Systems Integration

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Single-function warning systems are already available in some cars and light trucks. The next step is to provide multiple systems in one vehicle, which requires addressing some daunting human interface issues.

& the Human Factor

Driving has sometimes been described as years of boredom followed by seconds of terror. For experienced drivers, little thought is needed to control their car in most circumstances. Driving has become ritual. However, when the unexpected does happen, the driver must often make a life or death decision in a split second. The US Department of Transportation (US DOT) is looking into ways to use technology to enhance the driver's ability to deal with that critical interval.

Systems designed to help protect drivers from getting into crashes are already available on some luxury automobiles in the US. At present, such safety systems include those designed to alert a driver when the car is drifting too far left or right of the proper lane. When a driver starts to drift, the system issues a polite beep, simultaneously muting the radio if it is on. The driver instantly grasps the message and takes the appropriate action. Other systems warn the driver of a possible forward collision and prearm the brakes and restraint systems if sensors and algorithms determine that a crash is unavoidable.

But in the near future, life inside the car might not be so simple. Less than a decade ago, a lane departure warning system would have been in the realm of science fiction, but in the last few years, manufacturers worldwide have introduced such systems in regular production cars and trucks. In not so many more years, multiple safety systems, each with its own beep, whistle, flashing light, or other unique warning, will be vying for the driver's attention. At that point, technology might degrade rather than ensure safety on the road.

Inside Track

- Human factors applies knowledge of human capabilities and human limitations to the design of systems, tools, and consumer products for safe, efficient, and comfortable human use.
- An analysis of fatal crash statistics suggests that new crash warning technology could reduce the severity of, or possibly even prevent, close to half of all applicable vehicle accidents.
- The false alarm rate must be sufficiently low that the driver finds the system helpful rather than annoying. The driver should be able to understand how the system functions.
- It might be possible not only to anticipate potential threats but also to identify the driver response that is most likely to keep the vehicle from crashing.

Increasing highway safety is a complex and difficult task. Great strides have been made in making the motor vehicle crashworthy. Airbags and other safety systems help save lives and minimize injuries once a crash occurs. From crashworthiness, the logical next inroad into the safety frontier is crash prevention. A few automobiles already have crash mitigation systems that first warn the driver of a potential forward crash, brake the car if the driver does not respond, and prepare the safety systems to protect the occupants if a crash does occur. Some heavy trucks have forward collision warning in addition to lane change warnings.

All this technology has exciting potential in and of itself, but the creation of effective warning systems is more than the sum of its parts. It is more than efficiently integrating radar and ultrasonic and vision sensors. It is more than the arrangement of sensor suites and the accuracy of obstacle recognition and detection algorithms. Ultimately, none of this will work if the system fails to get the driver to understand that there is a hazard in the driving environment. This means that the message must be clear enough for the driver to react in time to avoid a crash—or at least minimize the damage if a crash still occurs. In short, drivers—the human factor—must be of utmost concern in integrating warning systems.

This puts a tremendous burden on system designers. How can the system be easily understood and be cost-effective enough that drivers will be willing to include it in their next new car? In aviation and commercial trucking, with its high-end vehicles, the cost of adding a safety system is more easily absorbed and pilots and commercial drivers are trained in how to handle dangerous situations. In sharp contrast to both these environments, the average automobile driver with a single-function safety system walks away with little more than an unread user guide and a vague introduction to the system's capabilities.

When integrating multiple systems, designers must deeply consider how one warning system's driver-vehicle interface (DVI) will work with other interfaces. As an integrated suite, the multiple-warning system must strive to be as driver-friendly as is, well, humanly possible.

To address this need, in 2005, the US DOT launched an ambitious program to integrate crash warning technologies and evaluate the integrated system with a field operation test program. The Integrated Vehicle Based Safety Systems (IVBSS) initiative aims to help automotive and heavy truck manufacturers accelerate the introduction of vehicle safety warning systems in US production vehicles. A significant part of this effort is to identify the human factor issues—which displays (auditory, visual, haptic, and so on) provide effective warnings and which are likely to overwhelm a driver when there are multiple warnings. The IVBSS team, led by the University of Michigan's Transportation Research Institute (UMTRI), has already drafted functional specifications and a systems architecture.

How warning systems work

Some luxury cars now offer one of three kinds of warning systems—forward collision, lane change and merge, and roadway departure—and some heavy trucks offer combinations. Select Japanese and European car makers introduced these systems in their home markets in the late 1990s, and in 2003, the systems began appearing in the US on luxury cars, where increased vehicle cost from adding the safety system is less of a concern.

Although these warning systems are too new to have any meaningful data on actual crash avoidance, the results of early field operational tests of single-purpose systems are promising. An analysis of 2003 crash statistics suggests that equipping all vehicles with an integrated warning system could reduce the severity of, or possibly even prevent, nearly two million crashes a year. Figure 1 shows the breakdown of this 2003 crash data. The data represents the crash types that are most likely to benefit from technologies in the IVBSS initiative. Early on, IVBSS members decided to concentrate on areas that would yield the greatest safety benefits and

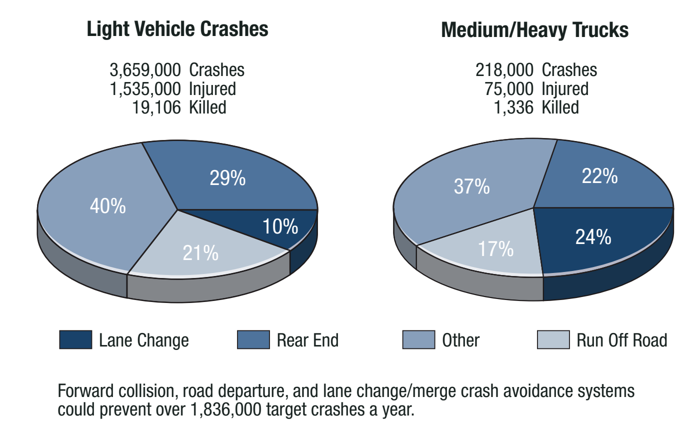

Figure 1. Types of crashes that an integrated warning system has the most potential to eliminate or mitigate. The data comes from the 2003 National Automotive Sampling System's General Estimates System.

not try to use every technology or solve every crash problem.

Although collision warning systems are relatively recent developments in automotive safety, many of these systems are based on technologies that have been proven in other applications. Current collision warning systems use various proven sensor types, for example, such as radar and infrared detectors, to measure the distance to another vehicle or obstacle and calculate if there is a threat of a crash. Figure 2 illustrates a roadway departure warning system that uses several sensors to detect the vehicle's lateral and longitudinal proximity to objects or features on the roadway. The system uses signals from these sensors to determine parameters such as time to collision, headway distance, distance to lateral vehicles, and lane position through a global positioning system and high-definition maps. The DVI activates a warning display when the warning algorithm determines that one of these parameters exceeds some predefined threshold.

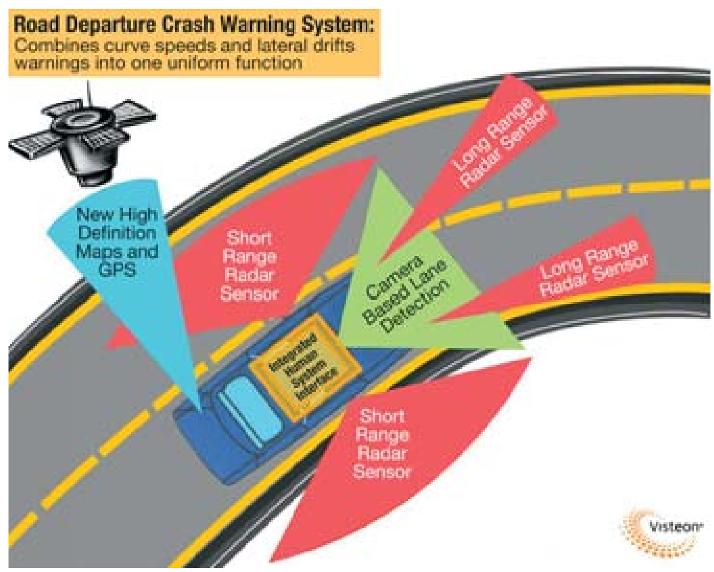

Figure 2. Roadway departure warning system and sensors. (Figure courtesy of Visteon, 2006.)

Forward collision warning

Perhaps the most common warning system is one that attempts to prevent forward collisions using sensors to detect obstacles in the vehicle's forward path. Such systems typically use information about the vehicle's speed and distance to such obstacles to calculate a time to collision. The system warns the driver when the time to collision drops below a certain threshold, generally 1 to 2 seconds. In many systems, the warning is both audible—such as a series of beeps—and visual—such as an icon that illuminates on the dash, as in Figure 3a or in a heads-up display. Figure 4 shows a forward collision warning (FCW) system tracking a lead vehicle.

FCW systems have been available for heavy trucks for nearly a decade. However, nearly every tractor and commercial truck is customized to meet the purchaser's specifications, and the accommodation of special electronics is routine for original equipment

(a) (b)

Figure 3. Sample icons for (a) forward collision warning and (b) verifying that an airbag is functional. The airbag icon is one of several symbols that the US Department of Transportation has standardized as part of efforts to arrive at a common driver-vehicle interface.

Figure 4. A forward collision warning system. Sensors detect the vehicle's proximity to other vehicles, providing data to a warning system algorithm. If the algorithm determines that the signals exceed a predetermined threshold, it activates the system to alert the driver.

manufacturers. Moreover, heavy trucks do not face all the same human factor issues as passenger cars, since trucking companies use trained operators and typically provide training for any new electronics installed.

Only a few luxury production cars offer FCW systems in the US market. Tier 1 automotive suppliers, such as Delphi, Visteon, Valeo, TRW, and Siemens, provide these systems to automakers but do not make them available as aftermarket products. However, for the last decade, FCW has been common in heavy trucks, where integration into the vehicle architecture is not as problematic.

Although not technically a safety warning system, an ally in forward collision prevention is adaptive cruise control. This system, which is becoming widely available even in non-luxury vehicles, automatically maintains headway if the lead vehicle is slower than the equipped vehicle's set speed. A 2005 US DOT field operational test[1] found that drivers of vehicles with adaptive cruise control tend not only to follow at a greater distance from the lead vehicle but remain behind the lead vehicle for a longer period, thus smoothing traffic flow and contributing to overall highway safety.

Lane change and merge warning

A lane change and merge warning system indicates to the driver entering a lane that another vehicle or some other obstacle is also in that lane. Lane change warning systems typically have only a visual warning because a nearby car can be in the vehicle's blind spot but no collision is imminent. From a strictly engineering view, it would seem logical to have the system activate only when the driver is using a turn indicator. However, data from a study of how drivers naturally drive[2] shows that drivers who almost hit another vehicle when making an intentional lane change use the turn signal but fail to check side view mirrors and blind spots.

Most product development teams believe that signaling indicates the driver is aware of other traffic. The typical design of a lane change and merge system thus suppresses the warning if a turn signal is in use. This study, however, indicates that drivers who get into trouble when changing lanes might think that using the turn signal means, "Get out of my way because I am leaving my lane." They signal but do not check for other cars. Thus, the use of a turn signal does not reliably indicate that the driver is aware of other vehicles. For that reason, it makes sense to have a warning even when the turn signal is on.

Roadway departure warning

Most roadway departure warning systems use machine vision to read the lane markings and warn the driver when the vehicle has crossed the lane boundary onto the shoulder or off the roadway. A roadway departure must always follow a lane departure, but for roadway departure, the system projects that the deviation will end in the vehicle's leaving the roadway. Roadway departures frequently lead to rollovers—a particularly dangerous type of crash. System warnings might be sounds; icons; haptic signals, such as a vibrating seat or steering wheel; or some combination of these.

A few passenger cars and SUVs have introduced lane departure warnings that alert the driver when the vehicle drifts out of the lane, but a full road departure system has not yet been introduced in passenger cars. Both lane departure and road departure systems are available in many heavy trucks, however.

Driver-friendly integration

No one is yet offering all three kinds of warning systems in a single production car. The obstacles are formidable. The hardware and software engineering solutions are challenging, but the core problem is how to merge and organize individual collision warning components into a comprehensive, understandable, and interoperable system.

The main issue in integrating multiple crash warning systems is the DVI design. There is a strong possibility that multiple warnings will overwhelm the driver, interfering with the driving task and/or degrading driver acceptance because of excessive false or nuisance alarms. Integration must be carefully planned and executed to avoid this possibility. In general the DVI should adequately capture the driver's attention without startling the driver, provide warnings in a manner that is compatible with the desired vehicle control response (brake or steer), and provide an orienting response, where appropriate, causing the driver to look in the direction of the hazard.[3]

When things go wrong

Part of creating an effective integration is understanding what is not effective. What does poor integration look like?

Suppose the driver, let's call him Bob, is driving a car with multiple systems that are just kludged together. A heads up display contains the FCW icon, a dedicated speaker on the A-pillar (next to the windshield) sounds a FCW alarm; the outside mirror has a blinking red light to warn of a vehicle in the blind spot, the right side of the driver's seat vibrates to indicate the vehicle has crossed over the lane line and through the radio speakers a voice is saying "Return to your lane." In Bob's view, the vehicle is sporting the newest "integrated" safety system: It not only detects potential collisions to the front and both sides of the vehicle, but also tells Bob how to get to his destination, keeps the car a set distance from the vehicle in front, and warns Bob when his tire has drifted over a lane boundary. Bob is sure that with this technology, he is completely covered. Today, however, events will prove him wrong.

> *Drivers vary in their visual acuity, cognitive ability, adeptness, reaction time, risk assessment capability, distraction level, alertness, and desire and ability to manage electronic clutter.*

As Bob sails down the freeway, he leans over to adjust his iPod and suddenly hears "Brake now!" He immediately puts his foot on the brake and slows the vehicle to avoid the driver ahead, who has suddenly changed lanes. Crisis avoided. At that moment, one of the speakers issues a loud beep. Bob can't remember if that beep means a front collision warning, a side collision warning, or simply that his MP3 player is having an issue. Has braking triggered a new collision threat? While he's frantically trying to figure out the source of the hazard, the navigation system cheerfully informs him that his exit is coming up immediately and that, by the way, he's in the far left lane. The system had already notified Bob once when the exit was a mile away, but the collision warning system had commandeered the audio and muted the notification. As Bob passes his exit and more beeps sound and icons light up, he thinks seriously of trading his state-of-the-art vehicle for a 1995 Volkswagen with nothing more complicated than a horn.

This scenario, while somewhat amusing to read, could be terrifying to live through. Bewildered Bob is more likely to have a heart attack than be empowered to respond calmly to an impending crisis. And Bob is only one type of driver in one kind of driving environment at one five-minute interval. Drivers vary in their visual acuity, cognitive ability, adeptness, reaction time, risk assessment capability, distraction level, alertness, and desire and ability to manage electronic clutter. Add to that the variability of driving situations and the changing behavior patterns over time, and you get a flavor of the complexity that interfaces must account for. Warnings must attract attention and be comprehensible but not annoying. The false alarm rate must be low enough that the driver finds the system a boon, not an obstacle, yet warnings need to be frequent enough that the driver knows what they are and how to respond. The system has to be reliable enough for the driver to create an accurate mental model of its function and trust that it will perform as advertised, but also not expect the system to perform beyond its limitations.

System adjustability

Another issue in creating a driver-oriented interface is whether or not to let the driver turn off or adjust warning characteristics. Not every driver wants the same volume or visual intensity. Some situations, such as a crowded roadway or construction zone, will predictably increase the frequency of false or nuisance alarms, which would obviously be annoying. But allowing the driver too much freedom can compromise the warning system's effectiveness. How many and what kind of adjustments should the driver be allowed to make? It is not clear from current research and practice how to definitively answer that question. The best interpretation of available information is that drivers should have some control over display and system sensitivity settings, especially if false and nuisance alarms are a problem, but they should be restricted to setting ranges that preserve the effectiveness of system operation.[4] Turning the system off, for example, should not be an option.

Standardized safety

Although drivers *have* accepted differing capabilities on safety systems—the presence or absence of antilock brakes, for example—having consistent system capability and function from one vehicle to another would provide greater safety benefits. Standardization makes it easier for the driver to know how the vehicle will perform and exactly what the DVI is communicating. This is critical, since drivers must know what to expect of the system in a given situation when they have very little time to determine how to react to avoid a crash.

The lack of standardized warnings is an issue for an integrated crash warning system with multiple subsystems that might issue warnings simultaneously. If each integrated system has a slightly different sensor suite, warning algorithm, and DVI, one system might issue a warning earlier than another, use different sounds to indicate the same hazard, or have different false alarm rates. Such inconsistencies can be problematic because a warning system will not be effective if the driver does not recognize the warning in time to take action.

Clearly, then, establishing minimum performance requirements as a basis for standard development should be part of any government-sponsored research on the integration of safety systems. Warning standards would specify minimum performance levels for alert loudness, arbitration of multiple warnings, display brightness, and so on.

Volunteer standards groups, such as SAE International (Society of Automotive Engineers) and the International Organization for Standardization (ISO) are already addressing the standardization of warning symbols and system capabilities, but it typically takes many years for a proposed standard to reach consensus and publication. Such efforts have established some symbols, such as the air bag icon in Figure 3b, and published requirements and test procedures for advanced driver assistance systems, such as adaptive cruise control[5,6] and forward collision warning.[7]

Current integration efforts

Perhaps the largest ongoing effort to find solutions for integrating individual safety systems is the US DOT's IVBSS. This Tier 1 initiative brings considerable expertise and funds to bear in evolving standards for system performance and driver-friendly interfaces. In addition to leader UMTRI, the initiative includes Visteon, Eaton-Vorad, Honda, Kenworth, Cognex (Assistware), the Michigan Department of Transportation, and Battelle. Mitretek is working with the National Highway Traffic Safety Administration (NHTSA), the lead US DOT agency for the project, to ensure that the systems being developed not only effectively warn of potential crashes but also aid the driver in making the correct response to avoid safety threats. A significant part of that effort is human factors engineering for the warning system's DVI.

Figure 5 shows a timeline for the IVBSS initiative, which has five main goals:

- Support the US DOT's efforts in advancing safety product development.
- Facilitate the introduction and commercialization of effectively integrated safety systems.
- Develop information on how best to communicate an integrated warning to the driver.
- Develop objective tests and criteria for system performance that simultaneously address rear-end, road-departure, and lane-change crashes.
- Develop and field-test integrated vehicle safety systems on the road with real drivers to understand the safety benefits of such systems.

The IVBSS initiative has already completed an update of human factors guidelines for collision avoidance systems, which is based on the preliminary guidelines completed in 1996.[3] This study provides guidance for developing a DVI, but it also indicates that the IVBSS program must still overcome obstacles in effectively warning drivers, especially in the presence of multiple safety threats.

Challenges

The effectiveness of IVBSS in preventing crashes depends on the degree to which its design is matched to the range of capabilities and characteristics of the driving population and to the variety

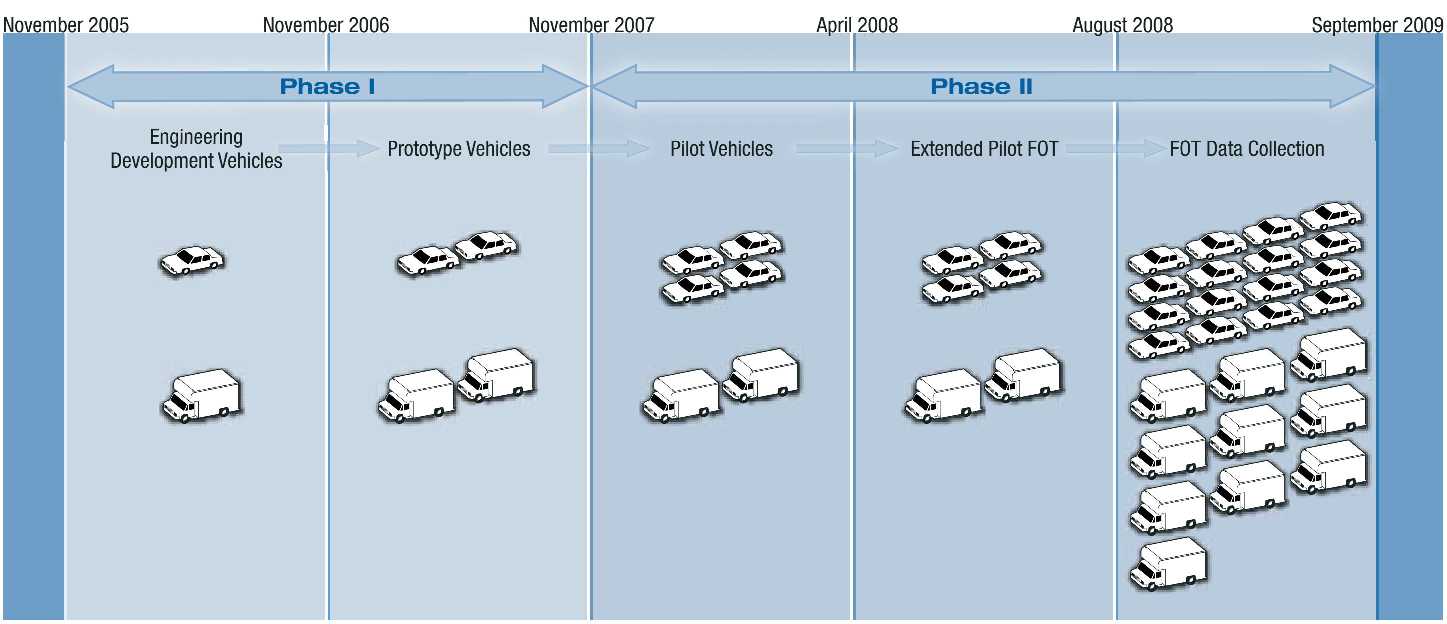

Figure 5. Timeline for the US Department of Transportation's Integrated Vehicle Based Safety Systems initiative. The initiative is evolving standards for system performance and driver-friendly interface design in a system that integrates stand-alone safety systems. FOT: field operational test.

of traffic scenarios that drivers encounter. The design of the DVI and warning algorithm is a key variable in the effectiveness equation. The warning algorithm uses information from multiple sensors to evaluate the crash threat. The DVI uses information from the warning algorithm to decide when and how to warn the driver. It can also receive control inputs from the driver to adjust settings such as loudness and perhaps a temporary override in heavily congested streets.

One goal of the IVBSS program is to develop DVI and warning algorithm requirements that optimize crash prevention while maintaining high driver acceptance. Numerous human factors issues must be resolved to achieve this goal. Two of the more challenging are

- **Interface independence.** Should the DVI be different and independent of the DVIs for the individual collision warning subsystems? For example, if a stand-alone FCW system is known to have an effective auditory signal, such as series of beeps, does it need to be changed when integrated with lane change and road departure systems?

- **Interface design scope.** Given the differences between light vehicles, such as passenger cars, and heavy vehicles, such as commercial trucks, and their drivers, could the same DVI design work for both?

The expectation is that an integrated system will detect more threats. With these capabilities, it may be possible not only to anticipate potential threats and hazards but also to identify the driver response that would be most likely to enable the vehicle to avoid the crash. Should the DVI tell the driver to brake or steer? If so, what is the best way to do that? If the DVI does have such a capability, will drivers respond appropriately?

Another challenge is how to effectively communicate multiple threats. Lane departure and forward collision, for example, can occur nearly simultaneously. Questions here include

- Is a multimodal presentation (such as icons plus beeps) more or less effective than using only one modality?
- Can drivers discriminate between alerts and effectively respond to each threat?
- Master alarms, where the same alarm is used to indicate all warnings, have proved effective in other settings, such as on aircraft. Does this concept have merit for multiple threat alerts in a vehicle-based integrated system?

Prioritizing warnings is also a complicated issue. What is the role of warning prioritization in the development of the DVI and what are the requirements for timing warnings and alerts? Can the integrated interface be effective *without* prioritization? If not, what rules and human factors principles should govern priorities? Under what traffic scenarios might warning prioritization be important? How frequently might near simultaneous alarms occur? What system design approaches can enhance driver performance when multiple warnings are likely?

Finally, most evaluations of warning systems and efforts to identify their performance requirements have focused on average drivers. In estimating safety benefits for an entire vehicle fleet, however, it is important to know how different driver groups can use warning systems.

Crash warning systems represent the next frontier in saving lives. In 2004, more than 42,000 fatalities due to motor vehicle crashes occurred in the US alone. Such crashes are the leading cause of death among Americans 2 to 34 years old.[8] As the next article "Proactive Prevention: Technology-Policy-Driver Partnership" in this issue describes, in addition to deaths and injuries to vehicle occupants, these tragedies drain the US economy of billions per year, and society seems to accept the financial and emotional costs associated with crashes as the price of mobility. Collision warning systems have the potential to address the causes of these crashes, possibly allowing drivers to either avoid certain types of accidents or greatly reduce their severity.

The IVBSS initiative is a strong first step toward ensuring that such technology reaches its potential. Solving the integration challenge will let drivers relax and be secure in the knowledge that their vehicles are ever vigilant in protecting them from hazards. And as that protection increases, life on the road will get better. This, after all, is why we work so hard to develop innovative technology and why the human factor—the driver—must always be in the forefront of system design.❖

References

1. W. Najm et al., *Evaluation of an Automotive Rear-End Collision Avoidance System*, US DOT, 2006; http://www-nrd.nhtsa.dot.gov/departments/nrd-12/pubs_rev.html.
2. G. Fitch et al., *The Study of Methodological and Crash Avoidance Issues Using the 100-Car Naturalistic Study Data: Subtask 4—Lane-Change Crash and Near-Crash Analysis*, US DOT, 2006, in press.
3. *Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices* (NHTSA Project DTNH22-91-07004), Comsis Corp., 1996.
4. J. Campbell et al., *Crash Warning System Interfaces: Human Factors Insights and Lessons Learned Final Report*, US DOT, 2006, in press.
5. *SAE J2399 Adaptive Cruise Control: Operating Characteristics and User Interface Requirements*; http://www.sae.org/technical/standards/J2399_200312.
6. ISO 15622, *Road Vehicles—Adaptive Cruise Control Systems: Performance Requirements and Test Procedures*; http://www.iso.org/iso/en/CatalogueDetailPage.CatalogueDetail?csnumber=27834&ICS1=3&ICS2=220&ICS3=20.
7. *J2400 Human Factors in Forward Collision Warning Systems: Operating Characteristics and User Interface Requirements*; http://www.sae.org/technical/standards/J2400_200308.
8. National Center for Injury Prevention and Control, *Web-based Injury and Statistical Query and Reporting System Leading Cause of Death Reports, 1999-2002*; http://webappa.cdc.gov/sasweb/ncipc/leadcaus10.html.

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