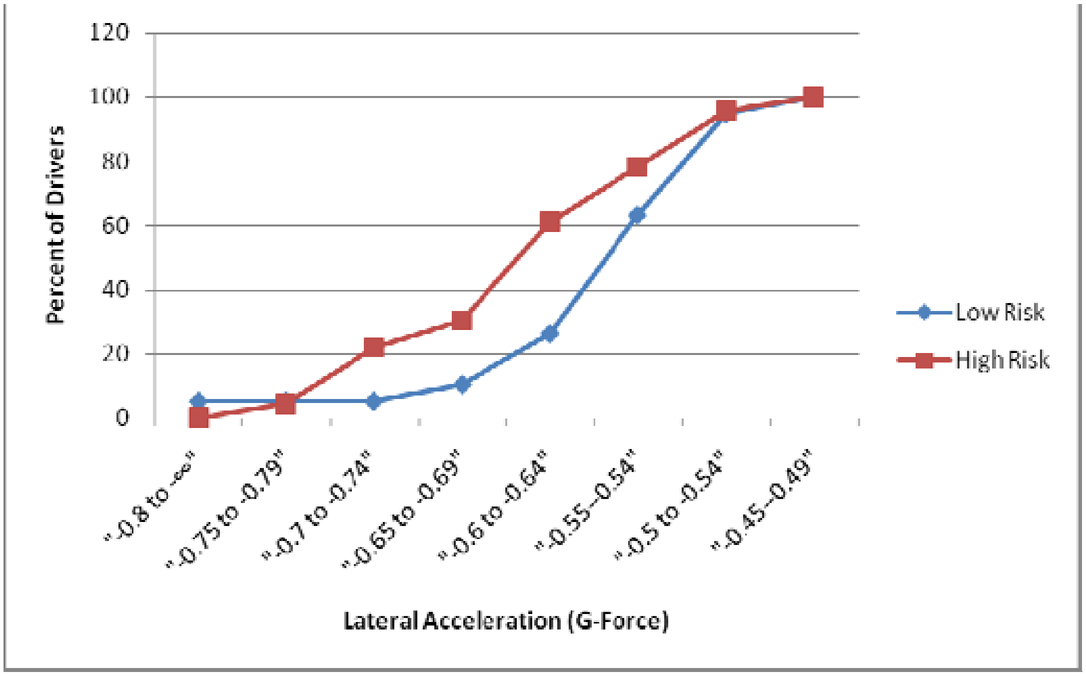


Figure 34. The Percent of Drivers who Performed at least one Driving Maneuver with a Peak Lateral Acceleration at the Presented Lateral Acceleration Levels

One final analysis was conducted to further assess the relationship between higher *g* acceleration and deceleration levels and involvement in crashes and near-crashes. Pearson correlations were conducted comparing the number of longitudinal decelerations greater than -0.6 *g* and the number of lateral accelerations (either positive or negative) greater than 0.6 *g*. Both correlations were significant with alpha levels less than 0.05. The correlation coefficient for longitudinal deceleration was 0.49. The correlation coefficient for lateral accelerations (both positive and negative) was 0.32; thus these analyses were accounting for 25 percent and 15 percent of the variance, respectively. While these correlations are moderate to modest correlations, in the field of behavioral sciences, these correlations should not be disregarded. While crashes and near-crashes are identified using a variety of different sensor data, as will discussed later, the comparison of these randomly selected, “normal” driving trip files account for more variance regarding crash and near-crash involvement than most other driver behavior models to-date.

Question 4. How do teen risk factors (presence of teen passengers, night driving, etc.) interact with teen driving performance and crash and near-crash event involvement?

During the first 12 months of independent driving, the teens drove a total of 48,214 trips. Teens were categorized as discussed above into “low risk” and “high risk” driver categories, based on number of crashes and near-crashes during the first six months of driving, but the analyses presented in this section were conducted on 12 months of trips. The data were reviewed to assess the percentage of total trip files where teens were driving with passengers present, driving with teen passengers present, driving unbelted, and driving at night. Each analysis compared the low-risk and high-risk teens. Figure 35 shows the number of trips taken by drivers in each group over the first 12 months of independent driving, and shows that almost the exact same proportion of trips were taken by low-risk and high-risk drivers in shared use and dedicated use vehicles (Chi Square, not significant).

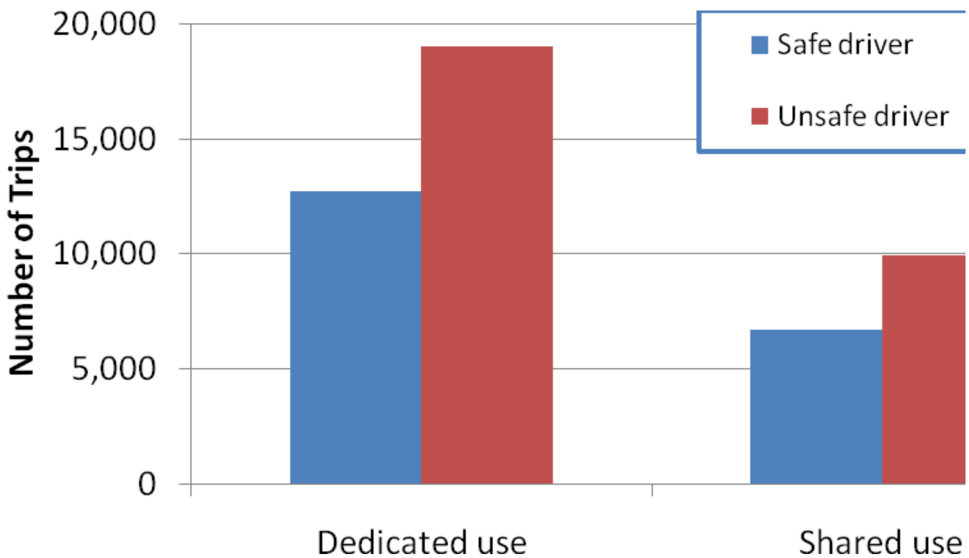


Figure 35. Number of Trips Taken in Shared Use and Dedicated Use Vehicles over the First Five Months of Driving by Teen Drivers categorized as Low Risk or High Risk

Figure 36 shows that high-risk drivers drove with passengers 42 percent of the time during the first month of driving, with a decreasing trend down to 35 percent of trips with passengers by the fifth month. The low-risk drivers drove alone more frequently than the high-risk drivers, and also showed a decreasing trend (from 38 percent of trips with passengers in the first month to 32 percent in the fifth month). Over the following seven months, the low-risk and high-risk drivers became more equal in their tendency to carry passengers, with the high-risk drivers leveling off and the low-risk drivers increasing the percentage of trips with passengers (Chi Square, $p < 0.0001$). These trends could have several explanations. The downward trend for both groups in the first five months may be due to greater parental trust (the parents gradually becoming more comfortable with the teens' driving, and releasing them to drive alone more frequently). The higher percentage of trips made with passengers for the high-risk drivers in the first few months may be indicative of greater parental oversight (parents realize that these teens are high risk, and are less willing to let them drive alone). Alternatively, these drivers may have been categorized as high risk because of something taking place with the passengers. This explanation can be further explored by examining the percentage of trips taken with teen passengers for each group. Figure 37 shows that the percentage of trips made with teen passengers stays somewhat stable for the low-risk drivers, but at a lower level than for the high-risk drivers (Chi Square, $p < 0.0001$). The high-risk drivers show a downward trend over this time. Thus low-risk drivers may either be restricted from driving with teen passengers, or may be inherently less likely to do so. The low-risk drivers may show a downward trend either because of increased parental restrictions or because more and more of their friends are driving and there is less need to carry teen passengers. Over the 12 months studied, the high-risk drivers took 28 percent of their trips with at least one teen passenger versus 21 percent for the low-risk drivers.

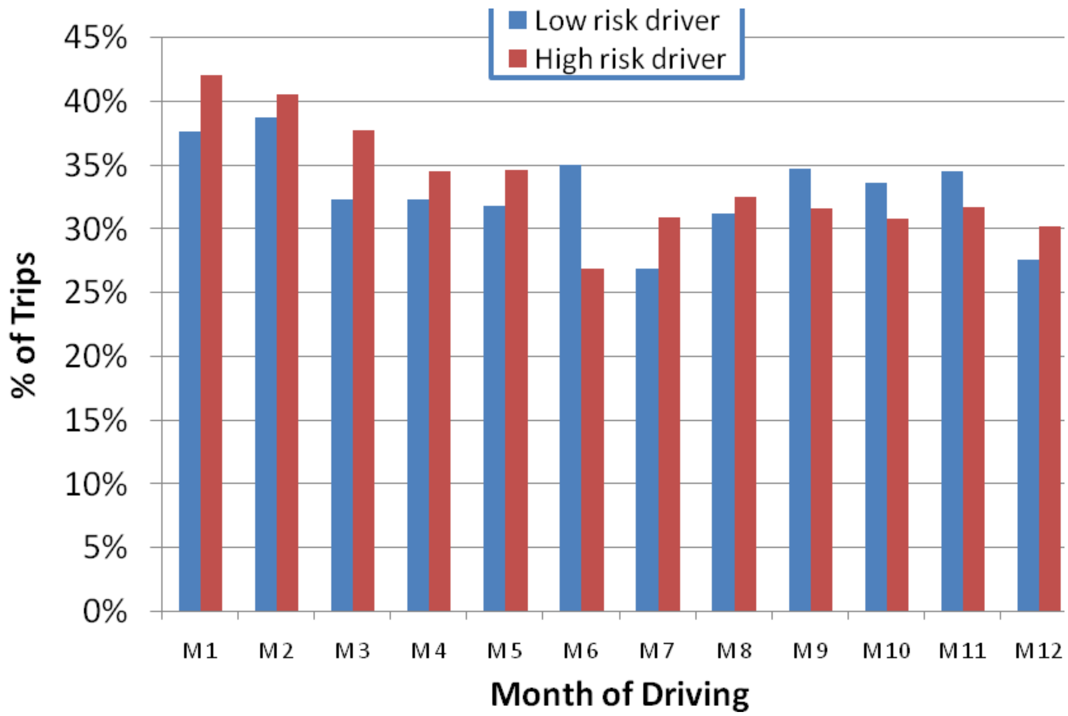


Figure 36. The Percentage of Total Trips where the Teen Driver is Driving with at least One Passenger of Any Age for the First 12 Months

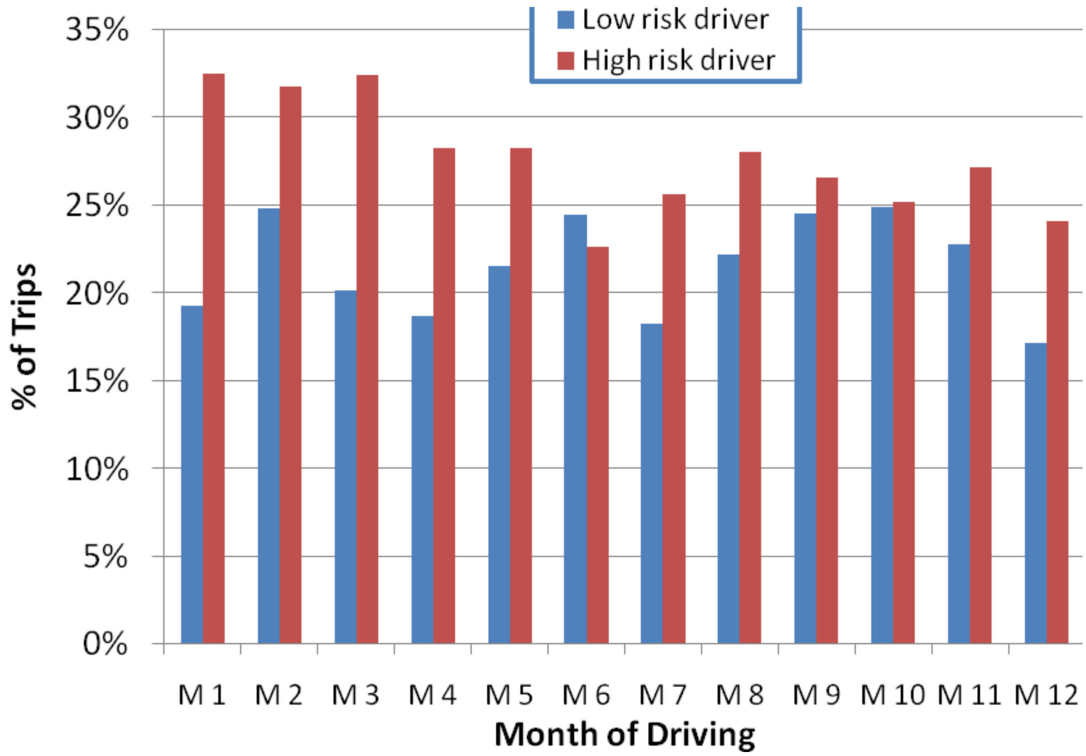


Figure 37. The Percentage of Total Trips where the Teen Driver is Driving with at least One Teenage Passenger for the First 12 Months

Another passenger analysis examined the percentage of time that teen drivers were driving with two or more teen passengers, which is illegal in Virginia (in most cases) for the first 12 months of driving. As shown in Figure 38, the high-risk drivers were two to three times more likely to violate this law than were the low-risk drivers (Chi Square, $p = 0.0006$). Over the twelve months of the study, low-risk drivers took only 2 percent of their trips with two or more teen passengers versus 5 percent for the high-risk drivers. Thus, there appears to be a relationship between being classified as a high-risk driver (based on rate of crashes and near-crashes) and driving with two or more teen passengers (in violation of state law).

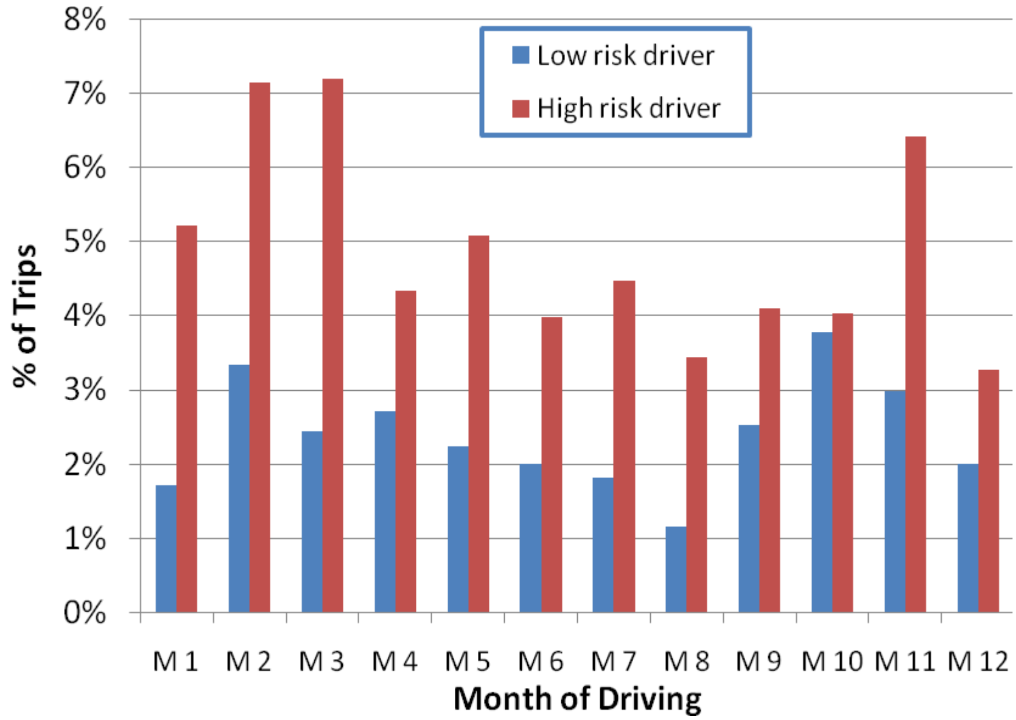


Figure 38. Percentage of Trips taken with Two or More Teen Passengers over the First 12 Months of Driving (GDL Violation in Virginia)

Analyses were also conducted to assess the frequency of nighttime driving for the low-risk versus high-risk drivers. Figure 39 shows that the percentage of nighttime driving trips is higher for the high-risk drivers, especially for the first five months. The two groups exhibited similar patterns during the last seven months, but over the 12 months, the high-risk drivers drove 26 percent of their trips at night versus 22 percent for low-risk drivers (Chi Square, $p < 0.0001$). Thus the high-risk drivers appear to have an increased exposure to the high-risk driving condition of driving at night. A related question is the percentage of trips driven during the curfew hours of midnight to 4 a.m. As shown in Figure 40, the low-risk drivers had more trips during curfew hours over the first few months of driving, but this trend was reversed in the last few months. Overall, high-risk drivers averaged 1.2 percent of their trips during curfew hours, while low-risk teen drivers averaged 0.9 percent of trips during curfew hours (Chi Square, $p < 0.0001$).

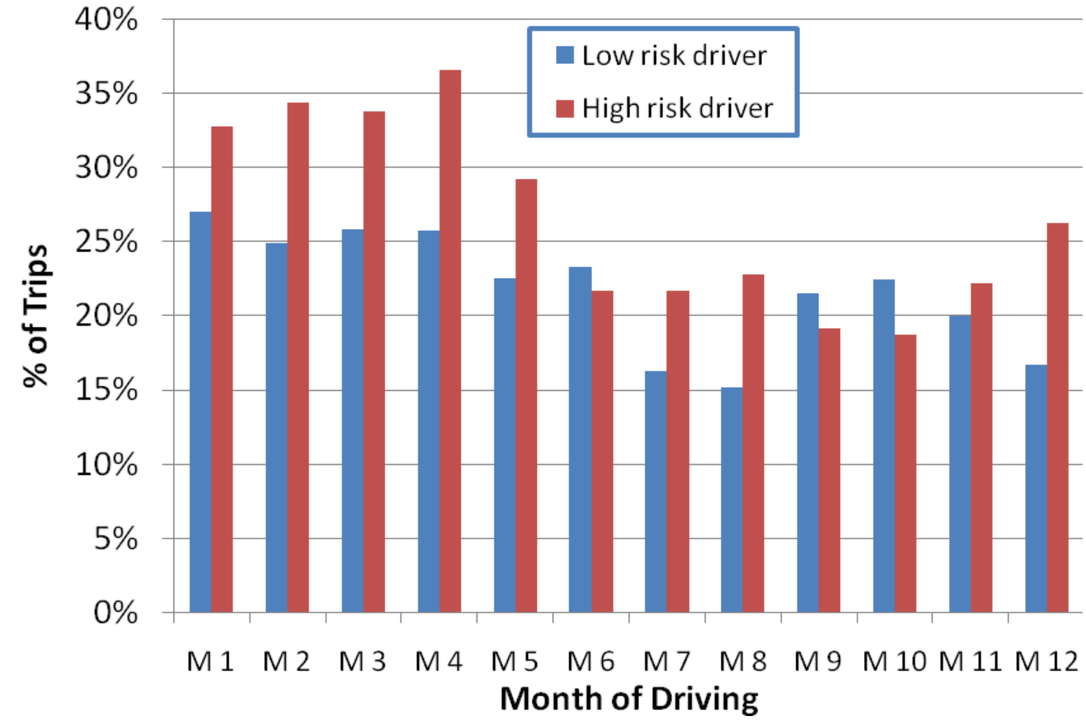


Figure 39. The Percentage of Trips where the Teen Driver is Driving at Night over the First 12 Months of the Study

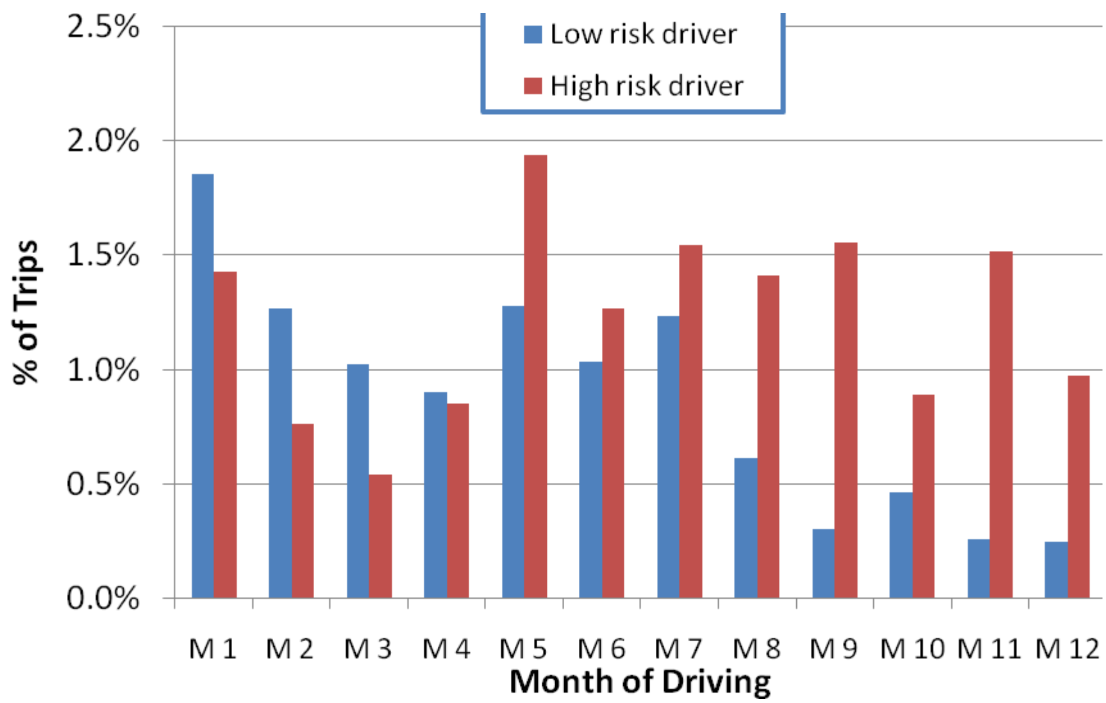


Figure 40. Percentage of Trips taken by Teen Drivers during Curfew Hours over the First 12 Months of the Study

Seat belt use was also examined for the low-risk and high-risk drivers. Figure 41 shows that drivers categorized as low risk were unbelted three to four times more often than the high-risk drivers. This result was driven by one driver categorized as low risk. This driver drove unbelted for 2,930 of the 3,115 unbelted trips by low-risk drivers (accounting for 94 percent of the unbelted low-risk driver trips). If this driver is eliminated from consideration, the pattern changes drastically, as shown in Figure 42. Without this one driver, high-risk drivers averaged 1.7 percent of their trips unbelted, and low-risk drivers were unbelted 0.8 percent of the time on average. An interesting pattern can be observed in that the high-risk drivers dramatically and suddenly increased their seat belt use in the sixth month, and then maintained seat belt use levels near those of the low-risk drivers for the remainder of the study (Chi Square, $p = 0.0036$).

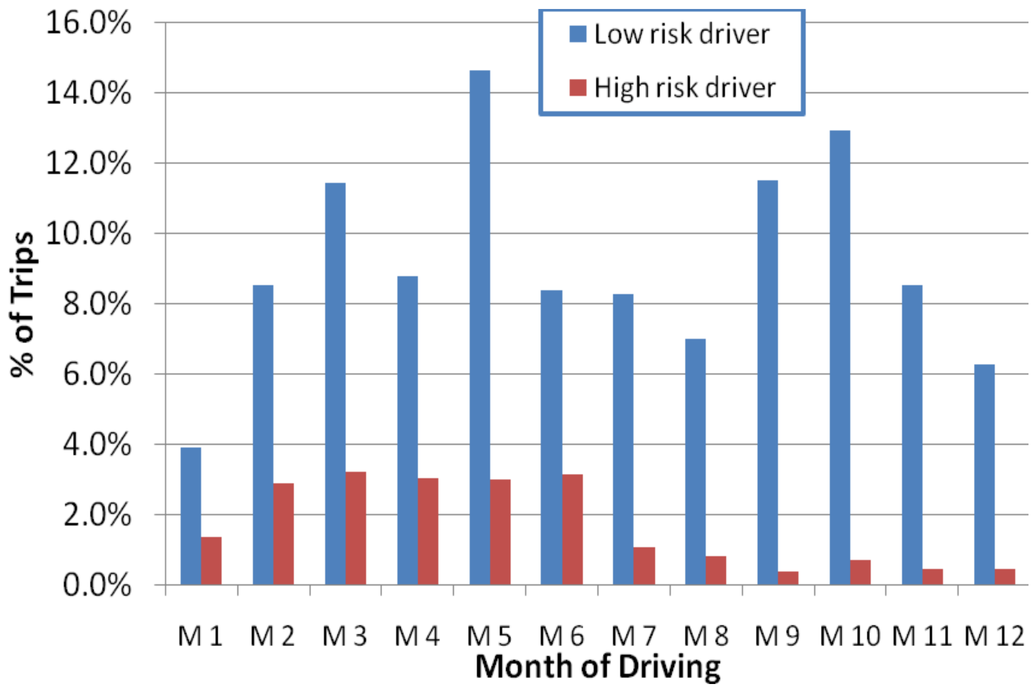


Figure 41. Percentage of Unbelted Trips taken by Low-risk and High-risk Drivers over the first 12 Months of the Study. The High Levels Observed for the Low-risk Drivers are almost entirely due to one Low-risk Driver who rarely used a Seat Belt.

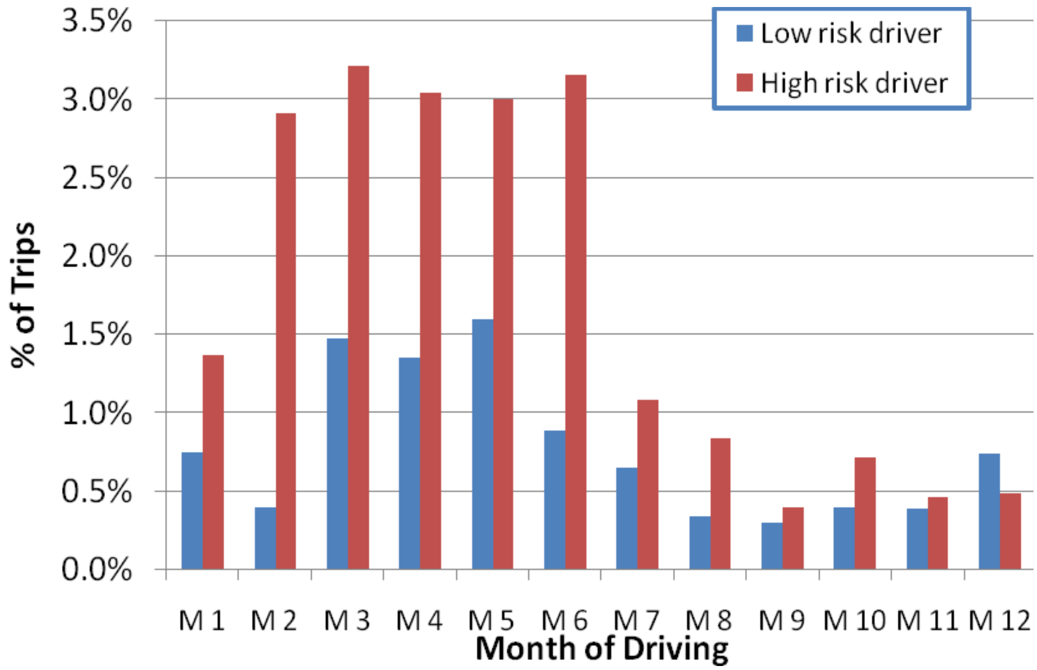


Figure 42. Percentage of Unbelted Trips taken by Low-risk and High-risk Drivers over the first 12 Months of the Study with one Rarely Belted Low-risk Driver Removed

A final analysis examined the relationship between driver seat belt use and passenger seat belt use when there were one or more passengers. Figure 43 shows that it was rare for an unbelted low-risk teen driver to have all passengers unbelted (average of 4 percent of unbelted trips), while it was four times more common for an unbelted high-risk driver to have all unbelted passengers (average of 17 percent of unbelted trips). The spike in month 11 for low risk drivers has not yet been investigated fully. Due to the low number of trips in each cell, no Chi Square statistics could be calculated for this analysis.

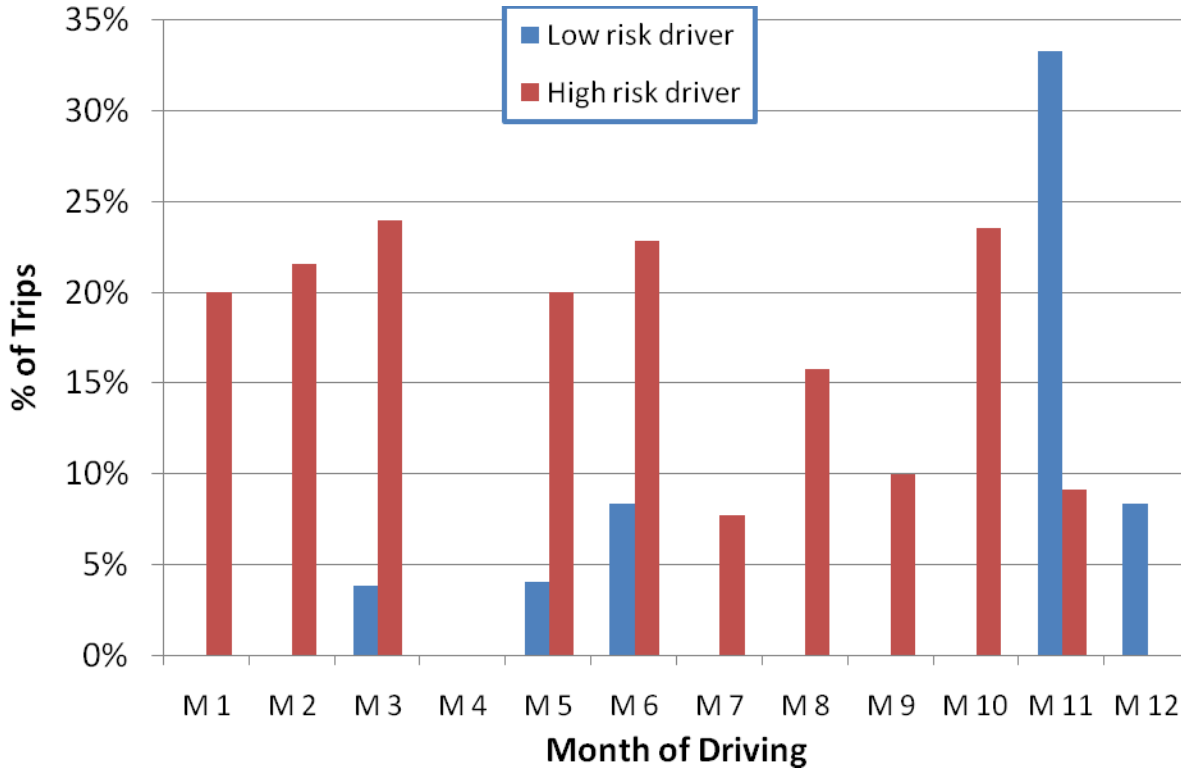


Figure 43. Percentage of Unbelted Trips taken by Low-risk and High-risk Drivers with all Passengers also Unbelted over the First 12 Months of the Study (with one rarely belted low-risk driver removed).

Question 5. Using the trigger criteria developed for the Naturalistic Teenage Driving Study, provide an assessment of the effectiveness of the triggers used (i.e., what percentage of crashes and near-crashes were valid and what percentage were invalid?). What would be the cost/benefit of altering these trigger criteria for an electronic co-pilot system?

As was discussed in the method section, the triggers shown in Table 6 were developed to identify crashes and near-crashes in the Naturalistic Teenage Driving Study. These were based upon the triggers used in the 100-Car Study and then further modified to both focus on crashes and near-crashes (as opposed to crashes, near-crashes, and incidents) while not missing any near-crashes. The yaw rate trigger and the speeding trigger have not yet been validated and thus will not be part of this discussion. These will potentially be used in future analyses of the Naturalistic Teenage Driving Study.

Table 6. Values of the Triggers used to Identify the Crashes and Near-crashes in the Naturalistic Teenage Driving Performance Data

Trigger Name	Value
Longitudinal deceleration	=-0.65g longitudinal deceleration
Lateral acceleration	± 0.75g lateral acceleration
Forward Time-to-Collision	Forward time-to-collision of 4 seconds coupled with longitudinal deceleration of -0.6g.
Forward Time-to-Collision plus Range	Forward time-to-collision of 4 seconds coupled with longitudinal deceleration of -0.5g and less than 100 feet to lead vehicle.

The validated triggers have been applied to the entire 18 months of data collected in the Naturalistic Teenage Driving Study. The results for all 18 months of data will be reported here. These triggers have been validated and level of severity assessed; however, reduction is not complete on all of these events.

These kinematic triggers resulted in 3,380 possible events. Note that crashes and near-crashes typically have more than one kinematic trigger, so reductionists did not have to review 3,380 unique events. Of these possible triggers reviewed, the reductionists validated approximately 12 percent. The percentage of valid triggers by trigger type is presented in Figure 44 for all possible triggers. Validation included not only crashes and near-crashes, but also those events labeled as legitimate judgment errors. These were included in this analysis because these might represent 'coachable' events for which teens should receive feedback. Note that 20 percent of all longitudinal deceleration triggers and 18 percent of the forward time-to-collision triggers were valid.

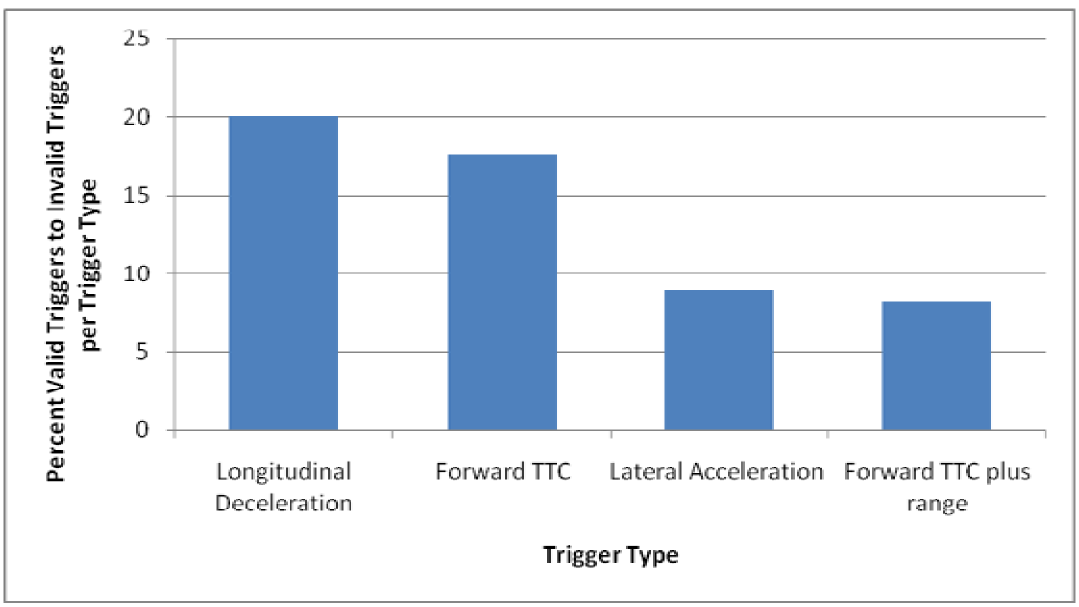


Figure 44. Percentage of Valid Triggers for Each Trigger Type

Of the valid triggers, the percent contribution of each trigger type is shown in Figure 45. So while longitudinal deceleration is the most easily and efficiently found trigger, the forward time-to-collision plus range trigger makes up the greatest percentage of valid events, followed by longitudinal deceleration. This result, compounded with the high percent of valid forward time-to-collision triggers, lends credence to the idea that both accelerometers and radar sensors are important for identifying and validating crash and near-crash events.

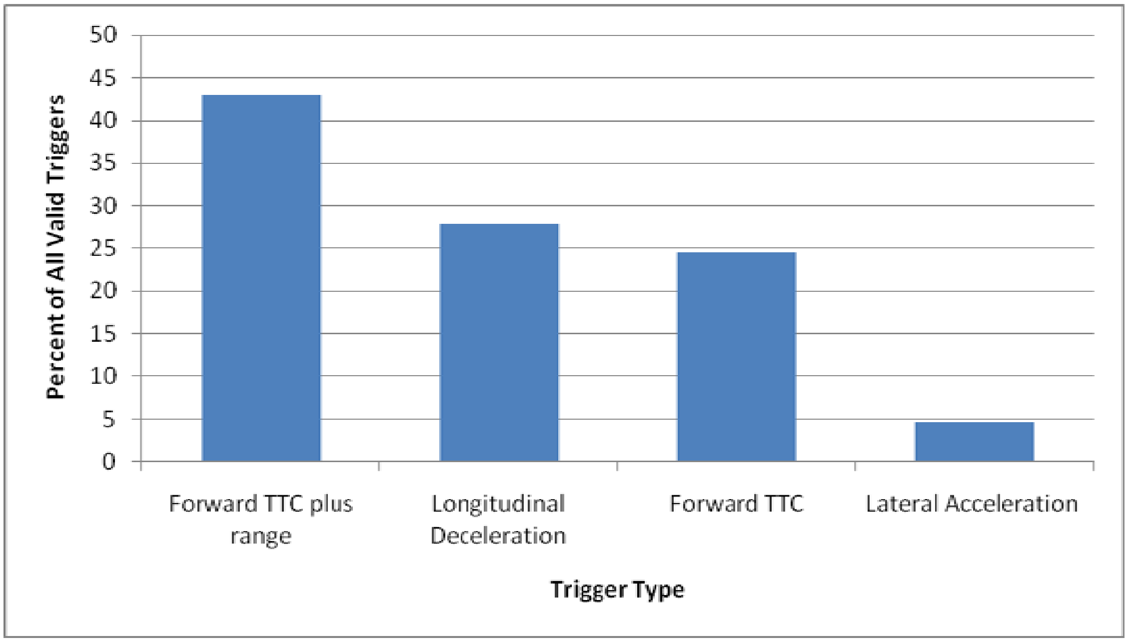


Figure 45. Percentage Breakdown for the Relative Contribution of these Trigger Types to the Valid Events

Each crash or near-crash is typically not identified by one trigger type. Thus a comparison to assess the number of unique events that the forward TTC trigger plus range identified versus the number of unique events that the longitudinal deceleration trigger identified was conducted. The results indicated that the forward TTC plus range trigger identified 25 unique of the total 35 events identified by this trigger (73.5% events were unique) whereas 8 of the 17 valid longitudinal deceleration events were uniquely identified (47.1%) by the longitudinal trigger.

Based upon the above results, both longitudinal deceleration plus distance to lead vehicle are important to efficiently and effectively identify useful events to teach teens to drive more safely. Without one or the other, a large percentage of events would be missed.

What would be the cost/benefit of altering these trigger criteria for an electronic co-pilot system?

An electronic co-pilot system clearly requires different triggering methods than the triggering used to identify crashes and near-crashes in the Naturalistic Teenage Driving Study. The results and discussion resulting from the analyses presented for Question 3 demonstrated that high levels of longitudinal decelerations and lateral accelerations were associated with involvement in crashes and near-crashes. These results also demonstrated that acceleration levels of 0.5 to 0.55 *g* produced a 'window of opportunity' in that a greater percentage of the high-risk drivers were performing these accelerations than were the low-risk drivers. This suggests that providing feedback to these drivers at these levels would be useful if it also reduced the occurrence of these deceleration/lateral acceleration levels.

The results from the assessment of trigger validity indicate that both accelerometer data as well as radar (or distance to lead vehicle) data are very useful and vital to the efficient and effective identification of potentially safety-relevant events. While these are both useful, they both come with different price tags regarding initial costs and eventual costs in post-processing time.

Radar sensors are very expensive and easily represent the most expensive sensor in the data collection suite, including cameras. Radar data is also expensive at the outset in that it requires considerable post-processing to use the data effectively. Fortunately, there are other options available to assess distance to the lead vehicle including machine vision, laser, lidar, and other options that could be explored that are far more cost effective.

Fortunately, accelerometers are relatively inexpensive and, if installed correctly, are the most robust sensors in the data collection suite. This is most likely why accelerometer data are available in almost all currently available commercial teen monitoring systems.

Potential other sensors include an incident button as well as EOR monitor. Based upon results from the 100-Car Study, an incident button would also be a very inexpensive sensor to incorporate into a teen electronic co-pilot. While it is currently unknown how valid the incident button responses were for the Naturalistic Teenage Driving Study, this sensor was ~80 percent valid in the 100-Car Study. Allowing the teens to flag their own data to review later would be an excellent tool in that they cannot only observe those events where they made a mistake, but also those events where they felt they responded appropriately.

Based upon the results from the eye glance analysis, an EOR monitor may also be a potential sensor for future teen monitoring systems. Given the results regarding higher secondary task engagement for the high-risk teen drivers and the prevalence of technology use while driving, providing a monitor for teens that reminds them to look up at the forward roadway may have the ability to decrease their percent EOR time. This does not necessarily need to be an eye tracker, but could also use machine vision or a head tracker. Research would be required to ensure that unintended consequences for this type of sensor would not develop; however, with careful design, this could also provide useful feedback for teens as well as their parents.

The results from this analysis also indicate that speeding appears to be related to crash/near-crash involvement. Technology is improving all the time; however, GPS matched with geographic information system (GIS)-type data is still fairly difficult and expensive to provide in an off-the-shelf system. Without the GIS-type data, speed limits are not easily linked to GPS data. Maximum speeds of over 70 mph are generally all the feedback that teens get with current systems. This is probably not sufficient and newer methods should be developed if a reduction in teen crashes and near-crashes is the goal.

GENERAL DISCUSSION AND CONCLUSIONS

The results from these analyses provide support that teens do engage in risky driving behaviors across the first few months of driving. The prevalence of engagement in these risky driving behaviors, in many instances, appears to increase across the first four to five months of driving as the teens become more comfortable with the mechanics of driving. These behaviors that can be easily monitored (hard braking and turning maneuvers) also appear to be linked to increased crash/near-crash involvement. Therefore, if effective feedback can be provided to teen drivers that results in a decrease in the prevalence of these behaviors, their involvement in crashes and near-crashes may also be reduced.

The results from this analysis also indicate that secondary task engagement, speeding, hard braking, and steering all appear to be related to crash/near-crash involvement. Teen driver monitoring systems should attempt to include some method of monitoring these behaviors and provide effective feedback regarding these behaviors to help reduce teen involvement in crashes and near-crashes.

These analyses represent a first step at assessing not only exposure levels for teen drivers to known risk factors but also the prevalence of various risky teen driving behaviors. There are very little data or analyses on these types of research questions in the teen driving literature and these represent a valuable contribution. Most of the analyses on driver behavior presented in this report were conducted on either the first four, five, or six months of driving (extending to 12 or 18 months in a few cases). In many of these analyses, trends appeared to be or were found to be significant. Most of these analyses should be conducted at a future date on all 18 months of data, as these analyses/results would greatly contribute to the knowledge gaps in the current teen driving literature.

Conclusions from Question 1

In response to the question regarding differences between teen and adult drivers, it was shown that teen drivers were involved in more than four times as many crashes or near-crashes per 10,000 VMT as were the adult drivers over the first five months of independent driving (6.5/10,000 VMT for teens and 1.4/10,000 VMT for adults). Teen driving performance is thus worse than that of adults at a very gross level. Adults had higher secondary task engagement than teens over the first three months, but the teen drivers showed a significant upward trend and surpassed the adults in the fourth month. Adults also had a higher percentage of traveling at least 5mph above the speed limit in the road segments than did the teens, but the teens again showed an increasing, significant trend of speeding over the four months examined. In summary, adults exhibited more frequent episodes of secondary task engagement, cell phone use, and speeding than did the teens. The higher crash and near-crash frequency as compared to adults cannot be explained by teen over-involvement in these potentially risky activities, since adults surpassed teens over the first four months in nearly all cases.

To better assess where and how teenagers drive during the first months of driving, teens were compared to adults to assess their exposure to night driving, driving with passengers, driving with teen passengers, and seat belt use. Key results from these analyses indicated that teens drive a greater percentage of trips at night than do their parents, including during curfew hours. While teens do not drive a greater percentage of trips with teen passengers as compared to adults, the greatest concern was regarding both the presence of teen passengers and seat belt use. When teen drivers do not wear their seat belt and have teen passengers present in the vehicle, there is a substantially greater chance that their passengers will also not wear a seat belt compared to when an adult driver does not wear a seat belt. This result may be a contributing factor to the high fatality rate observed for teen drivers nationwide.

Conclusions from Question 2

To further identify differences in teen driving, those teen drivers who were involved in a crash or near-crash during the first six months of driving (high-risk drivers) were compared to those drivers who were not in a crash or near-crash during the same time frame (low-risk drivers). These results indicated that the high-risk teen drivers engage in all secondary tasks more frequently, engage in high-to-moderate-risk secondary tasks more frequently, and speed more frequently than do the low-risk teen drivers.

These results provide further evidence that these risky behaviors are associated with higher risks of crash and near-crash involvement. The analyses conducted for Research Question 1 demonstrated that while teens engaged in these risky behaviors less frequently than did the adult counterparts, the analyses presented here show that the higher risk teens do in fact engage in these behaviors more frequently than the lower risk teen drivers.

Conclusions from Question 3

A third analysis was conducted using randomly sampled 'normal' driving data to assess the frequencies with which teen drivers actually perform high *g*-force acceleration, either braking or turning the vehicle. This is a unique analysis in that baseline teen driving data has never before been available to analyze and directly compare to teen crash/near-crash involvement. The results indicated that the high-risk teens do, in fact, engage more frequently in higher *g*-force braking and steering maneuvers than the low-risk drivers. The results also indicated that 78 percent of all high-risk drivers engaged in braking between 0.5 *g* and 0.55 *g* whereas only 47 percent of low-risk drivers engaged in braking at similar levels. This level of deceleration is thus a possible window in which teens should be given feedback that would potentially reduce the frequency of these hard-braking maneuvers and decrease their involvement in crashes and near-crashes.

It is important to understand that providing feedback on hard accelerations is primarily providing feedback on drivers' reactions in an attempt to avoid the incident. It may also be important and useful to provide feedback on those behaviors that may precede the occurrence of the event. This type of feedback will be available on future systems, i.e. eyes off road monitor. This type of feedback has not yet been explored or assessed but may provide a new arena in which to greatly enhance or improve the acquisition of safe driving skills.

Conclusions from Question 4

The fourth major analysis explored the exposure to various known risk factors for the low and high-risk drivers. This analysis provides some context for all of the analyses in that the high-risk drivers are in fact experiencing greater exposure to high-risk driving situations, including driving at night, driving with teen passengers, driving with more than one teen passenger in violation of state law, and driving without wearing a seat belt. However, a hopeful trend was observed in that the high-risk teen drivers increased their seat belt use in the sixth month to the level exhibited by the low-risk drivers, and maintained that level of seat belt use through the twelfth month.

Conclusions from Question 5

Finally, an analysis of the effectiveness of the Naturalistic Teenage Driving Study kinematic triggers was conducted to assess how well the triggers worked and how easy it would be to modify these trigger values for an electronic co-pilot for teen drivers. The triggers were generally

10 percent effective at identifying crashes, near-crashes, and poor judgment errors. While this is not an impressive result, the longitudinal deceleration and forward time-to-collision triggers demonstrated closer to 20 percent effectiveness. Both are important and vital to the efficient and effective identification of potentially safety-relevant events. Fortunately, there are less expensive options to assess the distance and/or TTC to the lead vehicle than radar. These options include but are not limited to machine vision, laser, and lidar, just as examples. What is key about these analyses is that acceleration data is probably not sufficient.

Other sensors/technology that would also provide critical information to teens would include a monitor for EOR time as these behaviors appear to be high risk. This does not necessarily need to be an eyetracker, this information could also be accomplished using machine vision or a head tracker. The analyses here only complement other literature in that secondary task engagement has been shown to increase crash and near-crash risk. Without providing feedback and/or reduction in the occurrence of these behaviors, reduction in crash/near-crash risk may not be possible.

Caveats and Limitations

Many of the caveats regarding these research questions and analyses were previously discussed. Some of the more pertinent caveats include the comparison of teen driving performance data to crash and near-crash involvement. First, many of the crashes were minor collisions, including high speed tire strikes. Many transportation researchers may not classify these as crashes; however, these events do represent a loss of vehicular control. Second, previous research has shown that the kinematic signatures of crashes are similar to near-crashes and thus have been used in combination prior to this report (Dingus, Klauer, Neale, Petersen, Lee, Perez, et al., 2006; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). Third, the high- and low-risk categories were based on crash and near-crash involvement in the first six months of driving only. There are several drivers who were involved in more crashes and near-crashes after the sixth month, and thus these ‘groupings’ may need to be modified for future analyses. Finally, it may also be informative to group teen drivers into three groups to better examine any differences that may exist between the ‘very high risk’ and ‘low risk’ groups.

These data were collected in one geographical location in Southwest Virginia. The two primary counties where data were collected can be best described as urban/suburban areas. The US Census considered Montgomery (where Blacksburg is located) and Roanoke Counties as urban population centers as both maintain populations over 100,000 people. Therefore, these results are most generalizable towards teen driving in other similar regions of the country, which is arguably more generalizable than collecting data in an urban/metropolitan environment.

These results represent first steps into teen driving research areas heretofore unexplored. The results imply that teen driver monitoring should continue to be explored. Teen drivers are engaging in risky behaviors and if we can reduce the prevalence of these behaviors, involvement in crashes and near-crashes could potentially be reduced. Further research is required; however, these results show great promise in the potential to reduce the teen crash rate and save teen lives.

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APPENDIX E1. List of Secondary tasks and operational definitions.

Categories	***Category Definitions***
Not Distracted	There are no observable signs of driver distraction
Lost in thought	Driver is looking at, or near, the location of the incident but exhibits an obviously delayed or slow response
Looked but did not see	Driver is looking right at where incident is occurring, but shows no reaction; that is clearly does not recognize that the incident is ocurring or the hazard is present
Singing	When driver is moving lips as if singing a song.
Dancing	This could be when the driver is using his/her arms to go with the beat of the music or moving head or torso.
Reading	This is reading material that is in the vehicle, but not a part of the vehicle (i.e., not reading external signs, or radio display). This could be reading directions, paper material, packaging. If reading a phone number, record as dialing cell phone.
Writing	Driver is writing using a pen or pencil on some kind of notpad or object. Does not include using a stylus for a PDA or similar device, or typing as in texting or other activity
Emotional distraction	Includes when driver is obviously emotionally upset, angry, crying, or other activity that requires the driver to be thinking about something other than driving
Passenger(s) Present	When a passenger is clearly present either in adjacent and/or the rear seat but the driver is not actively engaging in conversation with passenger.

Passenger/Driver Interaction	When the passenger is not visible, but the driver is clearly interacting with a passenger (other than a child) in the adjacent seat. This could be talking, listening, reacting to (i.e., laughing), moving toward or away from the passenger (i.e., reaching for the passenger, or avoiding a pat from the person).
Passenger in rear seat/Driver Interaction	When the passenger is not visible, but the driver is clearly interacting with a passenger (other than a child) in the rear seat. This could be talking, listening, reacting to (i.e., laughing), moving toward or away from the passenger (i.e., reaching for the passenger, or avoiding a pat from the person).
Child in adjacent seat/Driver interaction	When the child is not visible, but the driver is clearly interacting with a child in the adjacent seat. This could be talking, listening, reacting to (i.e., laughing), moving toward or away from the child (i.e., reaching for a child, not object, or avoiding a pat from the child). If the child is visible (even if the driver is not interacting at a given time), code this distraction.
Child in rear seat/Driver interaction	When the child is not visible, but the driver is clearly interacting with a child in the rear seat. This could be talking, listening, reacting to (i.e., laughing), moving toward or away from the child (i.e., reaching for a child, not object, or avoiding a pat from the child). If the child is visible (even if the driver is not interacting at a given time), code this distraction.
Moving object in vehicle	When any object moves unexpectedly in the vehicle that draws the driver's attention immediately away from their prior activity; including driving only, or driving plus other.
Insect in vehicle	Swatting at insect, moving body to avoid insect, looking around trying to locate insect.
Pet in vehicle	Any interaction with pet, including petting, talking to, or moving pet or pet carrier.
Reaching for object (not cell phone)	When driver reaches to pick up an object, other than a cell phone or is setting the object down/putting away.

Looking at object in Vehicle	When a driver clearly is looking at a visible object or thing located in the vehicle, other than those listed in other categories. Driver does not necessarily need to handle or manipulate for this category.
Talking/listening on cell phone	When a driver is talking or has phone up to ear as if listening to a phone conversation or waiting for person they are calling to pick up the phone. If driver has ear piece, reductionist must observe the driver talking repeatedly.
Dialing hand-held cell phone	When a driver is pushing buttons on a cell phone to dial a number or check something else on their cell phone. This would also include reading a phone number from a sheet of paper.
Dialing hand-held cell phone using quick keys	When a driver is pushing buttons on a cell phone to dial a number or check something else on their cell phone.
Dialing hands-free cell phone using voice activated software	When a driver speaks into open or activated cell phone with long, prior delay of no speaking into device and no button presses (i.e., most likely not in prior conversation).
Locating/reaching/answering cell phone	When the driver is reaching towards his/her cell phone and then putting the phone to his/her ear.
Cell phone - Other	When a driver is interacting with a cell phone in some manner, i.e., looking at a cell phone or holding cell phone in hand while driving.
Locating/reaching PDA	When driver reaches or starts to glance around for PDA.
Operating PDA	When driver is pressing buttons on the PDA.
Viewing PDA	When driver is looking at PDA, but not pressing any buttons
PDA - Other	When a driver is interacting with a PDA in some manner, i.e., looking at PDA and/or holding the PDA while driving.
Adjusting climate control	When driver interacts with climate control either by touching the climate control buttons, or glancing at the climate control on dashboard.

Adjusting radio	When driver interacts with radio either by touching the radio buttons on dashboard or steering wheel, or just glancing at the radio on dashboard.
Inserting/retrieving cassette	When driver picks up cassette in vehicle and pushes it into cassette slot and presses any subsequent buttons to get cassette to play/rewind/fast forward and then play, or when driver presses button to eject cassette and then places it somewhere in vehicle.
Inserting/retrieving CD	When driver picks up CD in vehicle and pushes it into CD slot and presses any subsequent buttons to get CD to play/rewind/fast forward and then play, or when driver presses button to eject CD and then places it somewhere in vehicle.
Adjusting other devices integral to vehicle	When driver interacts with a manufacturer-installed device other than those listed in other categories, either by touching or glancing at the device.
Looking at previous crash or incident	When a driver is looking outside of the vehicle in the direction of what is obviously an accident or incident.
Looking at pedestrian	When a driver is looking outside of the vehicle in the direction of a pedestrian (not in a construction zone) either on the side of the road or in front of them (i.e. using a cross walk or riding a bike at a red light).
Looking at animal	When a driver is looking outside of the vehicle in the direction of an animal either on the side of the road. This would not be used for an animal crossing the road.
Looking at an object	When a driver is looking outside of the vehicle in the direction of an object (not in a construction zone) on the side of the road (i.e. a box).
Distracted by construction	When a driver is looking outside of the vehicle in the direction of a construction zone. A construction zone would be defined as seeing a barrel, person in a hard hat, construction equipment or vehicles.

Other external distraction	When a driver is looking outside of the vehicle for purposes not described in previous categories
Eating with utensils	When a driver has food that will be put in his/her mouth via a utensil like a fork, spoon, knife, chopsticks etc.
Eating without utensils	When a driver has food that will be put in his/her mouth and a utensil is not used to place the food in the driver's mouth.
Drinking with lid and straw	When a driver uses a straw to drink from a container that has a cover on it and cannot easily spill if it tips over
Drinking with lid, no straw	When a driver drinks from a container that has a cover on it and cannot easily spill if it tips over (not using a straw)
Drinking with straw, no lid	When a driver uses a straw to drink from a container that does not have a lid
Drinking from an open container	When a driver drinks from a container that does not have a lid (not using a straw)
Reaching for cigar/cigarette	When driver reaches or starts to glance around for cigar/cigarette.
Lighting cigar/cigarette	When driver is reaching for and/or lighting cigar/cigarette.
Smoking cigar/cigarette	When driver has a lit cigar/cigarette in their mouth or hand.
Extinguishing cigar/cigarette	When driver puts out his/her cigar/cigarette, or hands it to someone else.
Combing/brushing/fixing hair	Any touching, adjusting, or combing/brushing of hair.
Applying make-up	Applying any body product to body. This would include lotions.
Shaving	Using any appliance to remove hair from body. This does not include tweezing.
Brushing/flossing teeth	Using any appliance to brush, floss or otherwise clean teeth or mouth.
Biting nails/cuticles	When driver bite nails or cuticles
Removing/adjusting jewelry	When driver removes or adjusts jewelry, including watches.

Removing or putting on glasses/sunglasses	When driver is putting on or taking off glasses or sunglasses
Removing /inserting contact lenses	When driver is removing or inserting contact lens(es) from eye(s)
Other personal hygiene	Other personal hygiene activities not described in previous categories

APPENDIX E2. List of Speeding Faster than Posted Speed Limit Options and Operational Definitions.

Speeding Faster than Posted Speed Limit Options	**Operational Definition**
Yes, Driver was driving at an appropriate speed.	Driver maintained an appropriate speed for the duration of the road segment.
No, Driver was driving at least 10 mph faster than the speed limit with traffic present.	At some point on the road segment, the driver was traveling faster than 10 MPH over the designated speed limit with traffic present within 120 feet (3 hash marks) either in front or behind the instrumented vehicle in any lane of travel.
No, Driver was driving at least 10 mph slower than the speed limit with traffic present.	At some point on the road segment, the driver was traveling slower than 10 MPH over the designated speed limit with traffic present within 120 feet (3 hash marks) either in front or behind the instrumented vehicle in any lane of travel.
No, Driver was driving at least 10 mph faster than the speed limit with no traffic present.	At some point on the road segment, the driver was traveling faster than 10 MPH over the designated speed limit and there was no traffic present within 120 feet (3 hash marks) either in front or behind the instrumented vehicle in any lane of travel.
No, Driver was driving at least 10 mph slower than the speed limit with no traffic present.	At some point on the road segment, the driver was traveling slower than 10 MPH over the designated speed limit and there was no traffic present within 120 feet (3 hash marks) either in front or behind the instrumented vehicle in any lane of travel.
Unknown	Select of very poor video and/or missing data.

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