

**White Papers for: *“Toward Zero Deaths: A
National Strategy on Highway Safety***

—White Paper No. 4—

SAFER VEHICLES

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FOREWORD

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NOTICE

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PREFACE

While many highway safety stakeholder organizations have their own strategic highway safety plans, there is not a singular strategy that unites all of these common efforts. FHWA began the dialogue towards creating a national strategic highway safety plan at a workshop in Savannah, Georgia, on September 2-3, 2009. The majority of participants expressed that there should be a highway safety vision to which the nation aspire, even if at that point in the process it was not clear how or when it could be realized. The Savannah group concluded that the elimination of highway deaths is the appropriate goal, as even one death is unacceptable. With this input from over 70 workshop participants and further discussions with the Steering Committee following the workshop, the name of this effort became “Toward Zero Deaths: A National Strategy on Highway Safety.” The National Strategy on Highway Safety is to be data-driven and incorporate education, enforcement, engineering, and emergency medical services. It can be used as a guide and framework by safety stakeholder organizations to enhance current national, state, and local safety planning and implementation efforts.

One of the initial efforts in the process for developing a National Strategy on Highway Safety is the preparation of white papers that highlight the key issue areas that may be addressed as part of the process for developing a National Strategy on Highway Safety. Vanasse Hangen Brustlin was awarded a task order under the Office of Safety contract (DTFH61-05-D-00024) to prepare nine white papers on the following topics:

1. Future View of Transportation: Implications for Safety
2. Safety Culture
3. Safer Drivers
4. Safer Vehicles
5. Safer Vulnerable Users
6. Safer Infrastructure
7. Emergency Medical Services
8. Data Systems and Analysis Tools
9. Lessons Learned from Other Countries

While driver error is more frequently cited as the primary contributing factor in crashes, it may be improvements to vehicles—automobiles, trucks, buses, etc—especially in form of advanced safety technologies that might have the most impact on reducing fatalities. Co-authors Richard Retting and Ron Knipling, examine the role of these vehicles in traffic crashes and offer numerous strategies that, if implemented, should result in significant progress towards zero deaths.

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INTRODUCTION

Decades of improvements in motor vehicle design, and continuous advances in automotive safety technology have contributed to a steady decline in motor vehicle fatality rates. A number of important, fundamental vehicle safety improvements are long established, and credited with saving thousands of lives. These include collapsible steering columns, laminated windshields, padded dashboards, and crumple zones to absorb/dissipate collision forces. One particularly low-tech approach -- the simple safety belt -- has perhaps saved more lives and prevented more serious occupant injuries than any other single motor vehicle safety device. During the 5-year period from 2004 to 2008 alone, seat belts are credited with saving over 75,000 lives in the US (National Highway Traffic Safety Administration (NHTSA), 2009A). Safety belts were later bolstered by frontal airbags, which became a standard safety feature in US automobiles more than a decade ago. According to NHTSA, the combination of a front air bag and a seatbelt reduces the risk of serious crash-related head injury by more than 80 percent. Newly proven safety technologies, such as Electronic Stability Control (ESC) and side curtain airbags, are beginning to penetrate the vehicle fleet in large numbers. The rich history of automotive safety achievements during the last decade of the 20th century and the first decade of the 21st century clearly demonstrates the ability of motor vehicle manufacturers to develop vehicle designs and incorporate vehicle safety features that dramatically reduce the fatality consequences associated with motor vehicle travel.

Successful implementation of an aggressive “vision zero” fatality policy will require moving beyond past accomplishments to further identify and implement effective vehicle safety design features and life saving automotive technologies. These approaches are the subject of this *Safer Vehicles* white paper, which focuses on specific vehicle design features and technologies that offer substantial promise or established evidence for markedly reducing traffic fatalities. This paper covers issues largely relevant to passenger vehicles and large trucks. Motorcycles are specifically addressed in a separate paper on Vulnerable Road Users.

This white paper addresses vehicle safety enhancements for both passenger vehicles and large trucks. While almost all onboard safety technologies have *potential* application to both vehicle types, as a practical matter some are primarily applicable to one or the other. Most core safety systems, however, are cross-cutting and applicable to both. Table 1 below lists 27 onboard safety technologies and classifies them as principally related to passenger vehicles, cross-cutting and applicable to both, or principally related to large trucks.

Table 1. Countermeasure principal applicability by vehicle category.

Principally applicable to passenger vehicles	Cross-cutting and highly applicable to both	Principally applicable to large trucks
<ul style="list-style-type: none"> • Alcohol Detection & Interlock • Emergency Brake Assist • Crashworthiness Enhancements 	<ul style="list-style-type: none"> • Electronic Stability Control • Forward Collision Warning Systems • Lane Departure Warning Systems • Backing Collision Warnings • Driver Alertness Warnings • Automatic Speed Control • Electronic Drivers License • Intelligent Lighting Systems • Intersection Collision Avoidance Systems • Road Condition Warning Systems • Electronic Data Recorders 	<ul style="list-style-type: none"> • Improved Brakes/Shorter Stopping Distances • Roll Stability • Onboard Safety Monitoring • Electronic Onboard Recorders • Side Object Detection Systems • Vehicle Condition Monitoring • Automated Transmissions • Truck-Specific Navigation Aids • Enhanced Trailer Conspicuity • Enhanced Trailer Rear Lighting/Warnings • Video Side Mirrors • Collision Aggressivity Reductions

Figure 1 shows major crash categories and percentages for all motor vehicle crashes in 2008. Major applicable countermeasures, most discussed herein, are indicated. While many countermeasures are applicable only to specific crash scenarios, there is some overlap. For example, Lane Departure Warning Systems primarily address road departures, but also address head-on crashes (not shown in the figure) since the two crash types usually originate due to similar causes. Some countermeasures with more generalized crash prevention actions include alcohol detection and interlock, crashworthiness/occupant protection enhancements, intelligent lighting systems, improved brakes, onboard safety monitoring, and vehicle condition monitoring.

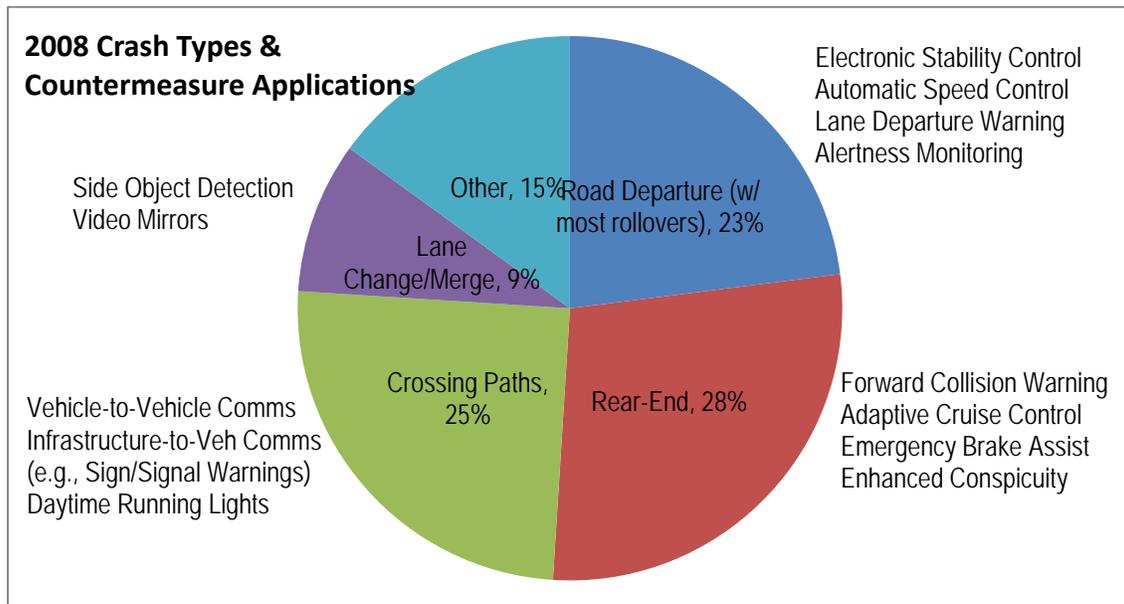


Figure 1. Major crash types (for all vehicles in 2008) and some applicable countermeasures. Source: Adapted from Sayer and Flanigan (2010); statistics from NHTSA.

This paper outlines a high-level vision to approach the goal of zero fatalities through Safer Vehicles, and identifies the most promising strategic measures to help achieve the vision. A range of safety measures are applicable across vehicle types, while other approaches are specific to either passenger vehicles or large trucks. Among numerous life-saving technologies and vehicle safety features cited, those with the highest priority – based on potential impact and/or relative ease of implementation – include the following:

- Alcohol Detection & Interlock
- Automatic Speed Control
- Electronic Stability Control
- Emergency Brake Assist
- Lane Departure Warning Systems
- Driver Attention Monitoring
- Ejection Mitigation
- Improved Side Impact Protection
- Side Object Detection Systems
- Daytime Running Lights

Potential fatality reductions associated with these vehicle strategies are provided in the White Paper, and summarized in Table 3. Also noted are significant obstacles and challenges to achieving widespread adoption of many of the vehicle safety measures, including the need for further technical development, implementation cost, potential legal liability, and public acceptance. Strategies to potentially overcome these obstacles and challenges are discussed.

PASSENGER VEHICLES & CROSS-CUTTING STRATEGIES

Cars, vans, and light trucks have become increasingly crashworthy, yet still account for about 25,000 occupant fatalities each year. In terms of further passenger vehicle safety enhancements, much of the industry emphasis has shifted from improving vehicle crashworthiness to collision avoidance technologies. Progress toward “vision zero” will depend on both continued advances in vehicle crashworthiness, as well as the development and widespread adoption of effective crash avoidance systems. The following section addresses promising vehicle safety design features and technologies deemed essential to help achieve the goal of a US highway system that produces zero fatalities. Due to the emerging nature and limited on-road experience with many of the technologies, safety benefits are largely characterized as promising, and not yet proven or definitively demonstrated. Findings of estimated or predicted effectiveness, where available, are focused on fatality effects rather than general crash reductions. This section includes both vehicle safety strategies that apply to passenger vehicles, as well as technologies that cut across vehicle types. The strategies are grouped by major safety function (e.g. improve driver awareness; vehicle-to-infrastructure communication). The technologies focus largely on crash avoidance, but also include opportunities to reduce crash severity.

VEHICLE CONTROL

Electronic Stability Control (ESC) uses automatic computer-controlled braking of individual wheels to assist the driver in maintaining control in critical driving situations, and is a major advance in vehicle safety. ESC monitors a vehicle's wheels to assess signs of lockup, loss of directional control (e.g., yaw), or excessive lateral acceleration (i.e., lateral skid or rollover risk). It modulates both the throttle and brakes to prevent wheel lockup, skidding, and yawing during braking and other extreme maneuvers. This in turn prevents lane departures (which may result in road departure, side impacts, or head-on crashes), rollovers, and in the case of large trucks, jackknives. Based on all fatal crashes in the US during 1999-2008, Farmer (2010) found ESC reduced fatal crash involvement risk by 33 percent to 20 percent for multiple-vehicle crashes and 49 percent for single-vehicle crashes. The percentage of vehicles with ESC has increased tenfold since the 1998 model year (IIHS, 2010). NHTSA has mandated ESC for light vehicles (passenger cars, multipurpose passenger vehicles, trucks, and buses with a gross vehicle weight rating of 10,000 pounds or less) and is considering a similar mandate for heavy trucks. NHTSA estimates ESC would save 5,300 to 9,600 lives annually once all light vehicles on the road are equipped with ESC. In June 2008, the NHTSA Administrator stated that, "Electronic stability control systems are second only to seat belts in terms of the potential for saving lives and reducing injuries". Widespread use of ESC will strongly support a zero fatality highway system.

Emergency Brake Assist measures the speed and force with which the brake pedal is applied to determine whether the driver is attempting an emergency stop. If the system determines that is the case, it applies additional brake pressure. When Brake Assist technology is used together with anti-lock braking systems (ABS), it results in faster and safer braking. Brake Assist can potentially reduce overall stopping distance by eliminating the delay caused by a common tendency to not brake hard enough or soon enough. These systems were originally found only on high-end luxury cars, but are now more widely available. In terms of the universe of fatal crashes in the US that could potentially be prevented, Farmer (2008) estimated that 3,079 fatal crashes annually are relevant to emergency Brake Assist. In terms of effectiveness, Lind et al. (2003) estimated Brake Assist has the potential to affect 40 percent of multiple vehicle fatalities and 18 percent of off-path fatalities in Sweden, and predicted that by the year 2015, would reduce these fatalities by 20 percent and 9 percent, respectively. Page et al. (2005) estimated would reduce pedestrian fatalities in the order of 10-12 percent. Dr. Clay Gabler (Associate Department Head of Virginia Tech-Wake Forest School of Biomedical Engineering and Sciences) sites crash effectiveness of pre-crash braking in the 50 percent range – approximately same as all other crash avoidance technologies combined (personal communication, March 15, 2010).

CRASHWORTHINESS

Crashworthiness of passenger vehicles will continue to be a vital component of fatality prevention efforts, as long as crash avoidance approaches fail to eradicate motor vehicle collisions -- especially those occurring at moderate and high speeds. The following vehicle crashworthiness measures support a comprehensive national strategy to help achieve zero traffic deaths.

Adaptive Occupant Restraints adjust the force of airbags and other restraint systems to the conditions of a crash. Unlike conventional seatbelts and airbags, which are designed to accommodate several occupant/crash scenarios and lack the capability of varying their output during impact events, adaptive occupant restraints can be activated for limited or full restraint depending on the situation. The determination of deployment force is based on numerous factors, including crash severity, type and sort of crash, the occupants' mass, size, and position. Such advanced restraint systems have been estimated to reduce the probability of a severe head or chest injury by about 15 percent (Clute, 2001).

Ejection Mitigation measures will reduce occupant fatalities by containing drivers and passengers within vehicles that rollover or otherwise subjected to extreme forces. In 2008, approximately 20 percent of fatality injured passenger car occupants and 37 percent of those killed in light trucks were ejected (NHTSA, 2010). Side window ejections comprise about 60 percent of ejection fatalities. Measures under consideration to reduce the risk of occupant ejection include side curtain airbags, advanced window glazing, and roof-mounted inflatable tubular structures.

Improved Side Impact Protection is needed to reduce the risk of occupant fatalities in side impact crashes. All passenger cars in the US are required to comply with FMVSS No. 214, a safety standard that mandates a minimum level of side crash protection for near side occupants. However, no such standard exists for far side occupants, even though far side occupants are exposed to significant risk. Gabler et al. (2005) examined over 4,500 far side struck passenger vehicles to evaluate the risk of injury from far side impacts. As a fraction of all occupants who experienced a side impact, far side struck occupants accounted for 43 percent of the seriously injured persons and 30 percent of the harm. Protection of the head and chest are priorities for countermeasure development.

Compatibility Between Roadside Hardware and Vehicle Designs should be the focus of joint efforts by both automotive and highway engineers. In 2005, there were 1,189 fatal crashes into guardrails. Gabler and Gabauer (2007) found side impacts of passenger cars into guardrails were substantially more dangerous than frontal impacts. The occupant of a car which side impacts a guardrail has a 30 percent higher probability of being fatally injured than car occupants in frontal impacts. Particularly dangerous are impacts with the end treatments of guardrail, which are designed to breakaway under the loads which are typical of frontal impacts. Because the side of a vehicle has little structure to protect an occupant, side impacts to guardrail ends can be especially dangerous. Guardrail end treatments also appear to be a potential rollover factor. Approximately 1 in 3 fatal passenger vehicle-guardrail crashes which resulted in a rollover struck guardrail ends.

External airbags should be further researched and developed as an added crashworthiness feature. Radar or other sensors being added for various crash avoidance technologies would trigger external airbags a few milliseconds before serious crashes to create more crush space and deceleration time. Much of the potential safety benefit from external airbags is associated with

pedestrians and other vulnerable road users. This technology also can protect occupants of small cars in collisions with larger vehicles.

Pop-up Bonnet Systems increase the ‘crush’ space between the pedestrian’s head and torso in pedestrian-vehicle crashes. When contact between the front bumper and a pedestrian occurs, the system pushes the bonnet upward creating a larger gap between the bonnet and engine, thus reducing the risk of severe head injury. Although the effectiveness of this technology in reducing pedestrian fatalities is unknown, and further research is needed, pop-up bonnet systems seem to offer promise for reducing pedestrian fatalities.

Crashworthiness of Low-Speed Vehicles is a growing safety concern due to increased popularity of neighborhood electric vehicles in communities with large retirement populations. Although basic safety features are required, such as headlights, taillights, stoplights, turn signals, rearview mirrors, windshields, and safety belts, these vehicles fall far short of crashworthiness standards applied to motor vehicles. Doors, for example, are optional. The combination of small vehicle size, sub-optimal safety performance, and frailty associated with older vehicle occupants introduces opportunities for fatal crashes that might otherwise be less severe.

IMPROVING DRIVER AWARENESS

Forward Collision Warning Systems (FCWS) monitor the roadway in front of the host vehicle and warn the driver of potential collision risks. FCWS are largely radar-based systems that interpret radar signals to determine distance and relative speed between the host vehicle and the object/vehicle ahead of it. FCWS produce audible and/or visual alerts when a vehicle is determined to be too close to another vehicle or object. As the time interval decreases, warnings become progressively more urgent. In addition to alerting drivers, FCWS are capable of initiating braking if the driver does not respond rapidly or with sufficient force. However, FCWS currently available in the US generally do not take any automatic braking action. FCWS are typically integrated with Adaptive Cruise Control (ACC) systems, which can be programmed by the driver to automatically maintain a minimum following interval to a lead vehicle in the same travel lane.

Farmer (2008) estimated that between 6,310 and 7,166 fatal crashes annually are relevant to forward collision warning/mitigation systems. Due to the relatively limited deployment to date, estimates of the effectiveness of FCWS in reducing fatal crashes are largely predictions rather than in-service evaluations. And these estimates vary widely. For example, Regan et al. (2002) estimated that approximately 30 percent of fatal crashes could become serious injury crashes with FCWS, while McKeever (1998) predicted that a 1.7 percent reduction in fatal crashes could be expected with FCWS. Somewhat more robust estimates of effectiveness for total crashes – not fatal crashes -- are available for large trucks, for which FCWS have been more systematically studied.

Lane Departure Warning Systems (LDWS) provide audible, tactile, and/or visual alerts to drivers that inadvertently stray across lane markings or are otherwise detected to be drifting off the road. LDWS warn drivers that they are beginning to drift or out of their lane. They function like an in-vehicle rumble strip. LDWSs are most applicable to "drift" lane departures due to driver inattention, drowsiness, or other impairment. LDWS do not address loss-of-control-related lane departures following directional instability. They also do not prevent rollovers due to excessive speed on curves or similar dynamic mishaps. Closely related to LDWS are ***Lane Keeping Assistance systems*** (LKAS), which actively support the driver in maintaining lane position at high speeds on relatively straight roads. LDWS may help prevent rollover crashes, which are potentially serious, and often fatal. Currently available LDWS are forward looking, vision-based systems that interpret video images to estimate vehicle state (lateral position, lateral velocity, etc.) and roadway alignment (lane width, road curvature, etc.). Unfavorable roadway conditions (e.g., missing or degraded markings, wet roads) can interfere with system functionality and hamper proper performance. More advanced versions incorporate visual imaging, GPS, and radar sensors to assess vehicle speed relative to upcoming horizontal curves and roadside obstacles. When lane markings are not present, some advanced systems search for longitudinal clues to indicate lane position. Most LDWS do not take automatic action to avoid a lane departure. Systems with intervention capabilities can either provide automatic braking or corrective steering if driver response is deemed inadequate.

FHWA (1998) estimated that road departure avoidance systems are relevant to approximately 38 percent of all road departure crashes, and Farmer (2008) estimated the annual number of fatal crashes relevant to lane departure warning/prevention systems was between 6,505 and 10,345. In terms of potential effectiveness, McKeever (1998) predicted an 8.4 percent reduction in fatalities could be expected with road departure avoidance systems. Regan et al. (2002) estimated that LDWS could lead to up to 30 percent of fatal crashes becoming serious injury crashes. Lind et al. (2003) estimated that LDWS and LKAS have the potential to affect 40 percent of run-off-road fatalities in Sweden, and predicted that by the year 2015, these systems would reduce run-off-road fatalities by 20 percent. Jermakian (2010b) estimated LDWS on large trucks could prevent or mitigate 10,000 crashes and 247 fatal crashes (about seven percent of truck-related fatal crashes).

Side Object Detection Systems (SODS) warn drivers of objects (usually other vehicles) located in blind spots on the sides of the vehicle. SODS monitor the lateral field using radar, laser, lidar, computer vision, or ultrasonic scanning technology. They function as a supplement to mirrors to aid lane changes, especially those to the right. About three-quarters of truck side impacts associated with a lane change/merge occur when the truck is moving to the right. This reflects the limitations of truck mirrors and the large blind areas on the right sides of tractor-semitrailers. Although lane-change crashes generally produce property damage only and are not generally associated with fatal injuries, heavy vehicles involved in lane-change crashes can cause significant harm to passenger vehicle occupants and nonmotorists.

SODS can provide potential crash avoidance benefits across vehicle types. Large trucks and transit buses have been the principal focus of early SODS deployment and evaluation efforts, because of their relatively large blind spots and associated crash potential (Paine, 2003a). Some deployment experiences indicate that more work is needed to improve the performance and design of these systems. For example, in a field evaluation of the first commercially available side collision warning system for transit buses, bus operators did not find the system usable in its current design, particularly with regard to the quality and frequency of visual and audible alerts (Rephlo et al., 2008). Farmer (2008) estimated that 428 fatal crashes annually are relevant to blind spot detection/warning systems. Estimates of the effectiveness of SODS in reducing fatal crashes are largely projections due to the relatively limited deployment to date, and these estimates vary widely. McKeever (1998) predicted full deployment of lane changing systems would produce a 0.2% reduction in fatalities. Lind et al. (2003) estimated lane change assistance technology has the potential to affect 20 percent of run-off-road fatalities in Sweden, and predicted that by the year 2015, these systems would reduce run-off road fatalities by 10 percent.

Backing Collision Warning Systems, also known as Rear-Object Detection Systems (RODS), use proximity sensing technology to detect objects -- including pedestrians – that are behind backing vehicles, and warn drivers if the vehicles is deemed too close to these objects. These technologies incorporate a range of proximity detection sensors (ultrasound, radar or laser-based) or video cameras (rear-view displays). NHTSA analysis indicates more than 400 non-occupant deaths occur in backing crashes each year. Given that driver attention in backing situations is generally focused away from the dashboard, warnings issued by reverse collision warning systems are typically auditory. The primary types of fatal crashes addressed by reverse collision warning systems involve motor vehicles backing into pedestrians. Glazduri (2005) investigated six commercially available reverse proximity sensor systems and found the effectiveness in reducing pedestrian collisions was highly dependent on vehicle speed. All systems resulted in the avoidance 95 percent of test collisions when speeds were between 3-4 km/h (1.9 – 2.5 mph).

Integrated Vehicle-Based Safety System (IVBSS):

This white paper addresses onboard safety technologies primarily as individual, separate systems. Most system R&D to date has proceeded in that manner. Developers recognize, however, that multiple systems on vehicles should be compatible and integrated. In a rapidly developing, imminent crash situation, systems must act in a prioritized manner, and drivers should be able to respond correctly and decisively. The U.S. DOT-funded Integrated Vehicle-Based Safety System (IVBSS) initiative is intended to design such an orchestrated, multi-element system. A current five-year, \$34M program has developed, configured, and field tested the IVBSS concept on 16 passenger vehicles and 10 combination-unit trucks. The current IVBSS suite includes three countermeasures, all designated in this report as priorities for large trucks:

- Forward Collision Warning System (FCWS)
- Lane Change/Merge Warning (also known as Side Object Detection Systems or SODS)

- Lateral Drift Warning (also known as Lane Departure Warning Systems or LDWS).



IVBSS subsystems are designed with standardized displays, controls, data storage units, data download protocols, and analysis software. Driver-vehicle interfaces are designed in consistent and similar ways to reduce driver errors and maximize *positive driver performance transfer* across different subsystems. Plus, there are engineering economies from combining system sensors, vehicle network interfaces, and processing units. In the event of simultaneous or conflicting crash threats, IVBSS “arbitrates” among various inputs and provides the clearest and most pressing warning to the driver. The IVBSS field tests assessed system safety benefits, driver acceptance, ease of use, and user willingness to purchase (marketability). The small size of the field tests did not permit reliable crash reduction estimates, but most drivers found the system to be helpful and would recommend it to other drivers. The current IVBSS configuration primarily addresses rear-end, lane change/merge, road departure, and head-on crashes (those involving unintentional lane departures). Together, these crash types represent about 60 percent of all car and truck road fatalities – more than 20,000 per year.

MODIFYING DRIVER BEHAVIOR

Alcohol Detection & Interlock Throughout the history of automobile travel, alcohol impaired driving has been a principal contributing factor in fatal motor vehicle crashes. In 2008, an estimated 11,773 people were killed in US alcohol impairment-related driving crashes (NHTSA,2009B). About one-third of all US traffic deaths occur in crashes in which at least one driver had a blood alcohol concentration (BAC) at or above 0.08 g/dL (IIHS, 2010A). Attainment of a highway system approaching zero fatalities will require substantial emphasis on vehicle-based technology that prevents alcohol impaired driving. Alcohol ignition interlocks can be effective in reducing recidivism among persons convicted of alcohol-impaired driving. Beck et al. (1999) found multiple offenders participating in an interlock program reduced the risk of committing alcohol-related traffic violations by nearly 65 percent. Alcohol ignition interlocks are in-vehicle device that prevent vehicles from starting until the operator provides a BAC test below a set level, usually .02% (20 mg/dl) to .04%. Interlocks currently are installed as a legal sanction or a requirement to resume driving privileges for a subset of individuals convicted of impaired driving, but the concept could dramatically reduce the incidence of alcohol impaired driving if applied to all motor vehicles.

In order for the present interlock technology to be applied as a standard vehicle feature, substantial advances would have to be made to the driver interface (e.g., avoid the need for drivers to blow into a tube; incorporate technology into the vehicle). Potential technologies have been identified that could detect alcohol from air samples through the driver’s skin using tissue spectroscopy, from emissions through the skin, from eye movements, and from driving performance. Additional technology reviews are being conducted to identify promising

alternatives, and research is being undertaken to evaluate their potential. It has been estimated that almost 9,000 traffic deaths could be prevented every year if alcohol detection devices were used in all vehicles (Driver Alcohol Detection System for Safety, 2010). Rapid advancement and subsequent widespread adoption of alcohol ignition interlock technology must be a cornerstone of vehicle-based efforts to achieve a highway system that produces zero traffic fatalities.

Driver Alertness Monitoring Drivers with diminished levels of vigilance and alertness pose a serious crash risk. Fatigue is a principal and prominent form of diminished driver alertness, which contributes to substantial numbers of fatal motor vehicle crashes. Analysis of 1989-93 FARS data by Knipling and Wang (2004) estimated drowsiness/fatigue was cited as a factor in an annual average of 1,357 fatal crashes resulting in 1,544 fatalities. Driver alertness monitoring systems monitor the performance of the driver, and provide visual, auditory or haptic alerts if the driver is determined to be impaired or inattentive. Beyond providing warnings, these systems can exert more forceful intervention by taking control of the vehicle and bringing it to a stop. Various technology solutions have been developed, and continue to be refined, including video-based systems linked with computer vision algorithms to measure slow eyelid closure and other characterizations of a driver's level of vigilance, including face orientation and pupil movement. Widespread deployment of in-vehicle systems to actively monitor a driver's level of vigilance is essential to preventing fatigue-related crashes.

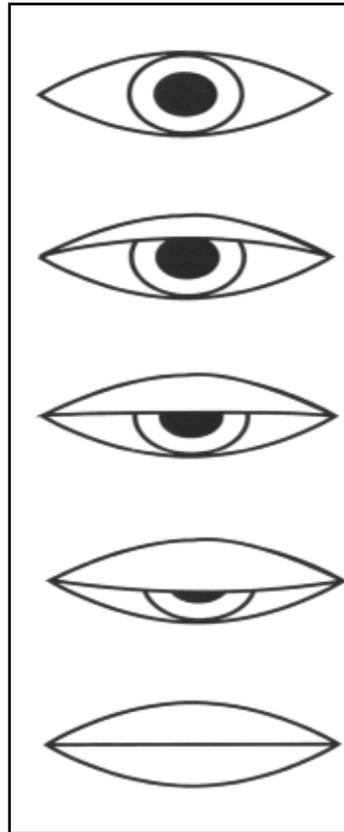


Figure 2. PERCLOS, measured by observing the degree of eyelid closure over a period of time.

As noted above, LDWS sensors can measure lateral lane position and thus track changes in drivers' lane-keeping performance, which is reflective of driving fitness. Deteriorating performance is one indicator of drowsiness; another is eyelid droop. PERCLOS, short for "Percent Closure" (Wierwille et al., 1994) is a quantitative measure of eyelid droop that has been well-validated as a measure of driver alertness (Figure 2). As eyelid droop worsens, other measures of driving performance also deteriorate (Dinges et al., 1998). A potential vehicle-based countermeasure to asleep-at-wheel crashes is a system which unobtrusively monitors both driver PERCLOS (or some similar eye measure of alertness) and driving performance (e.g., standard deviation of lane position) to provide drivers with real-time as well as post-trip summary information on their overall level of alertness while driving. Although it appears that no tested, reliable, and affordable system currently exists, this countermeasure concept is both technologically and operationally feasible.

Due to limited deployment and real-world experience, estimates of the effectiveness of these systems in reducing fatal crashes are predictions. Rumar, et al. (1999) suggested that driver and

vehicle monitoring systems have the potential to reduce fatal and injury crashes on motorways by 10 to 15 percent. Yoshimoto et al. (1996) predicted that a drowsiness monitoring system could result in 330 fewer fatalities per year in Japan.

Automatic Speed Control High travel speeds increase the frequency and severity of crashes. Crash energy increases by the square of vehicle impact speed change. Speed increases the distance a vehicle travels from the time a driver detects an emergency to the time the driver reacts, as well as the distance needed to stop once an emergency is perceived. In 2008, speeding was a factor in 31 percent of motor vehicle crash deaths, killing 11,674 people. Attainment of zero fatalities will require extensive measures to discourage and prevent speeding. Intelligent Speed Adaptation (ISA) is an in-vehicle speed control system that uses satellite and digital map technology to monitor vehicle speed and the speed limit, and implement some type of predetermined action when the vehicle is detected to be exceeding the speed limit. The action can either be a warning, or an intervention system where the driving systems of the vehicle are controlled automatically to reduce the vehicle's speed. ISA is in fact a collective term for three basic types of speed control systems:

- The least aggressive form of ISA warns the driver (visibly and/or audibly) that the speed limit is being exceeded. The driver him/herself decides whether or not to slow down. This is an informative or advisory system.
- A more aggressive form of ISA increases the pressure on the accelerator pedal when the speed limit is exceeded (the 'active accelerator'). Maintaining the same speed is possible, but less comfortable because of the counter pressure.
- The most aggressive form of ISA limits the speed automatically if the speed limit is exceeded. It is possible to make this system mandatory or voluntary. In the latter case, drivers may choose to switch the system on or off.

Reliable estimates of the effectiveness of ISA in reducing fatal crashes are not available due to limited deployment to date. However, predicted effects are quite large. The UK External Vehicle Speed Control (EVSC) project has made a prediction of the crash savings with intelligent speed adaptation (ISA), and estimated the costs and benefits of national implementation (Carsten and Tate, 2005). The best prediction of crash reduction was that fitting all vehicles with a simple mandatory system, with which it would be impossible for vehicles to exceed the speed limit, would save 37 percent of fatal crashes. A more complex version of the mandatory system, including a capability to respond to current network and weather conditions, would result in a reduction of 59 percent in fatal crashes.

A less technologically advanced approach to reducing excessive vehicle speeds involves the use of speed limiters or speed governors. This technology is already in limited use on a voluntary basis on large trucks. However, widespread, mandatory use of speed governors could help reduce fatal crashes on interstates and other high-speed roads. Large trucks with diesel engines have speed-limiting capability built into their engine control modules, and many trucking companies

use this to limit how fast their trucks can travel. Speed governors restrict the engine's fuel input. Speed retarders continuously dissipate energy, typically using a magnetic field in the vehicles transmission that creates a braking force in the drive system. The US lags behind Europe, Australia, and Japan in requiring speed limiters on large trucks. In 2002 the EU adopted a requirement mandating installation of speed limitation devices for all vehicles carrying 8 or more passengers and all vehicles weighing more than 3.5 metric tons. Under the regulation, these vehicles must have speed limiters set not to exceed 90 km/h (56 mph). An aggressive zero-fatality policy should include mandatory use of existing speed governor technology on large trucks, and extend this speed limiting technology to other vehicles.

Electronic Driver License technology is intended to address unlicensed vehicle operation, which is a longstanding, chronic safety problem associated with fatal crashes. Drivers with invalid licenses, no licenses, or unknown license status are involved in one of every five fatal crashes, which amounts to nearly 7,700 fatal crashes annually (AAA Safety Foundation, 2008). Likewise, about 25 percent of motorcycle drivers involved in fatal crashes do not have a valid motorcycle license. Electronic driver licenses is a smart card containing information about the driver and any driving restrictions, and can be used to decrease unlicensed vehicle operation. The license must be inserted into the vehicle to unlock the ignition system, and can be used as the ignition key. Only valid licenses which have been registered to a particular vehicle will unlock the ignition. Smart cards are not legal licenses, but can be used to restrict and/or monitor vehicle use. Goldberg (2005) estimated that throughout Europe and the US, between 5,000-10,000 fatalities could be prevented through adoption of electronic driver licenses. Lind, et al. (2003) estimated that systems that restrict some individuals from operating vehicles (electronic licenses and alcohol interlocks) have the 'verified' potential (based on other studies) to reduce all road fatalities by 1 percent, while the 'full' potential (an optimistic estimate based on full deployment) is 5 percent.

Controlling Driver Distraction is a major emphasis of USDOT due to the explosion of in-vehicle entertainment and communication technologies with high potential for creating driver distractions. Even when in-vehicle electronic devices are operated hands-free, significant changes in driver behavior may result due to the cognitive distraction. For example, Lee et al. (2001) found that driver use of a hands-free speech-based e-mail system was associated with a 30 percent (310 msec) increase in driver reaction time in car following situations. Although efforts to reduce distracted driving largely emphasize passage of laws banning driver use of hand-held devices, and enforcement of these laws, additional vehicle-based measures should be included as part of a national effort to reduce distracted driving. Barring development of in-vehicle technology that prevents driver use of hand-held mobile devices, the primary vehicle-based countermeasure seems to be systems that warn drivers when they are not paying attention to the road, as discussed elsewhere in this White Paper. These systems have the promise of preventing many kinds of distracted driving crashes, not just those associated with use of electronic devices.

CONSPICUITY & VISIBILITY

Intelligent Lighting Systems are intended to improve the safety and comfort of nighttime driving through automatic control of headlamp beam patterns according to driving conditions (e.g., vehicle speed, steering) and the driving environment around the vehicle (e.g., weather conditions, presence of other vehicles). Advanced automotive lighting technologies that offer safety potential or promise include:

- Automated Headlights, which automatically activate headlights when low ambient levels of luminance are detected;
- Auto-dimming Headlights, which automatically dim high-beam headlights when oncoming vehicles are detected; and
- Speed Adapting Headlights, which adjust the pattern of luminance to suit vehicle speed.

The primary types of fatal crashes potentially addressed by intelligent lighting systems involve motor vehicles striking pedestrians and bicyclists. Due to relatively limited deployment to date, estimates of their effectiveness in reducing crashes are predictions rather than in-service evaluations, and do not include estimates specifically for fatal crashes. The predicted effects of adaptive headlights in Germany were reported by eSafety Forum (2005). Assuming 70 percent penetration of the passenger vehicle fleet, 25 percent of crashes involving vulnerable road users in low visibility conditions would be affected leading to a 17.5 percent reduction in these crashes. Lind et al. (2003) developed crash reduction estimates for adaptive headlights combined with night vision enhancement systems, and predicted the potential to affect 30 percent of pedestrian fatalities and 15 percent of bicyclist fatalities in Sweden.

Daytime Running Lights (DRLs) are among the least expensive vehicle features with potential to reduce fatal motor vehicle crashes. DRLs provide a constant beam, typically about 80 percent of the headlight's normal luminance, whenever the vehicle is operational. Laws in Canada and many European countries require vehicles to operate with lights on during the daytime. DRLs increase vehicle conspicuity and make it easier to detect approaching vehicles from farther away, thus preventing daytime crashes. In a review of 24 studies by Koornstra et al. (1997), the authors concluded DRLs have the potential to prevent 25 percent of fatal daytime multiple vehicle crashes, and 28 percent of daytime pedestrian fatalities. Australian estimates show that DRLs may be able to reduce serious injury and fatal crashes by approximately 3 to 15 percent (Cairney and Styles, 2003; Paine, 2003a).

Night Vision Enhancement Although nighttime crashes are highly correlated with alcohol impairment and driver fatigue, fatal crashes are overrepresented during periods of diminished light levels independent of alcohol consumption and other risk factors (Tsimhoni and Green, 2002). In addition, age-related visual degradation can increase the risk of nighttime crashes. There are two basic categories of night vision systems, passive and active, each offering advantages and disadvantages. Active systems use infrared light to illuminate the road ahead and collect tiny amounts of light; passive systems capture the upper portion of the infrared light spectrum, which is emitted as heat by objects such as warm bodies. Night vision enhancement is

currently offered as optional equipment on a limited number of premium vehicles. Cadillac first introduced passive night vision in 2000 as an optional feature on Deville models, but discontinued this option in 2004. In 2002 Toyota introduced the first production automotive active night vision system on some premium models. This system uses headlight projectors emitting near infrared light and a CCD camera to capture reflected radiation. The signal is then processed by computer which projects an image on the lower section of the windshield. Other night vision systems are offered by Audi, BMW, Honda, and Mercedes.

Night vision systems can substantially increase the distance at which drivers can see objects at night. For example, Cadillac's thermal imaging system was reported to increase the viewing distance from about 300 feet with standard headlights, to up to 1,500 feet. In terms of potential effectiveness, Lind et al. (2003) estimated vision enhancement systems that include adaptive headlights have the potential to affect 30 percent of pedestrian fatalities and 15 percent of bicyclist fatalities in Sweden. Estimates of reductions expected with vision enhancement systems in Germany were reported by eSafety Forum (2005). Assuming 70 percent penetration of the passenger vehicle fleet, it was expected that 25 percent of vulnerable road user crashes occurring in low visibility would be affected, leading to a 17.5 percent reduction in these crashes. Despite potential benefits, there is concern that night vision could be a source of driver distraction.

VEHICLE-TO-VEHICLE & VEHICLE-TO-INFRASTRUCTURE TECHNOLOGIES

Aided by continued advances in wireless communications, vehicle-to-vehicle and vehicle-to-infrastructure technologies provide communication between vehicles, and with roadway infrastructure, to alert drivers to unexpected road conditions. These systems involve installation of Dedicated Short-Range Communications devices at intersections, on roadsides, and within vehicles. Cooperative collision warning systems target the prevention of multi-vehicle collisions, while vehicle-to-infrastructure applications address single-vehicle crashes and collisions with nonmotorists. The following vehicle-to-vehicle and vehicle-to-infrastructure applications hold promise for reducing fatal crashes:

Intersection Collision Avoidance Systems are being developed to detect and help avoid crossing-path crashes at intersections. They provide information to the driver to increase situational awareness and provide immediate hazard warnings to forestall potential collisions that could be caused by driver distraction, reduced ability to judge gaps in oncoming traffic, speed, or other factors. Intersection collision avoidance systems with promise for reducing fatal crashes include the following:

- ***Intersection Collision Warning*** - warns drivers when a collision at an intersection is probable
- ***Left Turn Assistant*** - provides information to drivers about oncoming traffic to help them make left turns at signalized intersections without left turn arrows
- ***Pedestrian Crossing Information*** – alerts drivers if there is danger of a collision with a pedestrian in a designated crossing

- ***Stop Sign Violation Warning*** - warns drivers if the distance to the prescribed stopping location and the speed of the vehicle indicate a relatively high level of braking is required to stop
- ***Traffic Signal Violation Warning*** - warns drivers to stop at the prescribed location if the traffic signal indicates a stop and it is predicted that the driver will be in violation

Road Condition Warning Systems are being developed to detect potential roadway-related crash situations with the goal of helping drivers avoid crashes through strategic warning messages. Although effectiveness of these technological approaches to crash avoidance are unknown, road condition warning systems with promise for reducing fatal crashes include the following:

- ***Curve Speed Warning*** - aids drivers in negotiating curves at appropriate speeds using information communicated from roadside beacons and monitoring vehicle speed
- ***Wrong Way Driver Warning*** - warns drivers that a vehicle is driving or about to drive against the flow of traffic

LARGE TRUCK CRASH COUNTERMEASURES

There are more than half a million registered U.S. trucking companies, and nearly 70 percent of all consumer, commercial, and industrial goods are delivered by trucks. In recent decades, commercial vehicle mileage has increased faster than the population, the economy, and general vehicle mileage. These trends are expected to continue in the decades ahead; the U.S. DOT predicts that truck freight will double by 2035.

THE LARGE TRUCK SAFETY PICTURE

Large trucks are defined as those with gross vehicle weight ratings (GVWR) of greater than 10,000 pounds; 80-90 percent of their crashes involve heavy trucks with GVWRs of greater than 26,000 pounds. The two major large truck configurations are combination-unit trucks (typically tractor-semitrailers) and single-unit trucks (also called straight trucks). Combination-unit trucks (CTs) are typically in long-haul service whereas most single-unit trucks (STs) are short-haul. In 2008, CTs had more than five times the average annual VMT of STs. Greater mileage means greater exposure to crash risk. In 2008, CTs were 25 percent of registered trucks, compiled 63 percent of truck VMT, and were 74 percent of trucks involved in fatal crashes (Craft, 2010).

In all, 4,229 people were killed in 3,733 fatal crashes involving large trucks in 2008. This was 11 percent of the 37,261 total traffic crash fatalities for the year. Truck crash fatalities in 2008 were down 12 percent from 2007 while truck VMT was roughly steady. The number of trucks involved in fatal crashes followed a parallel decline. Thus, from 2007 to 2008 the large truck fatal crash involvement rate also dropped 12 percent, from 2.04 to 1.79 per 100 Million VMT. This was the most impressive single year improvement in a decades-long decline in truck fatal crash rate. Figure 3 shows declines in large truck and passenger vehicle fatal crash rates from 1975 through 2008. Although the rates are converging, the 2008 large truck fatal crash rate was still 23 percent higher than the passenger car rate. Most impressive in Figure 3, however, is the

long-term declines in both rates. From its peak in 1979, the large truck fatal crash rate has declined by 68 percent to the 2008 rate.

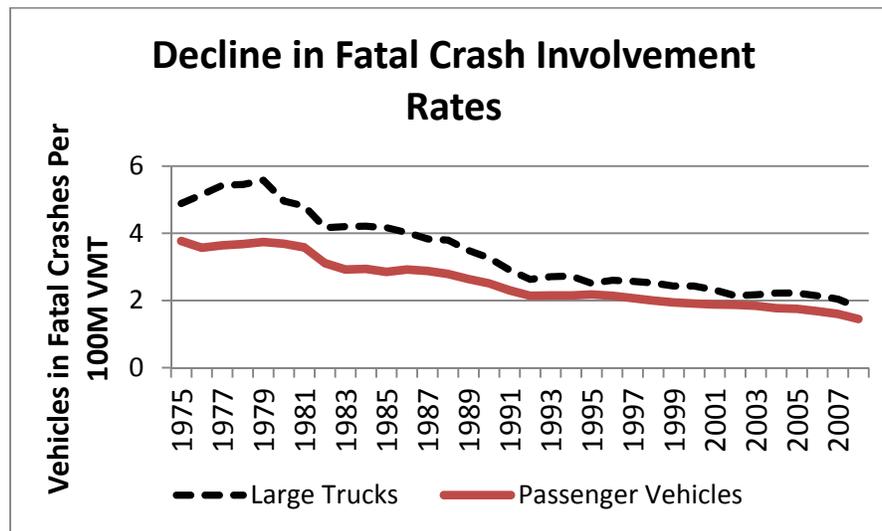


Figure 3. Trends of fatal crash vehicle involvement rates (per 100M VMT) for large trucks and passenger vehicles (cars, vans, and light trucks), 1975 to 2008. Source: FMCSA (2010)

Although fatal crash rates are persistently higher for large trucks than for passenger vehicles, the opposite is true for less severe crashes. For example, the 2008 large truck injury crash involvement rate was 71 percent lower than the passenger car rate. One safety advantage trucks have over cars is the fact that a much larger percentage of their mileage is on Interstates and other divided highways with relatively low crash risks.

Truck crashes tend to be more severe than those involving passenger vehicles. In 2008, 1.0 percent of large truck crashes resulted in a fatality, versus 0.5 percent for passenger vehicle crashes. The majority of fatalities and injuries from large truck crashes occur to persons outside the truck. These are mostly occupants of other vehicles, but include pedestrians and bicyclists. Roughly two-thirds of all harm (human and material) in large truck crashes occurs outside the truck (Wang et al., 1999). Of the 4,229 fatalities in 2008 resulting from crashes involving large trucks, 75 percent were occupants of another vehicle, 9 percent were pedestrians or bicyclists, and 16 percent were large truck occupants.

Interstate buses (motor coaches) are also considered to be commercial vehicles and are regulated in similar ways to large trucks. The two primary motor coach operations types are charter and scheduled service (intercity). In 2008 there were 151,000 registered motor coaches and 52 fatalities in their crashes. Though motor coach crashes are highly publicized when there are multiple victims, their overall crash and fatal crash rates are low.

The human and economic cost of large truck crashes is significant. Zaloshnja & Miller (2007) calculated the average comprehensive cost of a police-reported crash involving a large truck to

be \$91,112 in 2005 dollars. These costs encompass tangible economic human and material consequences, including medical and emergency services, property damage, and lost productivity. They also include the monetized value of pain, suffering, and quality-of-life reduction. An earlier study (Zaloshnja and Miller, 2002) estimated the annual total comprehensive U.S. costs for large truck crashes to be \$20 billion annually in 2000 dollars.

Truck drivers make many of the same kinds of driving errors as do light vehicle drivers, but their crashes are less likely to involve extreme unsafe driving acts such as reckless driving and alcohol use (Knipling, 2009). Among all crashes involving a truck and a lighter vehicle, principal fault seems to be more-or-less evenly divided (Council et al., 2003). For more severe crashes, however, principal fault (i.e., the critical driver error or other failure precipitating the crash) shifts strongly toward light vehicle drivers. In the FMCSA/NHTSA Large Truck Crash Causation Study (LTCCS) involving serious injury crashes, trucks were at-fault (assigned the “Critical Reason”) in 40 percent of their multi-vehicle crash involvements. This percentage varied greatly depending on crash severity, as follows:

- “B” (non-incapacitating injury): truck 46 percent, other vehicle 54 percent
- “A” (incapacitating injury): truck 37 percent, other vehicle 63 percent
- “K” (fatal injury): truck 23 percent, other vehicle 77 percent.

Although many serious large truck crashes are precipitated by the errors of other drivers, most vehicle-based truck crash countermeasures are designed to improve the safety performance of trucks and/or to intervene to prevent crashes caused by truck driver errors. Motor carriers have the greatest economic incentive to reduce those crashes resulting in high financial liability. Reducing truck-striking rear-end crashes, for example, is a top priority for fleets even though only about 5 percent of truck-light vehicle fatalities result from this crash scenario (Knipling, 2009; Craft, 2010).

THE IMPORTANCE OF LARGE TRUCKS IN VEHICLE TECHNOLOGY ADVANCEMENT

Large truck crashes are important in their own right because of their human and economic consequences – 4,229 fatalities in 2008. Another reason for their importance is the *opportunity* they provide for the advancement of vehicle-based and other safety technologies. Truck fleets are often the ideal testbed for the testing and implementation of advanced countermeasures. This is because of operational setting in which truck driving occurs, and because of the inherently superior economic prospects for safety technologies in the long-haul trucking environment.

Operational setting. Truck driving is supervised. Truck transport occurs within a government regulatory and enforcement regime which prescribes driver, vehicle, and route characteristics. More importantly, successful trucking companies closely monitor and manage their vehicles, drivers, and operations. Thus, they can be ideal testbeds for many safety interventions. Trucks are individually configured at the factory, so they can be built to buyer or researcher specifications. Most retrofit devices are also more easily installed on trucks than on light vehicles. Many large and safety-progressive trucking companies electronically monitor driving

using onboard recorders. These onboard recorders can provide rich data on driving, incidents, and vehicle performance. Data can be downloaded at carrier terminals or transmitted wirelessly through mobile communications. There can even be wireless data links to roadside inspection and enforcement. Finally, most fleet drivers are conscientious professionals committed to safety and supportive of potential improvements.

Superior economic prospects. Economic prospects for new safety systems are often inherently superior for long-haul trucks than for lighter vehicles. Ironically, this is because long-haul trucks are inherently *high-risk vehicles*, even though they have lower overall crash rates per VMT than light vehicles, and even though truck drivers generally engage in fewer driving misbehaviors (Knippling, 2009). The elevated crash risk of long-haul trucks comes from the high average severity of truck crashes and trucks' high annual and lifetime mileage exposures.

Average human and economic harm in CT crashes is at least twice those of light vehicle crashes (Zaloshnja and Miller, 2007; Wang et al., 1999). More importantly, CTs have very high annual mileage exposure. In 2008, average VMTs for different vehicle types were 11,432 for light vehicles, 12,362 for STs, and 64,764 for CTs. Plus, trucks have somewhat longer average operational lives than do light vehicles. These factors drive up life cycle crash costs for CTs to levels far above those of other vehicles. One direct comparison (Wang et al., 1999) found CT life cycle costs (all crashes regardless of fault and inclusive of all crash consequences) to be about five times those of STs, light trucks/vans, passenger cars, and motorcycles. The life cycle crash costs of *one* CT were estimated to be about \$70,000 in economic loss alone, and \$162,000 in comprehensive costs including monetized values of pain, suffering, and quality-of-life reduction.

These same differences in CT, ST, and passenger vehicle crash experience are seen in annual crash fatality statistics. Table 2 shows 2008 fatal crash involvement *rates* (per 100M VMT) and *likelihoods* (per million registered vehicles) for these three vehicle types. The CT fatal crash rate is 1.4 times that of STs and 1.3 times that of passenger vehicles. The big difference, though, is in fatal crash likelihood per one million vehicles. Here, the CT value of 1,253 fatal crash involvements per one million vehicles is 7.2 times that of STs and 7.6 times that of passenger vehicles. For a vehicle-based crash countermeasure that operate continuously, the most-pertinent metric for assessing benefits is the likelihood it will be activated to prevent a crash.

Table 2. 2008 fatal crash involvement rates and likelihoods for three vehicle types.

Statistic:	Vehicle Type:	CTs	STs	PVs
Fatal Crash Involvement Rate Per 100M VMT		1.94	1.40	1.45
Rate Ratio: CT to Other Vehicle Type			1.4×	1.3×
Fatal Crash Involvement Likelihood Per Million Vehicles		1,253	173	165
Likelihood Ratio: CT to Other Vehicle Type			7.2×	7.6×

These statistics show the high relative risks inherent in long-haul CT operations, but also the unique crash prevention *opportunity* associated with improving CT safety. Other factors being equal, a typical safety device installed on a CT and lasting its entire life will have much greater per-unit benefits than the same device installed on other vehicle types. New safety system applications can be cost-beneficial sooner on CTs, and then refined to later be cost-beneficial for other vehicle types. *Total* safety benefits will almost always be greatest for passenger vehicles, but *per-unit* benefits for most similar systems will continue to be greater for CTs. This advantage generally does not apply to STs because their mileage exposures are more like those of passenger vehicles. Thus, for physical, operational, economic, and public safety reasons, CTs can and should be the hosts for the greatest number and variety of vehicle safety systems.

OVERVIEW OF TRUCK SAFETY SYSTEMS

This section revisits some safety systems described for passenger vehicles, but with a focus on their use with large trucks. It also describes various systems principally or exclusively applicable to trucks. The textbox to the right lists specific countermeasures which will be addressed. Those in **bold** are regarded by the authors as having the greatest life-saving potentials. This judgment is based on the size of the crash problem they address and the degree to which their potential effectiveness and positive cost-benefits have been demonstrated. Systems not shown as priority should not be ignored, however, because they may still be safety- and cost-beneficial. There is no limit to the number of large truck crash countermeasures which could be implemented. Instead, each countermeasure should be evaluated based on its practicality and potential cost-benefits. If a system is truly cost-beneficial and does not interfere with other systems, then there is every reason to promote or even mandate its use. Even a “minor” safety system may be a successful one.

Large Truck Crash Countermeasures Addressed

- **Improved Brakes/Shorter Stopping Distances**
 - **Electronic Stability Control (ESC)**
 - Roll Stability Control (RSC)
 - **Forward Collision Warning Systems (FCWS)**
 - **Side-Object Detection Systems (SODS)**
 - Backing Collision Warning Systems
 - **Lane Departure Warning Systems (LDWS)**
 - **Onboard Safety Monitoring (OSBM)**
 - **Driver Alertness Monitoring**
 - Electronic Onboard Recorders (EOBRs)
 - Electronic Data Recorders (EDRs)
 - Vehicle Condition Monitoring (e.g., Tire Pressure)
 - Automated Transmissions
 - Speed Limiters
 - Truck-Specific Navigation Aids
 - Enhanced Trailer Conspicuity
 - Enhanced Trailer Rear Lighting/Warnings
 - Video Mirrors
 - Collision Aggressivity Reductions
 - Larger Trucks
- Bold** = Judged as priorities by the authors.

The implementation paths and prospects for truck safety systems are often fundamentally different than those of both passenger vehicle systems and non-vehicle-based systems. Trucking companies are much more likely to base their safety purchases on prospective monetary cost-benefits than are passenger vehicle owners. In addition, the Federal government generally mandates more vehicle safety systems for trucks than for passenger vehicles because more systems are applicable and because their public benefits per unit cost are more easily demonstrated.

Toward Zero Deaths focuses on fatality reduction, but a more pertinent measure of success for most truck safety systems is *Return on Investment* (ROI) per dollar spent. ROI incorporates device cost into its equation, putting “large” and “small” countermeasures on a common scale. Crash reduction in ROI calculation incorporates all harm, including human fatalities, injuries, and property damage. ROI can also incorporate *non-safety* benefits of systems, which may be considerable for truck devices. For many safety systems, concurrent benefits in efficiency, fuel-economy, and/or sustainability may rival or exceed safety benefits. ROI brings these

considerations into play and portrays promising onboard safety systems to buyers as attractive business investments.

TRUCK BRAKING, HANDLING, & STABILITY

Heavy truck brakes are inherently problematic because of the large size of trucks and the fact that most truck travel is at highway speeds. Loaded CT stopping distances are currently about 60 percent greater than those of a car. Truck stability during braking or other maneuvers is a concern because of trucks' and trailers' relatively high centers of gravity and because articulated vehicles (i.e., tractor semi-trailers) are subject to jackknives. Fortunately, there have been truck dramatic improvements in brake system capabilities and reliability in past decades (Freund et al., 2006; Perrin et al., 2007). Continuing and future improvements include faster initiation of braking and greater vehicle stability during braking through electronic control (Silvani et al., 2009). Brakes no longer have the single task of decelerating the vehicle; rather, they are seen as an integral part of Vehicle Stability Systems (VSS), as will be discussed below.

Improved conventional truck brakes (drum brakes) and new designs, such as disc and hybrid drum-disc brake configurations are improving truck stopping distances considerably (Perrin et al., 2007). Based on this potential, NHTSA has mandated truck stopping distance decreases of about 30 percent for new trucks, beginning in 2011. This will greatly reduce truck-car differences in stopping distance. Air disc brakes, such as shown in Figure 4, have potential advantages over drum brakes, including less needs for adjustment, more precise control and modulation by drivers, far less susceptibility to brake fade due to heat buildup, easier maintenance, and better vehicle stability during hard stopping. Stability benefits are achieved by a more uniform distribution of braking force across multiple wheels.



Figure 4. Truck Air Disc Brake. Courtesy Bendix Corporation.

In the LTCCS, one-third of large trucks braked prior to impact in their crashes (Knipling and Bocanegra, 2008). Theoretically, improved brakes would have some benefit in almost all of these crashes, usually by reducing impact force and sometimes by preventing the crash altogether. NHTSA estimates the annual reductions from its new truck brake performance standard to be 227 fatalities, 300 injuries, and more than \$169 million in property damage costs. Accordingly, improved brakes are designated in this report as a priority safety technology.

Unlike other priority truck safety technologies to be discussed, full penetration of this one (over time as the fleet turns over) is ensured by the NHTSA rule.

One of the most effective and revolutionary vehicle technologies for trucks, and all vehicles, is *electronic stability control* (ESC). NHTSA has mandated ESC for light vehicles and is considering a similar mandate for heavy trucks. Based on a review of crash data, Jermakian (2010b) has estimated that ESC systems on large trucks can prevent or mitigate 31,000 crashes resulting in 439 fatalities (about 11 percent of truck-related fatalities). Woodroffe et al. (2009) examined LTCCS CT loss-of-control crashes and other crash databases to judge probably ESC effectiveness and estimate national benefits from full penetration of the U.S. CT fleet. They estimated crash and human harm reductions to be 4,700 crashes, 126 fatalities, and 5,900 injuries. Economic losses avoided in 2007 dollars would be \$1.74 Billion. A study limited to STs and buses (da Silva et al., 2009) estimated target crash population sizes (not crashes prevented) for these commercial vehicle types. Their estimate was 2,200 annual ST crashes (1.5 percent of the total) and 1,000 bus crashes (1 percent of the total). Although there is a wide discrepancy between the Jermakian estimate and the combined estimates of the other two authors, there is no doubt that ESC is a priority technology for large truck crash reduction.

Compared to ESC, truck Roll Stability Control (RSC) is a relatively simple crash avoidance technology. RSC monitors lateral forces within a vehicle (i.e., centrifugal forces in a curve), combines it with vehicle data (e.g., center-of-gravity height), and predicts imminent rollover risk. When excessive lateral forces are detected, RSC automatically slows the truck, usually by depowering the throttle. This rapid intervention alleviates rollover risk. RSC also flashes a driver visual display and sounds an auditory alarm indicating that the system has activated. RSCs are also onboard monitors. They record lateral forces and provide a computer record of events for post-trip review. FMCSA (2009) estimated the costs RSCs for CTs to be \$440 to \$866 per vehicle, and the five-year return-on-investment (ROI) to be \$1.66 to \$9.36 per dollar spent. As part of the same study cited above for ESC, Woodroffe et al. (2009) estimated full-penetration RSC CT crash reductions to be 3,500 crashes, 106 fatalities, 4,400 injuries, and \$1.46 Billion in economic losses. This implies potential RSC benefits are 75 percent or more of ESC benefits. Others view ESC as a far superior technology. Bendix Corporation, a major ESC/RSC supplier, views RSC as having a crash reduction potential which is significant but far below that of ESC. That's because ESC acts to prevent and mitigate both directional instability (yawing) and roll instability, whereas RSC is limited to the latter (Bendix, 2010). Because ESC's capabilities encompass and exceed those of RSC, RSC is not designated as a priority technology in this white paper. It would certainly be one, however, if ESC were not available.

COLLISION WARNING SYSTEMS

Forward Collision Warning Systems (FCWS)

As discussed previously under passenger vehicles, FCW systems monitor the roadway in front of the vehicle and warn of rapid closing with a vehicle ahead, or other collision risks. Adaptive Cruise Control (ACC) is a natural partner to FCW because the same sensor readings can be

inputs to throttle controls to maintain steady highway following distances. ACC also reduces driver workload, an important concern in long-haul driving operations. A new NHTSA assessment of ACC (Silvani et al., 2009) estimates that full deployment of ACC on large trucks would prevent up to 320 fatalities annually.

FCWSs principally target rear-end crashes. Truck-striking rear-end crashes were 14 percent of serious truck crash involvements in the LTCCS (Knipling and Bocanegra, 2008). These crashes are probably also the biggest source of crash liability claims against trucking companies because the truck driver is almost always considered at-fault and because the vast majority of human harm occurs inside “innocent” struck vehicles (Knipling, 2009). Trucking companies should be highly motivated to prevent these crashes, and FCWSs are a perfectly tailored solution. FMCSA (2009) estimated FCWS costs to be about \$1,600 per unit and five-year ROIs to be \$1.33 to \$7.22 per dollar spent. Jermakian (2010b) has estimated that FCWSs on large trucks could prevent or mitigate 31,000 crashes and 115 fatal crashes (about three percent of truck-related fatal crashes). Because of FCWSs’ proven effectiveness and the harm their target crashes cause to the motoring public, FCWS is designated here as a priority technology.

Side-Object Detection Systems (SODS)

Another priority technology for large trucks is side object detection to prevent lane change/merge crashes. Side Object Detection Systems (SODS) detect objects to the side of the truck. They provide auditory warnings drivers when a side objects are detected. They function as supplements to truck mirrors to aid lane changes, especially those to the right. About three-quarters of truck side impacts following a lane change/merge occur when the truck is moving to the right. This reflects the limitations of truck mirrors and the large blind areas on the right sides of tractor-semitrailers.

Compared to passenger vehicles, large trucks are highly overinvolved in lane change/merge (LC/M) crashes. In one five-year study, combination-unit trucks (CTs) accounted for 2 percent of all motor vehicle crash involvements, but were 8.5 percent of the at fault vehicles in LC/M crashes (Wang et al., 1999). About 25,000 police-reported crashes involving a lane changing/merging truck occur annually. IIHS (Jermakian, 2010b) has estimated that 79 truck-involved fatal crashes could be prevented annually by universal use of SODS, which they termed “Side View Assist Systems.” Video mirrors, to be discussed later, are another countermeasure to LC/M crashes.

Backing Collision Warning Systems

Backing Collision Warning Systems, usually termed Rear-Object Detection Systems (RODS) for large trucks, use proximity sensors to detect rear-field objects and warn drivers of their presence (NHTSA, 2006). Less than one percent of serious crashes in the LTCCS involved trucks backing, but a much higher percentage of minor police-reported truck crashes and unreported crashes involve backing maneuvers. These crashes are an annoyance to trucking companies as they often result in vehicle downtime or customer (shipper and receiver) complaints and

restitution claims. Although RODS proximity sensors function effectively (Garrott et al., 2007), video mirrors, discussed below, probably have greater future potential as aids to safe and precise truck backing.

Lane Departure Warning Systems (LDWS)

As discussed earlier under cross-cutting systems, Lane Departure Warning Systems (LDWS) warn drivers that they are beginning to drift out of their lane. They function like an in-vehicle rumble strip. Note that LDWSs do not address loss-of-control-related lane departures following directional instability. They also do not prevent rollovers due to excessive speed on curves or similar dynamic mishaps. A product guide available on FMCSA's website lists six LDWS vendors, and states current prices to be in the \$1,000 to \$2,000 range. Figure 5 shows a functional schematic of a truck LDWS marketed by Iteris, Inc.

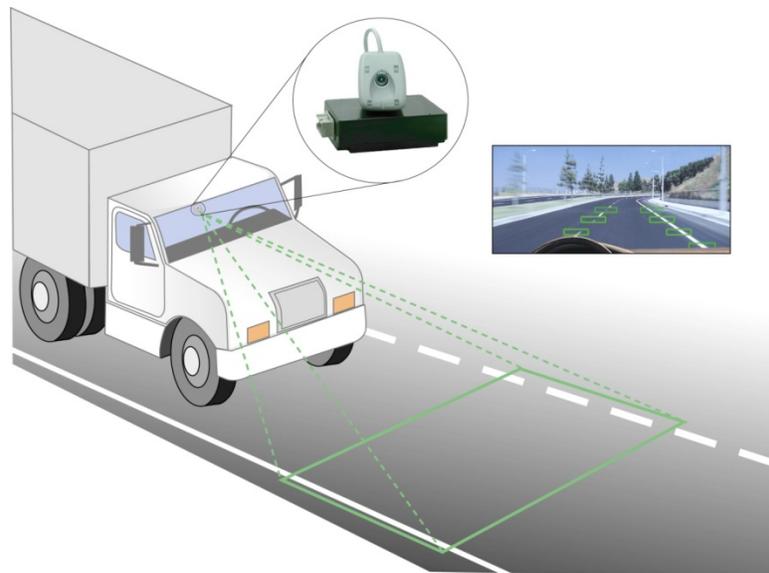


Figure 5. Functional schematic of lane departure warning system. Courtesy: Iteris, Inc.

LDWSs are most applicable to "drift" lane departures due to driver inattention, drowsiness, or other impairment. In the case of drowsiness, deterioration of performance usually begins well before actual lane breaks. In this case, LDWSs are potentially capable of providing corrective feedback to drivers well before they are in imminent danger. Yet most current systems base driver feedback only on imminent or actual lane breaks. The provision of LDWS feedback to drivers during their early, incipient performance deterioration is an application which should receive greater R&D attention.

FMCSA (2009) has estimated LDWS costs to be about \$800 per vehicle and five-year ROIs to be \$1.37 to \$6.55 per dollar spent. Jermakian (2010b) has estimated that LDWS on large trucks could prevent or mitigate 10,000 crashes and 247 fatal crashes (about seven percent of truck-related fatal crashes). Because of their high mileage exposures, CTs' lifetime likelihood of involvement in lane departure crashes is approximately three times that of passenger vehicles.

Because of the high CT potential for involvement in these crashes and the high potential that LDWSs have to prevent them, LDWS is designated here as a priority technology.

INTEGRATED VEHICLE-BASED SAFETY SYSTEM (IVBSS)

As described under passenger vehicles, the U.S. DOT-funded Integrated Vehicle-Based Safety System (IVBSS) initiative is designing and testing orchestrated, multi-element collision warning systems. IVBSS has been developed, configured, and field tested on 16 passenger vehicles and 10 CTs (Sayer and Flanigan, 2010). As illustrated in Figure 6, the current IVBSS suite includes three countermeasures, all designated in this report as priorities for large trucks:

- Forward Collision Warning (FCW)
- Lane Change/Merge Warning (also known as Side Object Detection Systems or SODS)
- Lateral Drift Warning (also known as Lane Departure Warning Systems or LDWS).

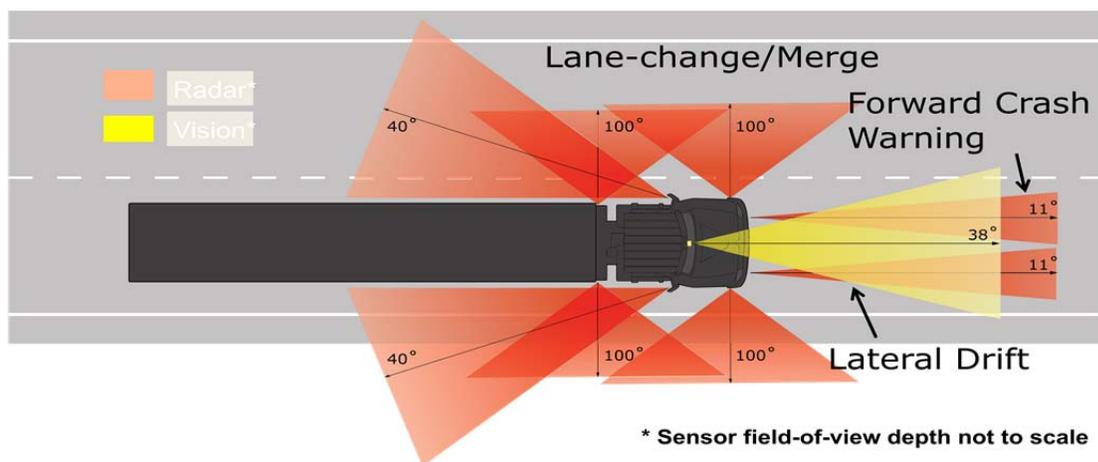


Figure 6. IVBSS truck safety system. Source: Sayer and Flanigan, 2010.

About 60 percent of all large truck crashes are potentially addressable by the IVBSS instrumentation suite. Field test results indicate that these three systems can be successfully integrated. Eighteen truck drivers using the IVBSS have generally found it to be helpful to safe driving, and would recommend it to others. Annoyance from excessive alarms remains as a concern, however (Sayer and Flanigan, 2010).

DRIVER BEHAVIOR & ALERTNESS MONITORING

Onboard Safety Monitoring (OBSM)

A fundamental difference between commercial driving and non-commercial driving is the fact that commercial driving is, or should be, *managed driving*. Management includes employee performance monitoring. In the case of driving, performance monitoring can and should include direct monitoring of driving behaviors.

Onboard Safety Monitoring (OBSM) is continuous measurement and recording of safety-related driving behaviors like speed, acceleration, and braking force. Potentially, OBSM can involve any safety-related driving parameter measurable in a vehicle. Vehicle speed and speed and hard braking applications are two frequently measured parameters. Almost all advanced collision warning systems, including FCWS, LDWS, and SODS can also function as monitors. They can provide real-time warnings and also post-trip summary feedback to both drivers and safety managers.

Truck and bus fleet managers regularly track their drivers' on-road events, including crashes, incidents, and violations. Yet, even though the technology is available, relatively few use OBSM to track the *source safety behaviors* that create these negative outcomes. Outcome tracking is necessary, but consider these OBSM advantages from Knipling (2009):

- OBSM documents specific driver behaviors causing crashes, incidents, and violations.
- Drivers can receive proactive corrective feedback before a crash, incident, or violation occurs.
- Evaluations and feedback are objective, timely, and frequent.
- Drivers can receive positive feedback and rewards for their successes.
- Driving behavior benchmarks can be set so drivers know where they stand in relation to carrier norms and expectations.
- Rewards and recognition can be individualized but also structured to reinforce group achievements, thereby fostering *esprit-de-corps*.
- OBSM can replace time-consuming ride-along driving observations, and it is more indicative of true behavior because no observer is present.
- OBSM can obtain a 100% sample of behavior.

No national estimates of the potential benefits of OBSM are available, in part because OBSM is not simply a vehicle-based technology. Rather, it is a carrier safety management initiative employing technology. One OBSM test in Israel (Toledo et al., 2008) used green (good), yellow (questionable), and red (bad) visual displays to give commercial drivers feedback on their driving safety. Drivers could see their performance indicators in real-time while driving and via a secure web link after driving. Driving risk was assessed based on vehicle speeds, lateral accelerations (e.g., on curves), and longitudinal accelerations (e.g., hard braking). In a testing involving 191 service drivers, feedback was provided without any adverse or other tangible consequences for drivers. Providing feedback alone, with no other consequences, resulted in a 33% mean reduction in risky driving behaviors for these drivers. Clearly, OBSM will be at the center of future safety improvements in commercial motor vehicle transport. Fatality reductions in the hundreds, or even one thousand or more, could be possible because of the pervasive driving behavior changes possible through correctly managed OBSM.

A simpler variation of OBSM involves capturing videos of critical events occurring during driving. A typical system has two cameras at the middle top of the windshield. One captures the

vehicle forward view and looks back at the driver to see the driver's face and record driver reactions. The system has an audio recorder and records a continuous video/audio loop. An accelerometer detects excessive lateral, longitudinal, or vertical forces, and prompts the device to save 10 seconds of data from before and after the triggering event. Managers or drivers themselves can then review events to see what went wrong. Hickman et al. (2009) field tested a video capturing device with 50 commercial drivers in operational service. After a no-feedback baseline period, the system was fully activated. Drivers and their managers reviewed and reconstructed triggered events as a performance improvement exercise. Event rates in two fleets decreased by 37 and 52 percent, respectively, during the intervention period. If such interventions can be conducted in a positive manner with sufficient rewards and positive feedback to drivers to ensure acceptance, there is every reason to believe that decreases in event rates can translate directly to decreases in at-fault crashes.

Alertness Monitoring

Another emerging technology, not yet widely implemented, is driver *alertness monitoring*. As described earlier, alertness monitoring can be based on driver lane-keeping as indicated by LDWS sensors, by eyelid droop (PERCLOS), or by both measures combined into a single optimized assessment. Alertness monitoring is potentially a much stronger countermeasure to commercial driver fatigue than Electronic Onboard Recorders (EOBRs, discussed below) because it would measure drowsiness and impaired performance directly as opposed to measuring driving time, which is only weakly associated with driver alertness (Knipling, 2009). Someday, even government regulation of commercial driver alertness and fatigue may be based on direct alertness monitoring of drivers rather than the current Hours-of-Service logging regimen.

Alertness monitoring has special relevance to commercial driving, but perhaps not for the reasons many people would assume. Commercial drivers' per-VMT rate of involvement in fatigue-related related crashes is probably no greater than that of non-commercial drivers. In the LTCCS, for example, eight of every nine car-truck asleep-at-the-wheel crashes were due to the *car* driver falling asleep (Knipling, 2009). In the LTCCS, about 4 percent of all serious large truck crashes were attributable to truck driver asleep-at-the-wheel. FMCSA has attributed 7.25 percent of fatal crashes to fatigue, in part by adding related inattention crashes. That percentage would translate to about 270 large truck fatal asleep-at-the-wheel crashes annually. A rough estimate of the number preventable through driver alertness monitoring is 100.

The special relevance of alertness monitoring to commercial driving is primarily due to crash *likelihood* and *severity* differences between trucks and cars, as discussed early in this section. Long-haul trucks (i.e., CTs) are driven far more miles than cars, and their crashes are much more severe. One study (Knipling, 1998) estimated CT life cycle fatigue-related crash costs to be ten times those of passenger vehicles and more than 20 times those of STs, which are primarily short-haul, day-use vehicles. Further, alertness monitoring benefits for truck safety might not be limited to the prevention of known asleep-at-the-wheel crashes. As a group, commercial drivers

are among the unhealthiest of Americans. Alertness monitoring and other OBSM systems might help motivate drivers to change their driving styles and even their lifestyles in holistic ways resulting in more pervasive benefits. This concept is discussed in the textbox below. Finally, alertness monitoring may someday be encouraged as a regulatory alternative to conventional HOS rules and logs. Which would be better, monitoring commercial driver hours or directly monitoring their alertness and driving performance?

What's Your Driving Average?

Every baseball player knows his or her batting average, and whether it is good or bad. Sports provide precise quantitative feedback to players on their performance. There are official or unofficial benchmarks for quality performance, such as a par score in golf. Do you know the same thing about your driving? Probably not. Most drivers, even high-risk drivers, think they are better than average drivers. It's called the self-assessment bias. It's easy for people to have this bias because they do not receive objective feedback on their driving, and there are no quantitative benchmarks for driving proficiency. Crash and violation histories are the best metrics we have, but they are unreliable because they are rare events affected by chance and confounded by differences in risk exposure. It's easy to invent excuses to dismiss their significance. Baseball and other sports, in contrast, have many quantitative performance metrics. Players know their scores.

This situation may gradually change over the coming decades. OBSM systems will give commercial drivers numeric feedback on their driving behavior. OBSMs are also being used with teenagers to help them (and their parents!) assess and improve teen driving. "Alertometers" will tell drivers their alertness scores, hopefully using a standardized, easy-to-understand scale. If you had such information about your own alertness while driving, how would you use it? Would repeated low alertness scores motivate you to get more sleep and otherwise change your lifestyle? A core principle of psychology is that feedback facilitates performance. Will objective feedback to drivers from onboard monitoring systems enable and motivate them to change?

ELECTRONIC ONBOARD MONITORS (EOBRs)

EOBRs monitor commercial driver Hours-of-Service (HOS) compliance by maintaining a readable electronic time record of vehicle movement. Truck drivers are currently permitted 11 hours of driving during a daily 14-hour maximum tour-of-duty. EOBRs cannot track non-driving work time, but they do track vehicle motion and thereby effectively deter drivers from driving excessive hours. EOBRs are used voluntarily by some fleets but are currently required only for those commercial fleets with the worst histories of HOS non-compliance. FMCSA is considering extending the EOBR requirement to a larger percentage of non-compliant carriers.

EOBRs are assumed by the public and many government officials to be effective countermeasures against commercial driver fatigue and asleep-at-the-wheel crashes. This assumption may be questioned, however. A number of researchers do *not* consider hours of driving, the principal EOBR recording metric, to be among the most important determinants of driver alertness on a daily basis (Hanowski et al., 2008; Knipling, 2009; Wylie et al., 1996).

Instead, the four principal alertness determinants are amount of sleep, time awake (with alertness typically dropping after 16 hours awake), time-of-day (reflecting circadian rhythms), and individual differences in fatigue susceptibility (Knipling, 2009). The first two of these are only indirectly addressed by EOBRs and HOS rules, and the last two are not addressed at all.

Ironically, the biggest benefits of EOBRs may not be from driver fatigue reduction, but rather from more efficient operations and safety management. Because EOBRs automate driver log-keeping, they save drivers time, streamline records and compliance management, and provide for better safety oversight of drivers through quicker identification of non-compliant drivers. Shackelford and Murray (2006) found EOBR benefits to include improved fuel consumption monitoring and fuel tax compliance, quicker tabulation of driver mileage and loads, easier tracking of vehicle and engine wear, real-time vehicle location monitoring, better communications and dispatching, and even improved driver morale.

Electronic Data Recorders (EDRs)

As described under passenger vehicles, Electronic Data Recorders (EDRs) record vehicle speed, accelerations, brake applications, and other dynamic parameters of interest in crash reconstruction. EDR data can be critical in crash investigation and litigation. The trucking industry generally holds the view that the same EDR-related laws and court rules should apply to equally to all vehicle types.

Vehicle Monitoring & Automated Functions

Mechanical maintenance deficiencies are common in large trucks. In the LTCCS, 40 percent of crash-involved trucks had some vehicle-related deficiency or malfunction, although these were the proximal cause (the “Critical Reason”) for only about four percent of crashes (excluding cargo shifts, which were another two percent). Numerous automatic vehicle condition monitoring technologies are now available to reduce this source of crash risk. These can provide continuous monitoring and feedback to drivers, recordings to EDRs and, potentially, to roadside inspectors through wireless transmission. Such monitoring can potentially include brake adjustment and condition (the most common vehicle-based problem in inspections and crashes), tires, lighting, vehicle weight, and other vehicle faults. In addition to vehicle condition monitoring, automated functions can extend to the task of driving (e.g., automated truck transmissions), to vehicle speeds, and to trip navigation.

Tire Pressure Monitors

In the LTCCS, about 1 percent of at-fault truck crashes were caused primarily by tire failure. Poor tire condition is the second most common vehicle source (behind brakes) of violations in truck roadside inspections. The most common cause of tire failure is underinflated tires. Underinflated tires become overheated and experience excessive flexing of their sidewalls. This can raise fleet tire replacement costs by more than 10 percent annually and reduce fuel economy by increasing rolling resistance (Freund et al., 2006). An FMCSA safety technology product guide, available on its website, describes various types of tire pressure monitoring systems available from nearly 20 vendors. The safety benefits come from reduced incidence of tire

failures. These devices also save pre-trip inspection time, improving operational efficiency. Part of the “equation” for assessing large truck safety systems is their *non-safety* benefits. Time pressure monitors are an excellent example.

Automated Transmissions

In cars, automatic transmissions are regarded as a convenience, not a safety feature. In large trucks, however, making gear-shifting easier can facilitate safety by reducing driver workload. “Work” refers primarily to the *mental* tasks of driving – perceiving, distinguishing crash threats, deciding, executing responses. Truck driving has a physical element as well, since manual shifting requires double-clutching, a more difficult and tiring task than shifting gears in a car. Because they reduce workload, automated transmissions can contribute to truck driving safety. The adjective “automated” rather than “automatic” is used because these transmissions are not fully automatic like those of a car. Schneider National, one of the nation’s largest truckload carriers, conducted an experiment in which a group of new drivers was trained and equipped with automated transmission vehicles while a control group used standard gears. New drivers using automated transmissions had a 26 percent lower first-year crash rate than controls. They also completed their training sooner on average, and had a 35 percent higher one-year retention rate with the company (Knipling, 2009).

Speed Limiters

Speed limiters were addressed previously under cross-cutting issues. As noted, speed limiters are already common on large trucks, though they not yet considered standard equipment. In European Union countries they are required on all heavy vehicles. In the U.S., NHTSA and FMCSA have proposed federal regulations for speed limiting heavy trucks, and the matter is under rulemaking consideration. The proposal would likely require that new trucks’ electronic control modules be programmed to limit top powered speeds to some set point. This would be an easy and low-cost engine modification. More difficult would be ensuring that they are tamper-resistant.

Much of the trucking industry favors mandatory speed limiters on large trucks. The American Trucking Associations (ATA) and other organizations have petitioned NHTSA and FMCSA to require speed limiters with a set point of 68 mph on new heavy trucks (ATA, 2006). Reduced crashes are the primary rationale, but other reasons include lower fuel and maintenance costs, reduced emissions, and longer tire life.

One should realize that speed limiters will not prevent most truck crashes arising from excessive speed. Most instances of “excessive speed” occur on lower speed roads and at speeds below 68 mph. Moreover, speed limiters would not slow the downhill speeds of trucks. In support of its petition, however, ATA (2006) cited an analysis of 2001-2005 FARS data on truck speeding-related crashes. In 20% of the speeding-related fatal crashes where the truck’s speed was recorded, that recorded speed exceeded 68 mph. Many of these crashes would be prevented or reduced by speed limiters.

Intelligent speed adaptation was also discussed earlier. This is a system which would use GPS navigation technology to “know” the speed limit or a recommended maximum speed for a road, or section of road. Carsten et al. (2008) fabricated and tested an intelligent speed adaptation system on a medium delivery truck. Although the system functioned as designed and excessive speeds for road conditions were reduced, driver acceptance was low and the system was considered distracting. This is a concept with promise, but one needing more refinement.

Truck-Specific Navigation Aids for Risk Avoidance

Proper use of Global Position System (GPS) navigation aids by commercial drivers can significantly reduce exposure to risk and, therefore, crash rates. *Truck-specific navigation aids* can provide both trip planning and in-vehicle GPS-synchronized directions customized to truck transport. GPS devices can steer drivers clear of roads where truck traffic and/or hazardous cargo is restricted or prohibited. They can warn drivers of low clearance underpasses (e.g., bridges with less than 14 feet of vertical clearance, the national standard for local roads and collectors) or other hazardous locations. If systems are frequently updated, they can route drivers around construction zones, where crash risks far exceed those on normal roads. Thirteen percent of truck crashes in the LTCCS occurred in work zones, versus less than one percent of truck driving exposure. Simply routing trucks away from undivided roadways and from those with high traffic densities can reduce crash risk considerably. Truck instrumented vehicle studies permit the comparison of incidents (e.g., hard-braking events) to exposure (random samples of driving) to determine relative risk (odds ratios) of various road types and conditions. Here are some examples of risk odds ratios relevant to smart routing of trucks:

- Construction zones vs. normal roads: 8.5 (relative odds of incident vs. controls)
- Undivided vs. divided roads: 5.3
- Dense traffic vs. moderate-to-light traffic: 5.9.

Truck-specific road information is needed, however. Many trucking companies warn their drivers not to use generic (i.e., passenger vehicle) GPS units because they do not contain information on truck-specific restrictions or hazards.

VISIBILITY & CONSPICUITY

Truck Conspicuity & Enhanced Lighting/Signalling

You wouldn't think that something as large as a truck would be hard to see, but many nighttime collisions between cars and trucks involve a car striking an unseen truck. Fortunately, this problem has been reduced by a Federal requirement for improved retroreflective tape on the sides and backs of truck trailers produced after 1997. These enhancements were found to reduce crashes into the sides or backs of trailers by 29 percent (Perrin et al., 2007).

Trucks and trailers are also required to meet standards for conspicuity lighting, including tail lights, brake lights, signal lights, and marker lights. In 2008, there were nearly 600 fatal crashes in which another vehicle struck a large truck in the rear (Craft, 2010). FMCSA is testing new

trailer rear conspicuity enhancements which would a) further enlarge reflective surfaces to include an octagonal stop sign-like display, and b) provide radar-triggered visual and even auditory warnings. The effort is comparing the warning effectiveness of various configurations, and will field test top designs (FMCSA, 2010). Truck-struck rear-end crashes are a sizable safety problem, but truck-based technologies addressing these crashes are not sufficiently advanced to warrant their being designated as priority countermeasures. More likely, FCWSs on vehicles which might strike trucks will be more effective in reducing these crashes.

Video Mirrors

As noted earlier, combination-unit trucks (CTs) are strongly overinvolved in lane change/merge (LC/M) crashes, especially those involving left-to-right lane changes. Over a vehicle lifetime, average CT crash costs from LC/M crashes are more than ten times those of light vehicles (Wang et al., 1999). The overinvolvement of CTs in these crashes is related primarily to poor visibility around trucks. Improvements have been made in conventional mirror design and coverage (e.g., convex mirrors, supplemental spot mirrors), but mirrors cannot possibly provide a truck driver full visibility around his or her truck.

Video cameras with in-cab displays can provide the same visual functionality as conventional mirrors, along with many enhancements. Cameras can be mounted on the sides of tractors and on the sides and backs of trailers, with dedicated video monitors for each in the cab. Although these are cameras, not mirrors, a natural name for them is “video mirrors.” The advantage of video mirrors is that the driver can see whatever the cameras see. Cameras can be placed almost anywhere, so there are no inherent blind areas. Cameras mounted on the back of a trailer can provide a precise, close-up perspective during backing.

The key safety issue for video mirrors is not whether they can provide visual information, but rather whether drivers can use them without making *negative transfer errors*; that is, errors made in switching from one type of device to a different one. A series of tests (Wierwille et al., 2007) has shown that truck drivers can generally make more precise vehicle maneuvers using video mirrors compared to conventional ones. Not only do video mirrors reduce blind spots – they also make it easier for truck drivers to judge distances from other vehicles and objects during close maneuvers. In a backing test, drivers backed their tractor-semi-trailers as close as possible to a loading dock without bumping it. Their average of 47” from the dock using conventional side mirrors was reduced to 10” using video mirror mounted on the back of the trailer.

COLLISION AGGRESSIVITY REDUCTIONS & OCCUPANT PROTECTION

Most harm in crashes involving large trucks is suffered by the occupants of other vehicles. Of the 4,229 truck-related fatalities in 2008, more than 3,151 (75 percent) were other vehicle occupants. A CT with an 80,000 lb. GVWR has 15-30 times the mass of a light vehicle. The laws of physics dictate that collisions between two bodies of such unequal mass will result in more abrupt speed changes and resulting damage to the smaller object. This characteristic of larger vehicles in relation to smaller ones is termed *collision aggressivity*. Other design features

contributing to truck collision aggressivity are the height and stiffness of truck and trailer bodies. Prospects for reducing truck collision aggressivity are limited compared to the dramatic potential for *preventing* crashes using the various technologies described in this white paper. One relatively simple approach would be to lower truck bumpers to improve vertical compatibility with smaller vehicles. Freund et al. (2006) discuss the potential use of hyperelastics, such as specially formulated polyurethanes, in the construction of truck bodies. In modeling studies of crash barriers, these materials have been shown to reduce force in forward impacts by as much as 65 percent. They could be used for specific truck body structures like rear underride guards. Given the size of trucks, any external modifications to their bodies are likely to be more expensive than similar changes to a car body. Their attractiveness from a cost-benefit perspective may be problematic.

Of the 4,229 truck-related fatalities in 2008, 675 occurred to truck drivers and other truck occupants. Many of these truck occupant fatalities were in rollovers. Bahouth et al. (2007) have noted that rollovers constitute just 4 percent of large truck crash involvements but account for 36 percent of truck driver fatalities. Many truck drivers killed in rollovers are unbelted, and many are ejected. Average injuries to unbelted drivers in rollovers (and in truck crashes in general) are more than twice as severe as those to belted drivers. According, a priority for truck occupant protection is ensuring safety belt use. Current Federal Motor Vehicle Safety Standards (FMVSSs) for passenger vehicles require a visual and auditory belt use reminder system, but no such requirement exists for trucks. Bahouth et al. (2007) concluded that such systems would be effective with truck occupants, just as they are in cars.

Air bags reduce car driver fatalities by 30% in frontal impacts. What about air bags for heavy trucks? Although no manufacturers currently offer truck air bags, Volvo and others are developing and testing them. In a high-speed truck forward impact with a fixed object, an air bag would likely have a similar life-saving effectiveness to that seen in cars. Crashes with such abrupt speed changes are less common in trucks than in cars, however. In a typical large truck collision with a car, an air bag would make little difference and might not even deploy because the impact deceleration of the truck is relatively small. Thus, while safety belts are equally important in trucks and cars, air bags have relatively less potential benefits in trucks. They may still be seen in trucks in future years, especially if their costs decrease.

Larger Trucks?

Across the entire transportation system, society seeks the highest performance for the lowest economic, environmental, and human cost. In the present context, one may ask whether the profile of truck configurations on our roadways could be shifted to result in higher freight productivity at lower cost, including the human cost associated with truck crashes. Higher productivity vehicles (HPVs) are those with GVWRs of more than 80,000 lbs., the maximum size of standard tractor-semitrailers. U.S. restrictions on truck size and weight have been frozen for nearly two decades, but many observers are now asking whether geographic and roadway restrictions on HPVs should be liberalized. At the June 2009 *International Conference on*

Efficient, Safe, and Sustainable Truck Transportation Systems for the Future in Ann Arbor, Michigan (website: www.magictrucks.org), speakers from around the world described potential benefits from more widespread use of HPVs. The most compelling HPV rationale is reduction of fuel consumption and associated carbon emissions, primarily because HPVs can haul the same cargo weight or volume in fewer trips.

The same concept could apply to safety. Although the motoring public reflexively fears larger trucks, there is a safety rationale for expanded HPV use, in addition to the environmental and economic rationales. One may extrapolate from a comparison between conventional STs and CTs. The two main truck types have roughly the same total crash costs per mile traveled (Wang et al., 1999). Since CTs carry far more freight, they are far safer than STs in terms of crash harm per ton-mile. In regard to HPVs, an Australian study (Moore, 2007) found their crash rate per freight ton-mile to be less than one-half that of regular combination-unit trucks. Two Canadian studies (Montufar et al., 2007; Tardif and Barton, 2006) compared HPV safety to that of conventional CTs and other configurations. Both concluded that LCVs offer both productivity and safety benefits if their operations are closely and intelligently controlled. On the other hand, Zaloshnja and Miller (2007) found HPV crashes to be more severe than those of CTs or STs. A definitive safety assessment would determine total crash harm per ton-mile for different truck configurations as well as other, similar metrics (TRB, 2010). It is hoped that society can make a rational judgment on future HPV use as opposed to an emotional one based on reflex.

Realizing Truck Safety Technology’s Potential

There appears to be an ever-increasing carrier interest in, and acceptance of, truck onboard safety technologies. Nevertheless, carriers want assurance of their safety rationales, likely outcomes based on real-world data, prospective ROIs, operational requirements (e.g., installation, maintenance, and training), data processing requirements, and driver acceptance (Houser et al., 2007). Bottom-line ROI is perhaps the single most important measure of truck safety system potential, because the decision to buy truck safety devices is usually an economic one. Providing detailed, current, and valid information to carriers on system ROI prospects is one important strategy for increasing technology sales. Industry has strong data privacy, security, and litigation concerns associated with onboard technologies which record vehicle status and driver actions. These concerns must be addressed. The textbox above, adapted from Knipling (2009) outlines a systems approach to assessing safety technologies and ensuring their success in the rigors of trucking. System developers and vendors should anticipate these concerns and design these elements into their products to ensure their successful deployment.

A Systems Approach to Truck Safety Technologies

An onboard truck safety technology must:

- Be truly **applicable** to the crash problem.
- Be **usable** by drivers and **acceptable** to them.
- Be **durable** and **reliable**.
- Be **maintainable** by carriers.
- Be **compatible** with legal, institutional, and cultural factors (e.g., does not create increased liability).
- Actually result in:
 - Driving **behavior change**.
 - Crash **problem reduction** (number and/or severity).
- If possible, provide **efficiency, fuel-economy, sustainability, and/or fleet management** benefits in addition to safety benefits.
- Be **affordable**.
- Be **marketable**.

A system is a chain: *all links must be strong!*

Apart from scientific, engineering, and operational challenges, there are economic obstacles to greater deployment of truck safety technologies. The industry’s most innovative and successful companies have sufficient capital and cash flow to finance purchases of vehicle safety technologies. But that’s not true of most companies, where tight profit margins are the rule. Two-thirds of the harm in truck crashes is outside the vehicle, experienced by other motorists or road users (Wang et al., 1999). The motoring public would benefit substantially from any improvement in truck safety. Accordingly, various safety organizations are calling for tax incentives to promote carrier purchase of advanced safety technologies. The *Commercial Motor Vehicle Advanced Safety Technology Act* is a bill before Congress calling for a 50 percent tax credit for the purchase of selected proven onboard technologies. Covered technologies would include collision warning systems, lane departure warning systems, vehicle stability systems (e.g., ESC), and brake stroke monitoring systems. Thousands of lives would be saved and tens of thousands of injuries prevented if more trucks were equipped with these systems. Congress should strongly consider providing this safety benefit to industry and to the motoring public.

BARRIERS TO IMPLEMENTATION

Robust, large-scale adoption of enhanced vehicle safety features and crash avoidance technologies are necessary in order to achieve zero fatalities, but will not come easily. Significant obstacles and challenges are discussed in this section, along with potential strategies to overcome barriers to implementation.

The development and implementation of vehicle design features that directly affect safety performance is a dynamic process that results from a complex array of technical, regulatory, and market factors. These include evolving industry standards, manufacturer preferences, consumer demand, government safety regulations, and economic pressures to minimize production costs. Efforts to aggressively implement life-saving vehicle design changes and equip all new vehicles with effective crash avoidance technologies are subject to processes that influence consumer choices and vehicle manufacturers' design decisions. Manufacturers generally require that technologies perform accurately over 99 percent of the time before being installed in vehicles. Applying these high standards to vehicle safety features and crash avoidance technologies ensures reliability and consistent safety performance. However, vehicle safety systems that do not perform accurately virtually all of the time require additional research & development, and as a result, may face significant delay in implementation. In addition, complex vehicle safety technologies must be carefully designed to avoid or minimize unintentional harm. For example, technological challenges in developing advanced air bag systems included designing air bags that can generate enough power to protect an average adult male as well as deploy in a manner that do not severely injure smaller occupants.

The costs associated with these R&D efforts must be viewed as recoverable by manufacturers in order for companies to make required financial investments. Given the life-saving potential of many vehicle safety features and crash avoidance technologies currently under development, and the prospect of many future applications, mechanisms should exist to encourage financial investment. These might include low-interest loans, tax incentives, financial prizes for major safety advancements, and government funding of non-proprietary safety technology.

Sharing early, reliable findings of real-world crash effectiveness data with vehicle manufacturers, and making them key partners in the decision making process for achieving vehicle safety performance, can advance progress. David Viano (a leading specialist in injury biomechanics and impact protection, and Editor-in-Chief of *Traffic Injury Prevention*) attributes much of the unusually rapid progress in implementing Electronic Stability Control (ESC) technology in US passenger vehicles to the sharing of early findings of ESC effectiveness data with vehicle manufacturers, thus making them key partners in the decision to install ESC (personal conversation June 4, 2010). To help expedite adoption of advanced vehicle safety designs, Dr. Viano also suggests offering vehicle manufacturers multiple options for compliance with NHTSA safety regulations, with basic (yet acceptable) safety requirements seeming relatively attractive and feasible compared with more ambitious stretch goals.

Another obstacle to large-scale adoption of enhanced vehicle safety features and crash avoidance technologies is a lack of consumer demand, or willingness to pay, for potentially lifesaving safety equipment as part of new vehicle purchases. To reduce vehicle production expenses and retail costs, many vehicle safety features are offered as options, or included in high-end luxury option packages. As long ago as the 1940s and 1950s, when first introduced by US automobile manufacturers, seat belts were offered as optional safety equipment, and did not become standard for many years. Short of government mandates – which should of course be adopted where justified -- achieving very high levels of market penetration of advanced vehicle safety technology will require a significant increase public demand and willingness to pay for added protection from crashes and serious injuries. Measures to increase market penetration include aggressive social marketing to change the culture of consumer demand for vehicle safety features; solid evaluations of safety technologies and widespread publicity of the results; financially-justified insurance discounts to incentivize consumers to elect effective safety options; and incentives tailored to commercial vehicle fleets. As government assumes a larger financial role in consumer health care – and already incurs large medical expenses for crash-induced injuries through Medicare and Medicaid programs – tax incentives should be considered to promote consumer and fleet purchase of effective vehicle safety features and crash avoidance technologies. Existing tax incentives encourage the purchase of energy-efficient appliances and home insulation devices.

In terms of crash avoidance technology, many important research and development issues remain to be addressed. Some of the most challenging issues involve the need to understand human interactions with automation technologies. Much research is needed on issues such as: driver attentiveness during partially and fully automated driving; making successful transitions among manual, partially automated; and potential changes in driving behavior when warning, control assistance, or automated systems are available (risk compensation, decrements in driving skills, etc.). For crash avoidance technologies that either provide warnings to drivers or automatically intervene in certain situations to avoid crashes, an important technical concern is the frequency of false positives. Because crash avoidance technology cannot be “right” all of the time, these systems will either fail to predict some crashes (under-sensitive), or provide unnecessary warnings in situations unlikely to result in crashes (over-sensitive). Under-sensitivity will compromise crash-avoidance effectiveness, while frequent false positives may lead drivers to ignore or turn-off crash avoidance warnings. These technical challenges can only be met by robust and adequately funded R&D efforts, including extensive feedback and evaluation from real-world driving experience.

Another challenge associated with crash avoidance technology involve the need for driver training, including not only instruction on how these systems work, but how drivers should react to warnings or other feedback. Some years back, the introduction of antilock braking systems (ABS) caused concern and confusion among many automobile drivers who did not understand how to correctly apply ABS. Human factors research is need to ensure warning and messages produced by crash avoidance systems are clearly understood by a wide range of drivers.

A significant challenge to implementing large scale deployment of vehicle-to-infrastructure technologies is the sheer size of the US roadway system, which includes more than 4 million miles of public roads that accommodates 3 trillion vehicle miles of travel annually. Because of the massive volume and varied nature of US roadway inventory, systematic and cost effective approaches will be needed to facilitate strategic implementation and achieve maximum benefits. It will be important to ensure coordination and synchronization among various vehicle-to-infrastructure technologies to allow maximize uniformity and allow infrastructure-based components to support multiple safety functions. High quality research evaluations will be needed to focus critical resources and assets on the most effective vehicle-to-infrastructure technologies. Finally, future bridge and roadway construction, rehabilitation, and maintenance activities should be used as opportunities to incorporate relevant vehicle-to-infrastructure technologies, using resources associated with those engineering projects.

Concerns about legal liability have long been associated with crash avoidance technology. Liability can be associated with claims that these devices either fail to prevent crashes, or perhaps are claimed to be the proximate cause of certain crashes (e.g., rear-end crashes that occur when emergency brake assist technology deploys unexpectedly). Mass produced industrial and consumer products face the additional threat of class action lawsuits, in which large numbers of claimants are represented by combined legal counsel. Given the life-saving potential of many crash avoidance technologies, and the potential for legal liability concerns to hamper widespread deployment, consideration should be given to establishing options for limiting liability against vehicle manufacturers and crash avoidance technology suppliers for installation of thoroughly vetted devices. Such a process might require testing and certification of these devices by USDOT.

Implementation of automatic speed control on US streets and highways would be highly controversial and contentious. Removal of drivers' freedom to choose their travel speeds would certainly face fierce resistance from many motorists and opponents of government regulation. The political and public acceptance obstacles may dwarf any technical challenges related to system design and operation. Regardless of the substantial obstacles and challenges, adoption of automatic speed control must play a prominent role in a long term strategy to approach zero traffic fatalities. Potential strategies to overcome implementation barriers include aggressive social marketing, substantial penalties for drivers convicted of traveling far in excess of posted speed limits, roadway designs that promote desired travel speeds, and substantial use of automated speed enforcement to dissuade drivers from speeding. Momentum toward automatic speed control can also be promoted by mandating the use of speed governors on large trucks, and perhaps by drivers of passenger vehicles convicted of severe traffic violations.

SUMMARY AND CONCLUSIONS

Although the vast majority of fatal motor vehicle crashes are attributed to unsafe driver behavior or inappropriate actions, and the vehicle itself is generally assigned a small role in the spectrum of direct causes and contributing factors to fatal motor vehicle crashes, aggressive adoption of

specific vehicle design features and vehicle safety technology offers considerable opportunities to avoid crashes and reduce crash severity. Thus, vehicle safety enhancements should play a critical role in a comprehensive national effort to eradicate traffic deaths. This paper has provided a high-level vision to approach the goal of zero fatalities through Safer Vehicles, and identifies the most promising strategic measures to help achieve the vision. Table 3 provides a summary of safety measures that are both applicable across vehicle types, and specific to either passenger vehicles or large trucks. This White Paper identifies numerous challenges and obstacles to successful, widespread implementation of the vehicle safety strategies, and potential opportunities to overcome these barriers.

Table 3: Summary of intervention strategies.

CROSS-CUTTING STRATEGIES (APPLICABLE TO PASSNGER VEHICLES & LARGE TRUCKS)				
Strategy	Aimed At	Potential Fatality Reduction	Who Bears Cost	Obstacles to Implementation
Alcohol Detection & Interlock	All fatalities with impaired driving as a factor	Estimated that almost 9,000 traffic deaths could be prevented every year if alcohol detection devices were used in all vehicles	R&D costs: Automotive Coalition for Traffic Safety and NHTSA	Sufficient technology advancement, cost, public acceptance
Automatic Speed Control	All fatalities with speeding as a factor	Estimated 30 - 40% reduction in fatal crashes	Largely off the shelf technology, already installed on most large trucks. ISA requires extensive measures to relay speed limits to vehicles.	Public acceptance, measures to relay speed limits to vehicles for ISA, further refinement of ISA driver interface
Lane Departure Warning Systems	Single-vehicle crashes, head-on collisions, sideswipe same-direction crashes, and sideswipe opposite-direction crashes	Estimated 10 - 40% reduction in fatal lane departure crashes. On large trucks, potential to prevent about 250 fatal crashes annually.	<u>R&D costs</u> : industry, with some assistance from USDOT <u>Acquisition costs</u> : consumers, truck owners	Cost, Driver understanding appropriate and response to warnings
Side Object Detection Systems	Various types and configurations of lane-changing crashes	Universal use could prevent an estimated 79 truck-involved fatal crashes		Cost
Driver Alertness Monitoring	All fatalities with inattentive or impaired driving as a factor	Estimated 5 - 10% reduction in fatal crashes; for large trucks, potential to prevent an estimated 100 fatal crashes annually (authors' estimate).		Cost, Driver understanding appropriate and response to warnings
Forward Collision Warning Systems	Angle crashes, front-to-rear crashes, and single-vehicle crashes	Estimated 2 to 3% reduction in fatal crashes, including large trucks		Cost, Driver understanding appropriate and response to warnings

Backing Collision Warning Systems	Primary types of fatal crash involves vehicles backing into pedestrians	Potential to prevent up to 400 fatal backing crashes each year	Largely off the shelf technology, and already installed on many vehicles. Consumers and truck owners pay for the cost of this equipment.	Cost
Electronic Stability Control	Run-off-road, rollover	Approx 33% reduction in fatal crash involvement. For large trucks, potential to prevent an estimated 126 – 439 fatalities annually.		Already in large number of vehicles, and being phased-in to vehicle fleet
Night Vision Enhancement	Pedestrian, bike, animal	Potential to prevent estimated 15 - 30% of fatal pedestrian and bicycle crashes		Cost, and concerns about potential driver distraction
Intelligent Lighting Systems	Primary types of fatal crashes involve motor vehicles striking pedestrians and bicyclists	Potential to prevent estimated 15 - 20% of fatal pedestrian and bicycle crashes under low visibility conditions		
Electronic Driver License	All fatalities with unlicensed or unauthorized vehicle operation as a factor	Potential to prevent estimated 1 to 5% of fatal crashes	<u>R&D costs</u> : industry, with some assistance from USDOT <u>Acquisition costs</u> : consumers, truck owners	Public acceptance, potential inconvenience
Daytime Running Lights	Multiple vehicle crashes, and daytime pedestrian fatalities	Potential to prevent up to 25% of fatal daytime multiple vehicle crashes, and 28% of daytime pedestrian fatalities	Minimal cost	Potential concerns about use in electric vehicles due to power drain; some drivers complain about headlight glare
Intersection Collision Avoidance Systems	Multiple vehicle angle crashes	Potential to reduce fatal intersection crashes by about 5% (authors' estimate)	<u>R&D costs</u> : industry, with some assistance from USDOT;	Accuracy, false positives, public acceptance, cost
Road Condition Warning Systems	Lane departure, rollover	Potential to reduce fatal crashes by about 5% (authors' estimate)	<u>Acquisition costs</u> : consumers & taxpayers	Accuracy, cost

STRATEGIES SPECIFIC TO PASSENGER VEHICLES				
Emergency Brake Assist	Rear-end, run-off-road, rollover	Estimated 20 - 40% reduction in fatal crashes	Consumers	Cost
Ejection Mitigation	Occupant injuries in side-impact and rollover crashes	Potential to reduce occupant fatalities by about 5 – 10% (authors’ estimate)	<u>R&D costs:</u> industry, with some assistance from USDOT <u>Acquisition costs:</u> consumers	Sufficient technology advancement, cost
Improved Side Impact Protection	Occupant injuries in side-impact and fixed-object crashes	Potential to reduce occupant fatalities by about 5 – 10% (authors’ estimate)		Sufficient technology advancement, cost
External airbags	Passenger vehicle occupants and vulnerable road users	Potential to reduce occupant and vulnerable road user fatalities by about 5 – 10% (authors’ estimate)		Sufficient technology advancement, cost
Adaptive Occupant Restraints	Occupant injuries in frontal and side-impact crashes	Potential to reduce occupant fatalities by about 5% (authors’ estimate)		Sufficient technology advancement
Pop-up Bonnet Systems	Pedestrians	Potential to reduce pedestrian fatalities by about 5 – 10% (authors’ estimate)		Sufficient technology advancement, cost
Compatibility Between Roadside Hardware and Vehicle Designs	Passenger vehicle occupants in collisions with guardrails	Potential to reduce occupant fatalities by about 2% (authors’ estimate)	<u>R&D costs:</u> industry, with some assistance from USDOT <u>Acquisition costs:</u> consumers Roadside hardware costs: state and local governments	
Crashworthiness of Low-Speed Vehicles	Occupants of low-speed vehicles (many of whom are older adults)	Proposed as a proactive measure as these vehicles grow in popularity	Consumers	Cost

STRATEGIES SPECIFIC TO LARGE TRUCKS				
Stronger Brakes/ Reduced Stopping Distances	All truck crashes with prior braking (approximately one-third of crashes).	227 annual fatalities from new NHTSA truck braking standard.	Vehicle buyer/ ultimately the public.	None. Slow penetration as fleet turns over, however.
Reduced Aggressivity of Large Vehicles	Passenger vehicle occupants in collisions with larger vehicles	No reliable estimate available. Five percent reduction in “other vehicle” occupant fatalities would equal nearly 200 individuals.	Vehicle buyer/ ultimately the public.	Demonstrating cost-benefits
On-Board Monitoring and Recording	Fatigue, work load, and behavior-related truck crashes	Benefits of full use (with active carrier management) would be huge. No specific estimate possible.	Carrier purchases systems. May have positive ROIs to carrier and thus no net cost.	Initial cost to carrier, technical support and management involvement required.
Truck Handling & Stability	Fatal truck crashes involving loss of control	ESC may prevent up to 439 truck-related fatalities annually (Jermakian, 2010b)	Vehicle buyer/ ultimately the public.	No major obstacles.
Tire Pressure Monitors	Fatal truck crashes caused by tire failure	Roughly 20 fatalities annually, based on LTCCS problem size estimate and assumption of 50% effectiveness. Substantial non-safety benefits as well.	Carrier purchases systems. May have positive ROIs to carrier and thus no net cost.	Initial cost.
Automated Transmissions	Fatigue and work load-related truck crashes	~25% crash reductions for new drivers, but no overall fatality estimate possible.	Vehicle buyer/ May have positive ROI.	Initial cost, perception that it is only a convenience.
Truck-Specific Navigation Aids for Risk Avoidance	Fatalities with navigational issues as a factor	Primarily an efficiency aid, but with secondary safety benefits. No overall fatality estimate possible.	Drivers or carriers purchase retrofit systems.	Valid concerns about device accuracy when non-truck systems used.
Truck Conspicuity & Enhanced Lighting/Signaling	Fatalities with truck conspicuity and nighttime visibility as a factor	Large target crash size (e.g., rear-end crashes into trucks) but no device effectiveness estimate possible today.	Vehicle buyer/ ultimately the public.	Demonstrating cost-benefits of new enhancements. Effectiveness of trailer-mounted warning systems unknown.
Video Mirrors	Various types and configurations of lane-changing crashes	Similar target crashes as SODS, but probably smaller potential fatality reduction benefits, perhaps 50 annually.	Carrier purchases systems. May have positive ROIs to carrier and thus no net cost.	Initial cost, driver training, technical support needed.
Enhanced Occupant Protection	Truck occupants in severe impact and rollover crashes	Truck driver fatalities would likely be reduced by more than 100 annually from full use of belt reminder systems.	Vehicle buyer/ ultimately the public.	Belt reminder systems: no serious obstacles. Other: demonstrating cost-benefits

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