

**IDEA**

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**Innovations Deserving  
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*Safety IDEA Program*

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**DRIVE-SMART Driver Monitoring and Crash Risk  
Mitigation System**

Final Report for  
Safety IDEA Project 18

Prepared by:  
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*April 2013*

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**TRANSPORTATION RESEARCH BOARD**  
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This IDEA project was funded by the Safety IDEA Program.

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Prepared for

Safety IDEA Program

Transportation Research Board

National Research Council

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The author would also like to acknowledge the participation and advice provided by the members of the project's Expert Review Panel as named below.

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# TABLE OF CONTENTS

<b>EXECUTIVE SUMMARY</b> .....	<b>1</b>
<b>IDEA PRODUCT</b> .....	<b>2</b>
<b>Basic Hardware Concept</b> .....	<b>3</b>
<b>Functionality</b> .....	<b>3</b>
<b>DRIVE-SMART System Technical Description</b> .....	<b>4</b>
<b>INVESTIGATION</b> .....	<b>7</b>
<b>System Integration and Testing</b> .....	<b>8</b>
<b>PLANS FOR IMPLEMENTATION</b> .....	<b>10</b>
<b>CONCEPT AND INNOVATION</b> .....	<b>10</b>
<b>Major Risk Factor Descriptions</b> .....	<b>10</b>
<b>CONCLUSIONS</b> .....	<b>11</b>
<b>INVESTIGATOR PROFILE</b> .....	<b>12</b>
<b>REFERENCES</b> .....	<b>13</b>

## **EXECUTIVE SUMMARY**

This project developed a driver monitoring and crash risk mitigation system, which is called DRIVE-SMART. This Safety Innovations Deserving Exploratory Analysis (IDEA) project included development and improvement of the electronic hardware and software components, integration, and testing of the system.

DRIVE-SMART is the only system that can provide in a single product a comprehensive risk assessment and driver assistance system. The DRIVE-SMART system assesses in real time five primary risk factors that contribute to an elevated risk of motor vehicle crashes. These include: drowsiness/fatigue, distraction, alcohol-related impairment, aggressive driving, and seat belt use. As outlined in the body of this report, alcohol-impaired driving contributed to 32 percent of fatal crashes<sup>1</sup>, aggressive driving contributed to 66 percent of traffic fatalities<sup>2</sup>, fatigue-related driving contributed to 30 percent of crashes<sup>3</sup>, and secondary task distractions contributed to approximately 80 percent of crashes<sup>4</sup>.

These statistics clearly demonstrate that assessment of all of these primary risk factors and successful intervention through timely and dependable notification to drivers and respective authority figures of elevated crash risks will result in improved safety.

The DRIVE-SMART hardware and software development progressed at a rapid rate. The Virginia Tech Transportation Institute (VTTI) now has a working hardware prototype that meets or exceeds all of the expectations.

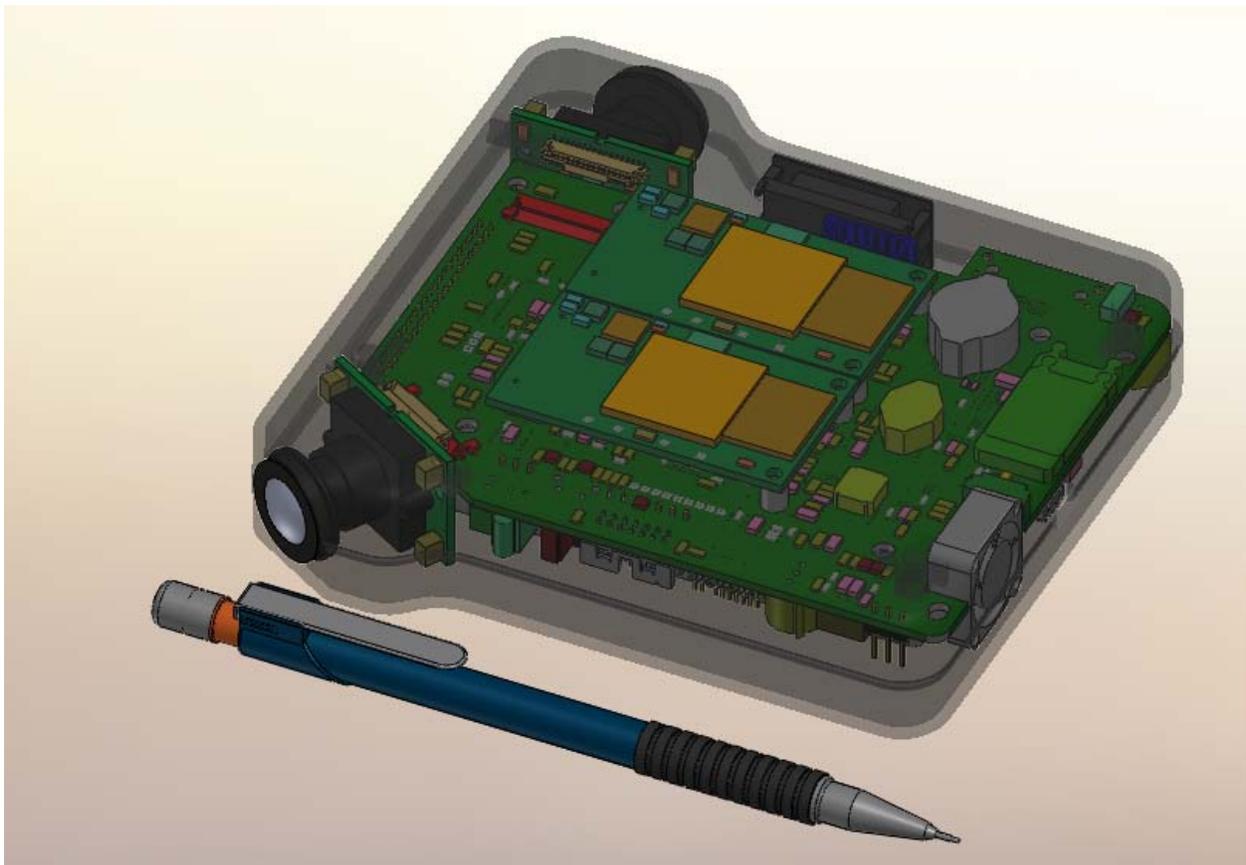
The goal of this Safety IDEA project was to develop and integrate hardware and software for a comprehensive, low-cost, easy-to-install driver monitoring and assistance system. The result is a prototype DRIVE-SMART system that is capable of providing driver and administrator feedback about five risk factors, including those which contribute to most of the crashes in the United States. In December 2011, the National Transportation Safety Board (NTSB) suggested that systems like this be mandated in commercial trucks. That was based upon a growing body of data that suggest that such deployment could help to reduce the number and rates of crashes for equipped vehicles. The DRIVE-SMART system represents a substantial step forward in both concept and capability of an affordable system.

## IDEA PRODUCT

Technologies are currently available to warn drivers of risky driving behavior. However, most currently available systems rely upon a single sensor to measure risk indicators such as drowsiness or distraction. This typically results in an unreliable assessment and underestimation of risk as warning algorithms are intentionally “desensitized” to prevent nuisance alarms. This presents obvious safety concerns and additional trust issues with drivers if they recognize these shortcomings.

In addition, the current state-of-the-art systems only address one or two risk factors such as distraction or aggressive driving. Risk is elevated by a number of factors, including: fatigue, distraction, alcohol impairment, aggressive driving, and seat belt usage. A system that can address most or all of these risk factors will therefore be capable of reducing driving risk to a greater degree.

Successful driving risk mitigation is predicated on the advancement of a system that provides a timely, accurate, reliable and comprehensive assessment of the risk factors described above. The DRIVE-SMART system uses multiple and sometimes redundant sensors to continuously monitor and record major risk indicators, uses those measures to determine respective risk factor levels, and provides real-time feedback to the driver and/or delayed reporting to authority figures as determined by system configuration. The original concept for the DRIVE-SMART system is shown in Figure 1.



**FIGURE 1** Conceptual rendering of the proposed DRIVE-SMART system.

## Basic Hardware Concept

The goal of the DRIVE-SMART system is the measurement and assessment of a range of risk factors in a manner that is unobtrusive and reliable while remaining affordable and easily installed. As shown in Figure 1, a single, self-contained hardware unit was developed that mounts just above the instrument panel (IP) on the forward windshield. The mounting location is somewhat flexible, and the mount is either permanent (e.g., screwed to the top of the IP) or “suction-cupped” to the windshield (e.g., a portable navigation system).

Fortunately, the advanced drivetrain, chassis, and accessory control systems used in modern vehicles employ a variety of sensors that report measured values on a centralized diagnostic and communication network, or vehicle bus. This vehicle bus provides both data for risk assessment and power for the DRIVE-SMART system. Thus, a single cable either permanently installed or simply plugged in (such as a portable navigation system) is all that is required for installation.

## Functionality

The contemporary version of the vehicle data bus, known as On-Board Diagnostics, implementation II (OBD-II), is a standard bus that allows various communication protocols, including, but not limited to, the Controller Area Network (CAN). Physical access to the vehicle bus, whether OBD-II or earlier standards, and knowledge about how data on the network are identified and structured are required to gain access to this information. Data on the vehicle bus provide much information that is useful when monitoring driving behavior and other risk factors.

While advancements in onboard vehicle system monitoring may provide a wealth of accessible driving performance information, additional sensors are required to monitor important risk factors and to provide an additional level of robustness to other sensors. In particular, an assessment of the driver’s physical state is required to best evaluate risk factors such as alcohol-related impairment, drowsiness, or distraction, which compose three of the five major risk factors. While direct measurement of blood alcohol content (BAC) is unrealistic for driver monitoring, the presence of alcohol vapors within the interior of the vehicle may be measured to indicate the presence of alcohol. Of course, other sources of alcohol may be present in the vehicle such as hand sanitizer or fragrances, which is why the use of multiple indicators of alcohol impairment (e.g., lane keeping) are proposed to calculate risk factors.

Driver drowsiness may be determined using camera surveillance and computer machine vision (MV) to determine percentage of eye closure (PERCLOS), a measure of slow eye closures that correlates highly with drowsiness. Driver distraction and to some degree drowsiness may also be measured by MV monitoring of eyes-off-road time and lane-keeping performance. The Virginia Tech Transportation Institute (VTTI) and others have developed non-invasive, visual sensors to directly measure impairment from these risk factors.

Figure 2 shows the concept for sensor monitoring of risk indicators with a corresponding mapping of risk factors. It is important to note that, with the exception of seat belt usage that has a binary value and is drawn from the vehicle data bus, all risk factors have multiple indicators to improve the robustness of their calculations. The DRIVE-SMART system monitors internal and vehicle-based sensors, calculates risk factor levels based upon pre-programmed algorithms, and provides intervention in the form of a real-time warning (system alert) to the driver and/or subsequent notification of an authority figure. System alerts are based on the levels of individual risk factors or some combination thereof. The alert algorithm may also be altered by a global modifier to adjust for secondary risks.

Alcohol Sensor

Distraction –

**FIGURE 2 Schematic diagram of sensors, indicators, and risk factors for the DRIVE-SMART system.**

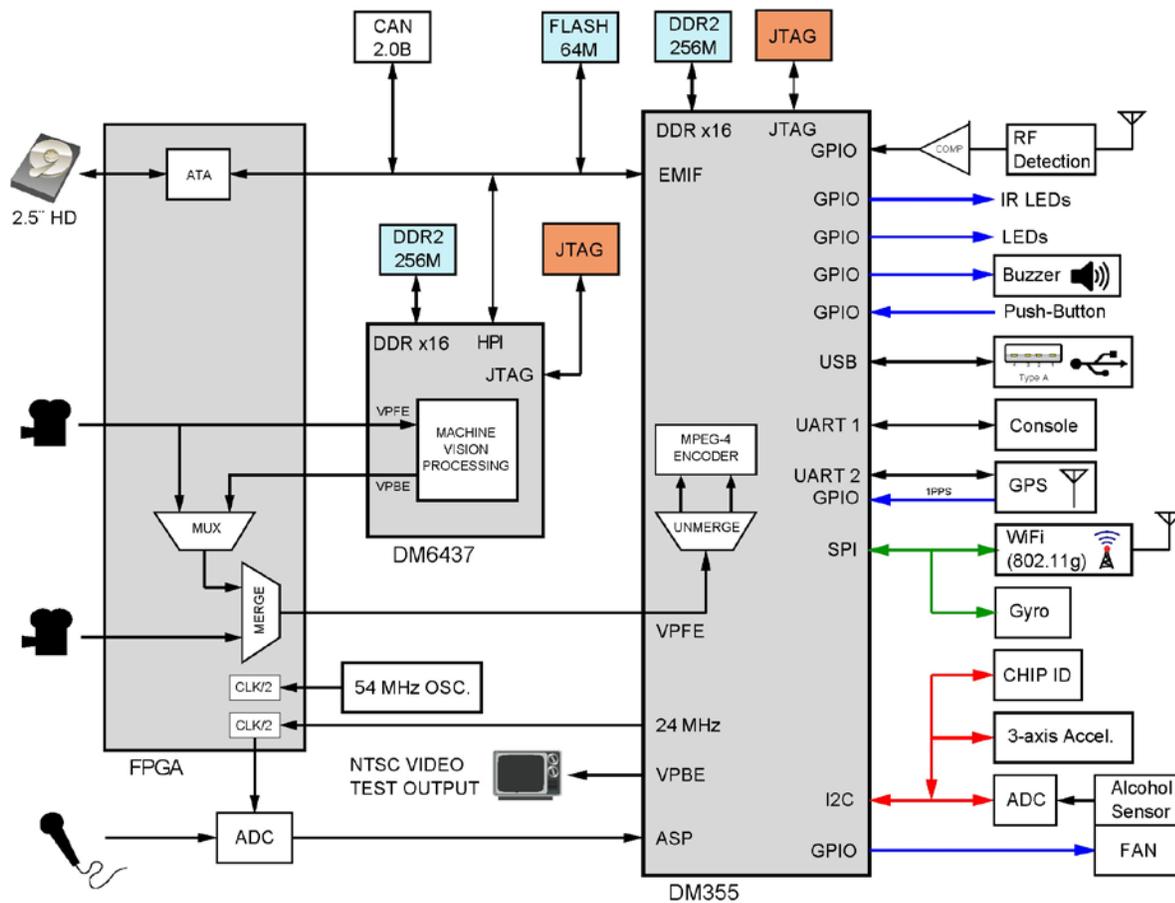
**DRIVE-SMART System Technical Description**

The DRIVE-SMART system uses views from two cameras, dedicated sensors, and data from the vehicle bus to monitor risk indicators and calculated risk factors. Parametric and video/audio data are then compressed, encrypted, and transferred to onboard storage. Data will be collected during one of three scenarios, as follows:

1. Epic-based data could be temporarily stored in a buffer and written to permanent storage only if predetermined algorithm criteria are met. Trigger algorithms will be based upon highly calculated risk factors; individual metrics such as high G forces, alcohol detection, or eyes away from the forward roadway; or crash indicators such as air bag deployment. Data will not be collected continuously during this scenario other than during defined epics.
2. Continuous data could be collected if onboard storage requirements are adequate.

3. A hybrid of continuous and epic-driven data could be collected. During this configuration, continuous data could be collected at a given time resolution (e.g., 10 Hz), and epic-related data could be collected at a much higher time resolution during events of interest (e.g., 100 Hz).

A block diagram depicting the current DRIVE-SMART functionality is shown in Figure 3. The system is highly capable from several perspectives: 1) It features powerful processors that allow the collection and storage of two video channels while performing in real time MV applications for lane position and driver head position; 2) It has the capability to input CAN information from the vehicle network; and 3) It has a variety of electronic sensors that include accelerometers and rate gyros, a global positioning system (GPS), and an alcohol sensor. In addition, the system can communicate via WiFi for data download, system health status, or incident notification. Also included is the capability to alert the driver via audio or visual alerts.



**FIGURE 3 Block diagram of the DRIVE-SMART system.**

The cameras, sensors, all electronics, and audible and visual driver notification systems have been integrated into a single, small unit that can be mounted on the windshield or dash areas so that views of the forward roadway and the driver's face are available. A DRIVE-SMART system using memory card storage and configured to collect epic-based data only is slightly larger than a deck of cards (Figures 4 and 5). Greater requirements for long-term, continuous data storage will currently involve the use of a larger storage media, which will result in a somewhat larger DRIVE-SMART enclosure.

A single cable is used to power the device and retrieve data from the vehicle bus by an existing diagnostic connection located below the steering wheel. High-speed digital signal processors (DSPs) and field

programmable gate arrays (FPGAs) were used during the final design to ensure timely sensor processing, risk factor calculation, and driver notification. A wireless interface (e.g., WiFi, general packet radio service [GPRS], etc.) was included to allow for notification of risks or warnings to authority figures, system health checks, software updates, and data uploads.



**FIGURE 4** Photograph of prototype DRIVE-SMART unit with removable hard drive attached.



**FIGURE 5 Photograph of prototype DRIVE-SMART unit with size perspective.**

## INVESTIGATION

The DRIVE-SMART hardware and software development progressed at a rapid rate following the initiation of the Safety IDEA project. As shown in Figures 4 and 5, VTTI now has a working hardware prototype that meets or exceeds all of the expectations. Specific development progress that has been made as a result of the Safety IDEA funding includes:

1. The porting of the VTTI “Road Scout” MV lane-tracking application to operate on the smaller and less costly DSP (DM6437). This required significant optimization of the algorithm to run on a DSP that is four times less capable than the DSPs currently deployed on other platforms of VTTI (e.g., the Second Strategic Highway Research Program [SHRP 2] Data Acquisition System [DAS]). A screen capture showing the Road Scout operating on the DRIVE-SMART DSP is shown at the top of Figure 6.
2. The porting of the VTTI “Mask” MV head pose tracking application to operate on the same DSP. The same algorithm optimization was also required here. A screen capture showing the Mask software working on the DRIVE-SMART DSP is shown at the bottom of Figure 6.
3. A variety of hardware and software tests were completed that improve the hardware design and software efficiency. Improvements that were made include:

- a. Replacement of the expensive parallel advanced technology attachment (PATA) solid-state hard drive storage and a redesign for inexpensive universal serial bus (USB) storage (which has recently become feasible).
- b. Change of the cell modem format to save approximately \$200 per unit.
- c. Increase in the horsepower of the main processor (to achieve the goal of also using DRIVE-SMART with associated algorithms as a warning system in a vehicle).

### **System Integration and Testing**

Integration of hardware, firmware, and software has now been completed. Bench-scale testing was initially performed, and initial in-vehicle testing has been completed. Operation of all software subroutines was tested individually and concurrently with other processes.

In addition, a system-level test was conducted on-road to assess system effectiveness during live traffic conditions. Detailed product-level, on-road tests include an assessment of the potential to reduce crashes and quantification of potentially detrimental factors such as false alarms. These tests will be ongoing throughout the product pre-deployment phase in the coming year.

### **Completion of Pre-Implementation Tasks**

Additional tasks have been completed that will allow the DRIVE-SMART system into the implementation phase. The result of these tasks is a system that can be cost-effectively mass produced. These pre-implementation tasks include:

1. Completion of the final layout of the main board to provide to a contract manufacturer (CM). The device has been designed to strive to aid the manufacturing process and keep costs low. This was accomplished through part selection, board design and layout, and ensuring the board is designed on the front end for testing in a manufacturing environment. The current intent is to be able to test at three stages: bare-board test, in-circuit or bed-of-nails test, and functional test. VTTI currently has one CM with which it will be working for two years at the point of production.
2. Completion of the final enclosure design in preparation for award to a plastics manufacturing house.



**FIGURE 6** Screen capture of “Road Scout” lane tracking and “Mask” head position software operating on the DRIVE-SMART prototype system.

## PLANS FOR IMPLEMENTATION

Between now and the end of the VTTI Safety IDEA project, the Institute will work with its Expert Review Panel to solicit feedback about the best path forward to implement the DRIVE-SMART system on a large-scale basis. This includes soliciting detailed feedback regarding the driver and fleet interfaces for risk factors and aspects of marketing, packaging, and interface with other systems (e.g., electronic log books).

## CONCEPT AND INNOVATION

As described above, the DRIVE-SMART system provides the means to assess multiple driver risk factors, serving as both a driver monitoring system and a driver assistance system. Driver monitoring systems have been shown in recent work<sup>5</sup> to provide substantial benefit for commercial trucking fleets. In December 2011, the National Transportation Safety Board (NTSB) recommended to the Federal Motor Carrier Safety Administration (FMCSA) that driver monitoring systems be mandated for inclusion in commercial trucks. In addition, according to the U.S. Department of Transportation (USDOT), of the 3.6 million rear-end, running off-the-road and lane-change crashes that occur each year in the U.S., nearly 48 percent may have been prevented through deployment of advanced integrated driver assistance systems<sup>6</sup>.

Driver monitoring and driver assistance systems are commercially available at present. However, the available monitoring systems only provide feedback about one or two risk factors. At present, DRIVE-SMART is the only system that can provide a comprehensive risk assessment and driver assistance system in a single, low-cost, easy-to-install product.

The DRIVE-SMART system assesses in real time five primary risk factors that contribute to an elevated risk of motor vehicle crashes. These include: drowsiness/fatigue, distraction, alcohol-related impairment, aggressive driving, and seat belt use. As outlined below, alcohol-impaired driving contributed to 32 percent of fatal crashes<sup>1</sup>, aggressive driving contributed to 66 percent of traffic fatalities<sup>2</sup>, fatigue-related driving contributed to 30 percent of crashes<sup>3</sup>, and secondary task distractions contributed to approximately 80 percent of crashes<sup>4</sup>.

These statistics clearly demonstrate that assessment of all of these primary risk factors and successful intervention through timely and dependable notification to drivers and respective authority figures of elevated crash risks will result in improved safety.

### Major Risk Factor Descriptions

**Alcohol Impairment** - Drivers are considered alcohol impaired when their BAC is 0.08 grams per deciliter (g/dL) or greater. Alcohol-impaired driving fatalities caused 32 percent of fatal crashes in 2007<sup>1</sup>, which resulted in an average of one alcohol impaired-related driving fatality every 40 minutes<sup>7</sup>. The introduction of an alcohol sensor, lane tracking, and eye tracking is beneficial in the implementation of a system designed to reduce alcohol-impaired drivers.

**Safety Belt Use** - The use of safety belts can reduce the risk of death or injury in an automobile accident by 45 to 60 percent<sup>8</sup>. The tracking of seat belt usage could lead to the discovery of factors used to determine why drivers do or do not use their safety belt and could aid in the design and improvement of driver compliance and safety.

**Driver Drowsiness** is the cause of approximately 30 percent of crashes<sup>3</sup>. It was found that impairments following 24 hours of sustained wakefulness have the same magnitude as a BAC of 0.1, which is 0.02 greater

than the legal driving limit. Hours of wakefulness of 18.5 to 21 produced measurements of driving performance similar to BACs of 0.05 and 0.08<sup>9</sup>. Characteristics of drowsy driving crashes include a single vehicle leaving the roadway at a high rate of speed with a lone driver<sup>10</sup>. Drowsiness can increase a driver's risk of crash or near-crash by at least a factor of four<sup>4</sup>. When drivers are drowsy, a lane-crossing event, long eye closure, and inaccurate steering are ideal indications of an oncoming road departure error<sup>11</sup>.

**Aggressive Driving** is defined by the National Highway Traffic Safety Administration (NHTSA) as occurring when “an individual commits a combination of moving traffic offenses so as to endanger other persons or property.” NHTSA estimates that 66 percent of all traffic fatalities are caused by aggressive driving behaviors<sup>2</sup>. Specific behaviors that constitute aggressive driving include<sup>12</sup>:

- Tailgating
- Weaving in and out of traffic
- Improper passing
- Passing on the shoulder
- Improper lane changes
- Failure to yield the right of way
- Preventing other drivers from passing
- Unwillingness to extend cooperation to motorists unable to merge or change lanes due to traffic conditions
- Driving at speeds far in excess of the norm resulting in frequent tailgating or frequent and abrupt lane changes
- Running stop signs or red lights
- Flashing head lights
- Sustained horn honking
- Glaring at another driver to show disapproval
- Yelling
- Gesturing

**Driver Distraction** - Naturalistic and epidemiological studies and surveys performed at VTTI and elsewhere confirmed that drivers who are not necessarily drowsy, affected by alcohol, or acting aggressively can still be momentarily impaired by inattention to vehicles ahead, often resulting in rear-end collisions<sup>13</sup>. Many crashes occur when otherwise attentive and unimpaired drivers are distracted by an event in or outside the vehicle. Secondary task distraction is a factor in approximately 80 percent of crashes and 65 percent of near crashes. Reaching for a moving object increases the risk of a crash 9 times, looking at an external object by 3.7 times, reading by 3 times, dialing a handheld device by almost 3 times, and talking or listening on a handheld device by 1.3 times<sup>4</sup>. The drivers' eye-glance patterns revealed that as cognitive demands increased, concentration on the road center increased while periphery decreased, which could result in non-detection of all hazards<sup>14</sup>.

## CONCLUSIONS

The goal of this Safety IDEA project was to develop and integrate hardware and software for a comprehensive, low-cost, easy-to-install driver monitoring and assistance system. The result is a prototype DRIVE-SMART system that is capable of providing driver and administrator feedback about five risk factors, including those which contribute to most of the crashes in the United States. In December 2011, the National Transportation Safety Board (NTSB) suggested that systems like this be mandated in commercial trucks. That was based upon a growing body of data that suggest that such deployment could help to reduce the number and rates of crashes for equipped vehicles. The DRIVE-SMART system represents a substantial step forward in both concept and capability of an affordable system.

## INVESTIGATOR PROFILE

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Dr. Thomas A. Dingus is Director of VTTI and is the Newport News Shipbuilding Professor of Engineering at Virginia Tech. Since 1996, Dr. Dingus has managed VTTI operations and research. This multi-disciplinary organization is currently the second largest U.S. university-affiliated transportation institute with more than 300 faculty, staff and students and more than \$29 million in sponsored research expenditures during Fiscal Year 2011.

Dr. Dingus has directed transportation safety and human factors research since 1984 and has thus far managed more than \$150 million in research funding. He has served as the Principal Investigator for numerous large-scale projects focused on data collection systems and methods, including:

- **The SHRP 2 Naturalistic Driving Study (NDS).** Sponsored by the Transportation Research Board (TRB), the SHRP 2 NDS S06 is the largest NDS undertaken to date and is the model for similar efforts being pursued internationally. VTTI is working closely with SHRP 2 staff and S07 site contractors staffing six data collection sites across the United States. The project responsibilities include: design and acceptance testing of the DAS; overseeing procedures for protection of participants; coordinating study protocols; developing approved consent forms and related supplemental materials; facilitating successful Institutional Review Board (IRB) submissions across all IRBs involved; training of S07 project personnel in terms of driver assessment, DAS installation, and data handling; attending S07 project kickoff meetings; conducting S07 project site readiness inspections; overseeing participant recruitment; adhering to the sampling plan; managing the triage response to all remote DAS self “health” check and automated collision notification messages; monitoring the progress of hard drive removals and data uploads to the VTTI data center; maintaining the data collection schedule; and processing, storing, and providing access to study data for ongoing and subsequent research projects.
- **The 100-Car Study.** Sponsored by NHTSA, this was the first instrumented vehicle study undertaken with the primary purpose of collecting large-scale naturalistic driving data. The data collection effort resulted in a data set comprising ~2,000,000 vehicle miles of driving, almost 43,000 hours of data, 241 primary and secondary driver participants, 12 to 13 months of data for each vehicle, five channels of video, and many vehicle state and kinematic variables.
- **The Drowsy Driver Warning System Field Operational Test (DDWS FOT).** Sponsored by NHTSA, the primary goal of this FOT was to determine the safety benefits and operational capabilities, limitations, and characteristics of a DDWS that monitors drivers’ drowsiness. To determine how the DDWS works in a naturalistic environment, in-service commercial vehicles were instrumented with a state-of-the-art DAS, and four video cameras were installed to record the driver’s face and the driving conditions around the vehicle. This approach resulted in an extremely large data set of more than 12 Terabytes (TB).

Dr. Dingus also helped establish the VTTI spin-off, Transecurity, LLC. Transecurity is designed to provide advanced, onboard vehicle systems; proactive driver crash risk analysis; and driver performance tracking.

Research conducted at VTTI provided the foundation for the commercialization of a safety system currently being tested as part of an FMCSA-funded evaluation study.

Dr. Dingus is a Fellow of the Human Factors and Ergonomics Society (HFES) from which he has received several awards, including the A.R Lauer Award career achievement award for outstanding contributions to the field of safety. He has had the honor of testifying before a U.S. Congressional sub-committee (three times), the National Transportation Safety Board, and the National Council of State Legislatures (twice) about issues of driver distraction and attention.

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