Human Factors Study of Driver Assistance Systems to Reduce lane Departures and Side Collision Accidents

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Abstract

This study investigated the human factors issues related to the implementation of lane departure warning systems (LDWS) to reduce side collision and run-off-road crashes for heavy trucks. Lane departures can be either intentional (e.g., to pass another vehicle or avoid an object in the roadway) or unintentional (due to drowsiness, inattention or distraction). The report discusses the recent research and applications literature that evaluates the problem of lane departure accidents and the potential for LDWS to reduce the frequency and/or severity of those accidents. The report also discusses the issues related to the use of LDWS data that are recorded to improve the fleet and individual driver safety performance. The value of systems that range from simply warning the driver, with no even recorded, to the transmission of an event with the possibility of real-time intervention if driver performance is perceived to be degraded (e.g., due to fatigue or drowsiness). The study addresses the resources necessary to effectively integrate the information from these systems into the driver management system toward the goal of facilitating safe driving behaviors and reducing costly accidents. Truck accident data were analyzed to further evaluate the potential for safety benefits from LDWS. The Large Truck Crash Causation Study (LTCCS) data were analyzed with respect to the types of crashes that could be affected by LDWS (e.g., departed roadway, inattention, etc.). The analysis focused on rural highways and interstates with posted speed limits of above 50 mph. In addition, safety data for eight large commercial trucking fleets were analyzed to determine the relative frequency of accidents for which LDWS would reduce the occurrence or severity of lane or roadway departure accidents. The results indicated that, although the frequency of lane departure and run-off-road accidents was found to be relatively low, the consequences of these crashes can be very high. In addition, the relative frequency of lane departure accidents varied greatly from fleet to fleet. This indicates that the decision to implement LDWS or what type of LDWS to implement must depend upon a fleet’s own experience, rather than aggregate data.

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Introduction

The continual improvement of safety is important for commercial trucking operations, state and federal regulatory agencies and the general public. Figure 1 illustrates the encouraging fact that the fatality rate for heavy trucks has been significantly reduced over the past thirty years (*FMCSA Large Truck Crash Facts*, 2006). This improvement in safety outcomes has been the result of changes to roadways, driver behavior, and vehicles characteristics. For example design roadway characteristics, such as wider shoulders and energy absorbing barriers have improved safety and reduced traffic fatalities. A number of studies have illustrated the effectiveness of rumble strips on both the roadway shoulder and centerline (Harwood, 1993; Noyce and Elango, 2004). With respect to driver behavior, the decision to travel on limited access, multi-lane highways (e.g., interstates) that have traditionally experienced lower accident rates has been beneficial. The increased use of seat belts by truck drivers has reduced the injury severity and number of fatalities. Improvements to the vehicles, such as improved brakes, air bags, anti-lock brakes, etc. have also contributed to the reduction of fatalities.

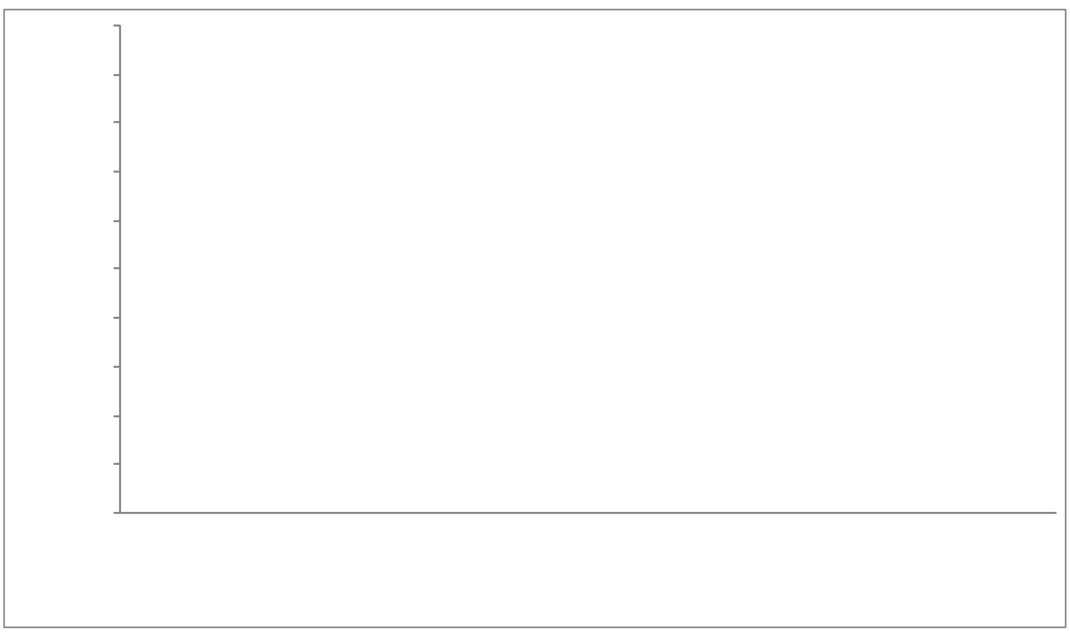

Figure 1. Reduction of Fatality Rates for Heavy Trucks Accidents

This reduction in highway accidents has, to a great extent, been due to what are often referred to as “passive” safety systems, in that they do not involve the real-time involvement and actions by the driver. Although the fatality rate was at an all time low in 2006 (2.34 fatalities per 100,000 vehicle miles traveled), the downward trend has leveled out during the last four years. Traffic safety authorities contend that the additional gains that can be expected from these passive systems will be more difficult to achieve in the future.

Another generation of safety systems in heavy trucks has been termed “active” safety systems. There are two categories of active safety system. One type of active safety systems is “semi-automatic” in that it involves a vehicle response without the input of the driver. Roll stability control systems are an example of this type of system. The sensors detect an unsafe condition (e.g., high lateral acceleration) and use a combination of engine and brake controls to reduce the potential of a rollover crash. These systems have been found to be effective, while “adding only marginally to the cost of a tractor trailer” (Pape, Harback, McMillan, Greenberg, Mayfield, Chitwood, Barnes, Winkler, Blower, Gordon, and Brock, 2007). The Federal Motor Safety Carrier Safety Administration has published a *Concept of Operations and Voluntary Operational Requirements* document for vehicle stability systems (Houser, Pierowicz and Fuglewicz, 2005a). Other examples of the semi-automatic, active safety systems are adaptive cruise control and forward collision avoidance systems. In these cases, forward-looking radar (or lidar) detects the distance, relative speed and acceleration/deceleration of a leading vehicle. If the combination of these factors indicates a potential collision, the vehicle is slowed by the actions of the engine, transmission and/or brakes to allow more space between the vehicles. The Federal Motor Safety Carrier Safety Administration has also published an operations and requirements document for automated cruise control/collision warning systems (Houser, Pierowicz and McClellan, 2005).

The second category of active safety systems involves the driver being more directly “in-the-loop.” These are generally designated as “warning” systems. That is, the sensors detect the potential hazardous condition and the is notified with an auditory warning, visual display, and/or haptic motion in the steering wheel or driver’s seat. . The driver is responsible for taking the corrective action necessary to avoid the hazard. Some side collision warning systems fall into this category. The sensors detect when another vehicle is alongside or in the “blind spot” and a warning is given to the driver (e.g. on the mirror or in the driver’s line of site). Another configuration provides a warning signal if the driver activates the turn signal when there is another vehicle in close proximity. The types of systems are not necessarily well delineated by the terminology. For example, some “forward collision warning systems” (also called “headway warnings”) detect the hazard (based on distance/speed/acceleration) and informs the driver with an auditory and/or visual signal. However, the same term is also used to represent a semi-automatic system that uses “active braking” (e.g., defueling or engine brakes) to slow the vehicle without, or in addition to, the driver’s input.

The focus of this report is on safety systems that are intended to reduce accidents associated with leaving the travel lane. Two terms are used for this scenario: lane departure and roadway departure (also referred to as run-off-road). The difference between these two results and different definitions for each can lead to different estimates of the relative frequency of these accidents. For example, Pomerleau, Jochem, Thorpe and Batavia (1999) estimated that “run-off-road” accounted for 20 percent f all police reported crashes and over 41 percent of all in-vehicle fatalities. These authors used the 1992 General Estimation System (GES) and Fatal Accident Reporting System (FARS) data bases and noted that the majority of the crashes occurred on straight roads (76 percent) and during good weather conditions (73%). Sen, Smith and Najm (2003) used the definition of “lane change crash” that was restricted to two-vehicle crashes that occurred when one vehicle encroached into the path of another vehicle initially on a parallel path with the first vehicle that was traveling in the same direction. Using this definition and the GES data base for 1999 the authors concluded that approximately 539,000 lane change crashes occurred. Of these, approximately 10% involved large trucks changing lanes and light vehicles going straight. The reverse situation, light vehicles changing lane accounted for 5 percent of the crashes. They also noted that the highest relative frequency of crashes for trucks occurred during the “merging” scenario (42 percent). It is interesting to note from their data that the light vehicles collided with trucks going straight at twice the proportion of the reverse situation. An important characteristic of the crashes investigated in this study was that 74 percent of the on-roadway lane change crashes occurred at speeds of less than 45 mph (although speed was not documented in 25 percent of the cases). Benavente, Rothenberg and Knodler (2006) found that lane departure crashes accounted for 19 percent of all crashes in Massachusetts. However, due to the high relative severity of this type of accident, 46 percent of the lane departure crashes resulted in a fatality. Najm and Smith (2007), in a study of the 2003 GES data, found that lane change crashes accounted for 23 percent of all police reported heavy-truck crashes. This study also found that road departure (run-off-road) crashes accounted for 15 percent of the heavy truck crashes. According the Large Truck Crash Causation Study (FMCSA, 2007) 32 percent of the sample of large truck crashes were coded with a critical event of running into another lane or off the road.

Lane departure accidents can be associated with intentional or unintentional control actions of the driver. For example, changing lanes to pass another vehicle on a four-lane roadway can lead to a crash if there is another vehicle in the adjacent lane. Even a roadway departure (run-off-road) crash can be “intentional” if the maneuver was required to avoid an object (e.g., deer) on the roadway. These types of crashes are reasonably easy to analyze and document with respect to the initial action that caused the accident. The “unintentional” actions of leaving the lane due to distraction, inattention or drowsiness are often more difficult to detect and categorize. Distractions can be an action that the driver initiates (inserting a CD) or uncontrolled (unexpected movement of a person or item in the vehicle). Lerner, Singer, and Huey (2008) found that drivers often did not consider the immediate roadway characteristics or conditions when deciding to use in-vehicle systems. From a review of the literature, Ranney (2008) concluded that distraction is involved in approximately 10 percent of on-road accidents. Using the 1999 Automotive Sampling System/General Estimates System (GES) Sen, Smth and Najm (2003) estimated that distraction contributed to approximately 15 percent of the lane change crashes. Stutts, Feaganes, Reinfurt, Rodgtman, Hamlett, Gish and Staplin (2005) in a naturalistic driving study observed that drivers were engaged in potentially distracting activity during approximately 15 percent of the time their vehicles were moving. It is important to note that these studies investigated the general driver population, not commercial drivers, particularly on rural interstates that account for the vast majority of the miles travelled. Hanowski, Perez and Dingus (2005) in a naturalistic study of long-haul truck drivers documented 2737 “critical incidences” (crashes, near-crashes, and crash-related conflicts). Of these, 178 (2 percent) were attributed to driver distraction. In addition, of the 178 distraction related incidences, 43 were accounted for by only two drivers. As with many constructs, “inattention” can have different meanings. Wang, Knipling and Goodman (1996) in a study of light vehicle used the NHTSA Crashworthiness Data System (CDS) to divide “inattention” into three categories: distraction (13.2%), looked but did not see (9.7%), and sleepy/fell asleep (2.6%) for light vehicle drivers. For long-haul and short-haul truck drivers, Misener, Nowakowski, Lu, Koo, Margulici, Spring, Johnston, Kim, Kickey, Kuhn, Kretz, Robin, and Walker found that “inattention” included multitasking while driving (e.g., planning the next stop, interpreting ineffective road signage, etc.). For commercial trucking operations, some in-vehicle information systems (e.g., text based messaging) can also distract the driver’s attention from the primary task of driving (Llaneras, Singer and Bowers-Carnahan, 2005). The Large Truck Crash Causation Study (FMCSA, 2007), found that, when the truck caused a two-vehicle crash, 46 percent were coded with the critical reason being driver recognition (inattention or externals distraction). The LTCCS Summary Tables (2006) indicate that inattention was an associated factor in 12 percent of the one-vehicle crashes. From the LTCCS data, Misener, et al. (2007) state that, “overall, inattention or distraction was an associated or related factor in over 25 percent of crashes.” The LTCCS Analysis Brief (FMCSA, 2007) reported that driver inattention was an associated factor for 9 percent of the truck crashes. The estimates from the LTCCS study were 2 percent and 8 percent for internal and external distraction being an associated factor, respectively.

In addition to the state of the roadway or the vehicle, the state of the driver is another important factor in the occurrence of lane departure and roadway departure accidents. One area that has recently received an increasing amount of attention, particularly for commercial drivers is fatigue and drowsiness. McCartt, Rohrbaugh, Hammer and Fuller (2000) reported that nearly half of the long-distance truck divers reported falling asleep while driving. Approximately 25 percent reported falling asleep in the past year. The physical condition of apnea has also been receiving increased attention within commercial fleets, as well as regulatory agencies (Pack, Dinges, and Maislin, 2002; FMCSA, 2002). In addition to fatigue and drowsiness, decreased attention can also be related to intoxication or the use of prescription, nonprescription or illegal drugs. The LTCCS Summary Tables (2007) indicate that prescription drug use was an “associated factor” (as opposed to a cause) in 26% of the crashes. Alcohol and illegal drug use by the truck driver were coded as being an associated factor in a relatively small number of cases, (1 percent and 2 percent, respectively). However, alcohol and illegal drug use were coded as associated factors in 9 percent and 7 percent of the cases, respectively, for the other vehicle driver.

Whether an accident occurs as a result of the driver's intentional action or whether it is due to unintentional travel onto the shoulder or into an adjacent lane, a system that warns the driver of the risk would seem to be beneficial. The next section addresses the recent literature related to the development and use of LDWS.

Background of Lane Departure Warning Systems

One of the initial objective of this research effort was to evaluate the effectiveness of lane departure warning systems (LDWS) for commercial truck operations. However, during the period of the study, a number of large scale studies were initiated to evaluate the hardware and software, as well as to make recommendations for the driver interfaces. As previously discussed, some of the studies have addressed LDWS only, while others included LDWS that was integrated with other systems (e.g., side collision alert). Although the implications of an integrated system are discussed later, the focus of this report in on lane departure warning systems.

There are a number of "platforms" that have been used to evaluate these systems. These have included (1) laboratory studies, (2) driving simulator studies, (3) test-track studies, (4) naturalistic driving studies, (5) field operational tests and (6) actual fleet experience using the systems. For example Kullack, Ehrenpfordt and Eggert (2007) conducted a laboratory study to evaluate a behavioral approach that relied on the reflexive principle to reduce the driver's reaction time to lane departure. Svenson, Gawron, and Brown (2005) and Gawron, Brown, Ahmad, Smyser, Watson and Tang (2007) used the National Advanced Driving Simulator to compare four different automobile crash avoidance systems with different capabilities. Ference, Szabo and Najm (2007) presented "crash-imminent" test scenarios to evaluate in-vehicle safety systems (including LDWS) using a test tracks environment. Lee, Olsen and Wierwille (2004) used an instrumented vehicle in a "naturalistic" driving study to investigate driver behaviors with and without LDWS. Field operational tests (FOT) have been conducted for both automobile (Emery, Srinivasan, Bezzina, LeBlanc, Sayer, Bogard and Pomerleau, 2005; Alkim, Bootsma and Hoogendoorn, 2007; Wilson, Stearns, Koopman and Yang, 2007) and heavy trucks (de Ridder, Hogema and Hoedenaeker, 2003; Battelle, 2004; Orban, Hadden, Stark and Brown, 2006; Houser, Groeller, and Bishop, 2006; LeBlanc, Sayer, Winkler, Ervin, Bogard, Devonshire, Hagen, Bareket, Goodsell and Gordon, 2006). Ball,Versluis, Hendrickson, Pittenger, Frank, Stewart, and Murray (2005) documented decision variables that contribute to the decision of whether to employ crash avoidance technologies in commercial trucking operations. They surveyed motor carriers management, drivers, owner-operators, truck manufacturers, safety system manufacturers and insurance companies to document the factors that are involved in the development, purchase and use of on-board safety systems. Recently, a number of commercial fleets have been installing LDWS on many or all of their trucks. As this process proceeds, the exposure (e.g., sample sizes) will become sufficient to draw valid conclusions about the overall functional effectiveness of LDWS.

There are three primary scenarios that can lead to hazards resulting from lane departures. One scenario is the intentional changing of lanes with another vehicle in the blind spot. The potential for this type of crash could be reduced with a blind spot detection system, but would not be reduced by systems that only detect the lateral position of the vehicle. A second scenario involves the vehicle leaving the lane on a curve due to the excessive speed or avoiding an object on the roadway. Roll stability control systems have the potential to reduce the occurrence and/or severity of this type of accident. Again, a system that only provides a warning of the vehicles proximity to the lane boundary would not provide a significant benefit for this situation. The third scenario involves an unintentional lane departure due to inattention, distraction or drowsiness. This is the scenario in which the lane departure warning system would provide the most benefit. Pomerleau, Jochem, Thorpe and Batavia (1999) found that 53 percent of road departure crashes involving heavy trucks involved inattention or drowsiness.

From the laboratory studies to the field operational tests, the results have illustrated benefits of LDWS. For example one of the older studies, Pomerleau, Jochem, Thorpe and Batavia. (1999), estimated that LDWS could prevent approximately 30 percent of the road departure crashes in heavy trucks. This value is higher than the estimates of de Ridder, Hogema and Hoedemaeker (2003), who concluded that approximately 10 percent of the heavy truck injury accidents on secondary roads and motorways could be prevented if equipped with LDWS (referred to as a "lane drift warning system"). Orban, Hadden, Stark and Brown (2006) concluded that LDWS would decrease the number of large truck crashes by approximately 24 percent. The results of one field operational test are encouraging, although difficult to interpret statistically. During the field operational test reported by Houser, et al. (2006), there were no crashes associated with lane departures during the 5,842 driving days (1.4M VMT). Houser (2006, 2008) concluded that 21 to 23 percent of single vehicle roadway departures and 17 to 24 percent of rollover crashes could be reduce with the use of the LDWS based on the field operational test data. LeBlanc (2006) also observed no crashes resulting from lateral drifting in their study of light vehicles. The study included a side radar warning system. This study did observe that the number of excursions close to the lane boundary was reduced by 50 percent. This indicated an improvement in lane-keeping performance, although the relationship of this measure to actual crashes is unknown. Note that the first three studies evaluated lane departure systems alone, without side collision sensors or active steering. The differences in these results illustrate that the design and use of the systems, as well as the driving environments and driver population, can significantly affect the estimates of the benefits.

In addition, the measures and metrics used to evaluate the systems are important to the conclusions that can be drawn. The metrics used to evaluate LDWS can be either “system performance measures” or “human performance measures.” An example of the broadest system performance measure is run-off-road crashes (Boyle and Najm, 2001; Najm, Koopermann, Boyle and Smith, 2002). This has high face validity, but occurs relatively infrequently (low sample size) and it can be influenced by many factors that would not be affected by lane departure systems (e.g., avoiding an animal on the highway). These factors can lead to relatively low sensitivity of this type of system performance measure. A system performance measure that has more sensitivity is the number of lane border crossings (LeBlanc, et al, 2006). Although this is a more sensitive measure, the construct validity is lower in that it is not a direct measure of safety (accidents). System performance can be measured in the context of LDWS by the performance of the hardware and software, independent of the driver response and accident outcomes (McLandres, Spitzer, Hammerl and Smith, 2003). Talmadge, Dixon and Quon (1997) developed an instrumented vehicle to investigate lane change maneuver to collect information relevant to the evaluation of lane change crash avoidance systems. Szabo, Murphy and Juberts (1999) conducted an effort to develop a quantitative set of metrics to measure the performance of the LDWS hardware and software systems. Subsequently, Szabo and Norcross (2007) published a set of objective test and measurement methods for evaluating road departure crash warning system hardware and software that focused on two areas: correctness and timing.

An example of a performance metric that is on the “human performance” end of the spectrum was used by Tanaka, Ishida, Kawagoe and Kondo (2000). In their study, the electrical muscle potential (electromyography) of the driver’s muscle used in steering maneuvers (deltoid) was used as a measure of the driver’s workload with and without LDWS. The conclusion of this study was that the LDWS was effective in reducing the driver’s workload. Although this is one operational definition of “effectiveness” of a LDWS, it has low predictive validity relative to the impact of the systems on accident rates and severity.

Another dimension of the measurement of effectiveness relates to whether the metric is addressing “performance” or “preference.” User acceptance surveys are a good example of “preference” measurement. Although driver’s opinions are subjective, they are an important dimension of LDWS overall effectiveness. In fact, they might be one of the most important factors in the successful implementation of these systems. Van der Laan, Heino, and De Waard

(1997) developed a questionnaire procedure to evaluate the driver acceptance of new in-vehicle safety systems that has been used successfully in LDWS studies. Each of nine items (e.g., nice/annoying, raising alertness/sleep inducing, etc.) is rated on a five-point scale. These authors separated the concepts of "usefulness" and "satisfaction." The procedure was found to be both sensitive and reliable.

In addition to performance measures that address tracking performance and preferences, other studies have included other behaviors that have been associated with the use of the systems. For example, Leblanc, et al. (2006) found that drivers significantly increased their use of turn signals when passing compared to when they did not have a LDWS. Driver workload is another factor that has been investigated with objective (steering variation) and subjective (survey) methods. De Ridder, et al. (2003) concluded that LDWS systems could increase a driver's workload, particularly on narrow lane roadways.

Issues Related to Lane Departure Warning Systems (LDWS)

The research discussed above illustrates the importance of lane departure accidents and have indicated potential benefits of LDWS. However, there are a number of issues related to the systems that need to be addressed. This report does not address the hardware and software aspects of the systems. There are an increasing number of suppliers of LDW systems and there are rapid advances being made in the physical capability of the systems. The result is that any discussion of this area is obsolete by the time that it is published. The focus of this report is on the driver interface and the use of the data collected to improve safety performance cost effectively. Campbell, Richard, Brown and McCallum, (2007) provide a good review of the human factors aspects of the driver interface for collision warning systems. In addition, Houser, Pierowicz and Fuglewicz (2005b) and LeBlanc, Sardar, Nowak, Tang and Pomerleau (2008) provide operational requirements for LDWS in heavy trucks that address the driver interface. This report discusses specific issues that are not addressed in those publications.

The most basic systems (functionally, not technologically) detect a potential hazard and warns the driver. In this case, when the truck is near the lane boundary a warning signal is given to the driver. The signal can be auditory, visual, haptic or a combination of these modes. The auditory signal is generally a "rumble strip" sound due to the familiarity of drivers with this sound as a warning of lane departure. The advantage of an auditory sound is that it is omni-directional and does not require a focused attention on a particular location. One issue with some of the current systems is that the same signal is used for both departing the left and the right side of the roadway. Although the signal is "coded" by the location of the speakers (left or right), if a driver is drowsy, their sound localization ability is diminished. Particularly in the case where the driver is used to rumble strips only on the right boundary, the "natural" immediate response could be to turn the vehicle left, even if they are crossing the left boundary. It would be better to have two, different auditory sounds that can be distinguished based on frequency or waveform, in addition to location of the speaker.

Tan and Lerner (1996) found that experimental subjects could localize the direction of an auditory warning signal in a vehicle “with reasonable speed and accuracy” and with relatively few perceptual reversals. They did find that there were large differences in performance based on the sound system and speaker locations. In addition, the subjects in this study were not fatigued or drowsy and there were no competing sounds (e.g., radio/CD) other than simulated traffic noise. Harder, Bloomfield and Chihak (2003), in a study of auditory warnings for snowplow trucks, recommended hazard-specific warning signals. A “double beep” was preferred to a single sound for side collision and a “screech” sound was preferred for a forward collision avoidance warning.

A general human factors principle for warning systems is to instruct the human as to the correct action (Use Stairs) rather than to avoid the incorrect actions (Do Not Use Elevator). The analogy to this situation would be that the signal would indicate which direction to turn the wheel, rather than the opposite. However, rumble strips inherently indicate the location of the hazard and, thus, the correct response is to turn away from the hazard.

The issue of false alarms (false positives) is important in the context of driver acceptance. This is particularly the case if the data are recorded for later evaluation or transmitted, real-time to the back office. From the driver’s perspective, if their performance is evaluated based on the incidence of recorded lane departure events, it is important that the false alarm rate is low. A false alarm, in this context, is defined as a warning that is given by the system although there was neither a valid threat nor an unnecessary risk behavior exhibited by the driver. For example, sensor malfunction (e.g., due to snow) or actions taken to avoid an obstacle with no other vehicle in the area represent false positives. These errors are also referred to in the literature as “annoyance” or “nuisance” signals. Both the research studies and the experience of drivers in field operational tests have indicated that auditory false alarms tend to be more annoying than visual signals (Calmpbell, Hooey, Camey, Hanowski, Gore, Kantowitz, and Mitchell, E., 1996). This is particularly the case for auditory “speech” warnings. This is primarily due to the fact that the auditory signal less easily ignored than a visual display.

The field operational tests have included a driver acceptance component to the evaluation. Most of these studies have found acceptance to be relatively high. For example Battelle (2004) found that 62 percent of the driver indicated that their driving changed “somewhat” or “a lot” as a result of using the LDWS. However, it is important to note that these studies evaluated systems that only warned the driver and did not record their performance for later evaluation. When the capability of recording the incident is included in the system, driver acceptance is significantly reduced. Similarly, when the driver has the ability to turn the system off (e.g., in heavy traffic) the acceptance of the system increases. De Rider et al. (2003) found that 50 percent of the professional truck drivers would prefer to drive with the LDWS. However, 29 percent would prefer not to have the system and the remaining 21 percent were non-committal. These results were obtained for systems that did not record the data for future evaluation.

Part of driver acceptance is the drivers trust in the system to provide them with accurate and useful information. Rudin-Brown and Noy (2003) found that the presence of reliable lane departure warnings improved the drivers' lane-keeping performance. However, drivers reported a high amount of trust in the systems even when the accuracy was low. The potential for unjustified reliance on an inaccurate or malfunctioning system could have serious safety implications. The majority of the system evaluation studies that have been cited above addressed the ability to detect hazardous conditions. That is, a system that can reliably detect the difference between "true positives" (detection of lane boundary proximity) and "true negatives" (no warning when the vehicle position is not at the lane boundary) provides good sensitivity. However, false positives (false alarms) in which the system detects a hazard when one does not exist can reduce both the operational effectiveness of the system, as well as driver acceptance and use. Some evaluation studies (e.g., Svenson, et al., 2005; Gawron, et al, 2007) did not provide false alarms during the test trials. Talmadge, Chu, Eberhard, Jordan and Moffa (2000) found that a relatively high false alarm rate (42 per our) was not considered to be annoying by the subjects. These were naive subjects in a vehicle with which they were not familiar. The warning was only visual and approximately one-third of the warnings were not noticed by the subjects. Other technical reports have concluded that much lower false alarm rates can negatively affect driver opinion. Tan and Lerner (1996) recommended a false alarm rate of less than 10 percent for intersection collision avoidance systems, based on engineering judgment. The consequences of a false alarms obviously affects the acceptable level for false alarms. For a condition that results in a high probability of a life threatening threat, a higher false alarm rate is more acceptable. For LDWS, a study by Campell, Richard, Brown and McCallum. (2007) stated that the acceptable level for false alarms had not been addressed in the research literature. These authors recommend that the rate for a LDWS should be less than once per week, based on expert judgment.

Beyond annoyance, false alarms can also have a negative consequence when an "overcorrection" occurs. In a study of rumble strips, the over-correction effect can be exacerbated for drivers who have degraded performance due to alcohol, fatigue, etc. (Spainhour and Mishra, 2008). One potential contributor to the problem of overcorrection is the observation in the field operational test that the drivers indicated that they were sometimes "startled" by the warnings (deRidder, et al., 2003). The ability of the driver to adjust the intensity of the warning signal can reduce the potential of a startle response. Batavia (1999) discussed the possibility of having adaptive lane departure systems that adjust for the tracking behavior of the driver. He characterized drivers as being "loose" (higher lane position variance) and "tight" (lower lane position variance). It might be appropriate for the threshold for warning be different for the two groups. The objective was to reduce the number of "nuisance" warning by matching the person's lane tracking behavior. Goldman, Miller, Harp and Plocher (1995) and Gawron et al. (2007) also discussed the potential of adopting systems that adapt to individual drivers capabilities to improve the effectiveness of warning system.

One issue that relates to LDWS, as well as to other active safety system is whether drivers will actually become less attentive when using the systems. Anecdotal evidence from interviews indicates that some drivers drive longer (and become more drowsy) on highways that have rumble strips on the shoulders. The rational is that the rumble strips will keep the driver awake. Rudin-Brown and Noy (2002) discuss the theories related to the drivers' goal of maintaining an "acceptable level of risk." This literature goes back 25 years to the concept of "risk homeostasis" (Wilde, 1982). The theory is that people tend to develop individual levels of acceptable risk. When the risk is reduced (e.g., with seat belts), they adopt behaviors that tend to bring back to the acceptable level (e.g., driving faster or accepting shorter gap distance when passing). Summala (1988) also discusses drivers adaptation to risk in the context of highway safety.

Ho (2006) addressed the situation of multiple threat scenarios for in-vehicle collision warning systems. For example, a driver's action to avoid an obstacle on the roadway could be negatively affected by a lane departure warning. This can also occur when multiple warning systems are used in a vehicle (e.g., LDWS and forward crash warning). In this case, the different signals can compete for the driver's attention and it is important that the signals do not result in confusion. In addition, to the extent that there are differences in the seriousness of the threats, it is important that the driver does not increase the potential or severity of the risk by attending to the less critical signal. The concept, referred to by the authors as "zero-risk" is that if the consequences of risk are not experienced, people (e.g., drivers) cannot rationally evaluate the risk and, subsequently, control their own driving behavior.

There are many issues related to the implementation of LDWS. Many of these are being addressed the research and applications literature as discussed in this report. In addition, as the hardware and software technology advances, many of the issues will be resolved. However, these same advances will potentially cause new issues to emerge that are not being adequately addressed. A good example is the area of active control (e.g., steering and/or braking) in combination with the warning. The research on the human interface aspects of these systems seems to be inherently behind advances in the technology. The traditional approach has been to determine “what is technologically possible” and then determine “the best implementation” of the technology. An alternative approach is to determine “what would be most beneficial” and then develop the technology required to meet that requirement. The next part of this report addresses the question of how information gained from LDWS might be used to analyze safety systems (including driver training) to positively change driver behavior and reduce the potential for accidents.

Data Issues Associated with LDWS in the Driver Management System

During discussions with both drivers and management personnel in commercial trucking operations one of the most important issues to be addressed is how the data are handled. As previously discussed, LDWS can range from simply warning the driver, with no data recording to a real-time interactive response from the back office of the company (e.g., dispatcher). Each of these approaches to LDWS data will be addressed.

If the system only warns the driver, with no incidence recorded, there is no data to be transmitted, saved or controlled. This type of system has had the best driver acceptance due to the reduced concern for how the data could be used or misused. However, this type of system also provides the least capability of being used to improve the individual driver performance and or the company safety experience through the driver management system.

The next level of LDWS data complexity is to record the lane departure event on the vehicle ECU or independent storage for future download and analysis. This can be a separate system or part of an integrated system that includes other events (e.g., hard braking, etc.). In addition, other scenario data can be collected to be used in conjunction with the lane departure event. For example, road speed, accelerator position, brake activity, etc. can be used to determine if the event was part of a larger intentional or unintentional maneuver. These data can also be used for accident reconstruction through recordings for a few seconds both before and after an impact. However, this is not the context for the current report.

An issue from both the perspective of the driver and the trucking company management is the use and control of the data. Drivers are concerned with the “big brother” issue and being evaluated on what they might consider invalid or unreliable measures. Companies are concerned with the legal liability issues of having information that might have been used to predict a problem but were not analyzed or, more seriously, were analyzed but without taking corrective action.

The downloaded data can be used to evaluate the company drivers, as a group, without individual identification. This allows the company to know if there should be specific training related to particular driving behaviors. The analysis can include demographic information to determine if particular groups should be the focus of additional training (e.g., new drivers, geographic regions, older drivers, etc). However, grouped data obviously does not allow for targeted training, discipline or reward for an individual driver based on performance measures. The analysis required to determine whether the driving behavior of individual drivers should be addressed is more complicated. The issue revolves around that issue of "true positive," "false positive," true negative" and "false negative" conditions.

A "true negative" response is simply the fact that the system is not indicating a problem when there is no hazard involved. In the case of LDWS, this would occur when the driver is within the lane or indicates an intentional departure from the lane (e.g., with the turn signal). The objective is that this condition would occur 99.99^+ percent of the time for a good driver under normal conditions.

	Hazardous Condition	**No Hazard**
Warning	True Positive	False Positive (False alarm)
No Warning	False Negative (Miss)	True Negative

The "true positive" condition is the reason lane departure systems are implemented; that is to detect and reduce the potential of accidents. Although the frequency of this condition is hopefully very low, when it does occur, it is important that the system works effectively. The evaluations in the applications literature that were discussed in the Introduction and Background sections of this report have extensively addressed the ways of documenting and evaluating these issues.

The two types of errors that can occur with the systems are often the larger concern from the standpoint of both driver acceptance and company concerns. First the "false positive" condition (also referred to as a "false alarm") occurs when a warning is given although there is no hazard present. From the driver's perspective, a false alarm is can also be characterized as a warning when the driver was aware of the hazard. This is sometimes referred to as an "annoyance" or "nuisance," rather than a false alarm.

The final category is a “false negative” condition in which no warning is given, even though a hazard exists. The most serious danger posed by this condition is if the drivers develop a reliance or even dependence on the system to the point where their attention to the driving task is reduced. As discussed previously in the literature review, there is evidence that this type of behavior change can occur.

Figure 2 illustrates the relationship among these conditions in a Signal Detection context. The two distributions represent the two situations, *No Hazard* (on the left) and *Hazard* (on the right). For the purposes of the example consider “crossing the lane boundary” as the hazard. The threshold criterion (vertical line on the graph) represents the distance from the boundary at which the warning is given. To the left of the vertical line, no warning is given and to the right of the vertical line the driver receives a warning. The area under the “No Hazard” curve to the right of the line represents the frequency of false alarms (false positive). The area under the “Hazard” curve to the left of the line represents the frequency of misses (false negative). As the distance from the lane boundary to the threshold increases (moving the vertical line to the left), the chances that the boundary will be crossed decreases (true positive warning increases). However, this inherently results in more false alarms (false positives) in which the warning occurs, although the driver would not have crossed the boundary. If the threshold position of the warning is changed so that the vehicle is closer to the line before the warning is initiated (vertical line moved to the right), the false alarm rate is be reduced; however, more false negatives (misses) would occur and the vehicle would cross the boundary more often.

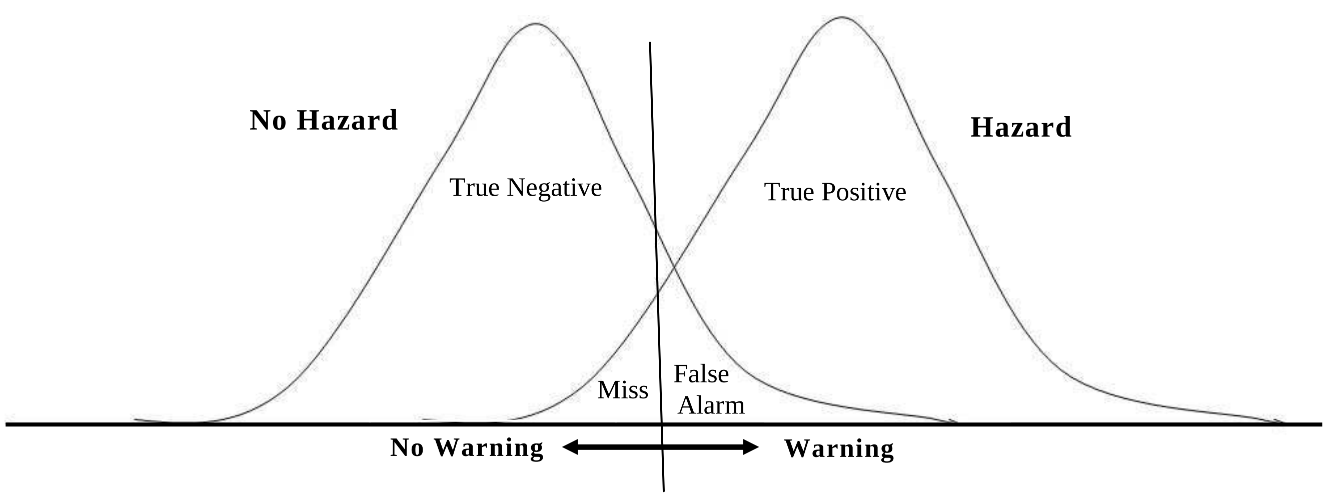

Figure 2. Representation of Warning Error Trade-offs

There is a natural trade-off between the frequency of false alarms and the frequency of misses. The drivers’ acceptance of LDWS is negatively influenced by the false alarms. However, by accommodating this concern, it is possible that the effectiveness of the systems could be reduced. If the frequency of false alarms is high, the driver will become habituated to the warning signal to the point where it is ignored or not even noticed. Both of these scenarios are an issue in how the data are used in the driver management system. Both false alarms and misses negatively impact the ability to effectively use the data from the LDWS to measure and improve driver performance.

The previous discussion addresses the threshold that is used to warn the driver of a potential hazard. In addition, the choice of the threshold used to decide what data should be stored, downloaded and analyzed has a significant effect on the time and personnel required to document and interpretation the data. One of the primary concerns of commercial fleets that are trying to decide whether to implement LDWS that store and/or transmit lane departure information is the time required for the analysis and interpretation of the data.

One issue is the definition of a lane departure event. For example, leaving the lane to avoid an obstacle is actually a positive maneuver. However, a high number of lane departures in a relatively short distance (or period of time) is potentially an indication that the driver is drowsy. The issue becomes, how many departures in what distance should be recorded as an "event." In addition, the duration of the departure might be an important indicator of a fatigued, drowsy or inattentive driver.

Surveys have indicated that many commercial truck drivers tend to track toward the shoulder of the road rather than down the center of the lane. It is felt by these drivers that the potential treat is higher from traffic on the left of the truck than it is toward the shoulder on both two-lane and multi-lane highways. This might indicate that lane departures toward the shoulder should be weighted lower than departures to the left.

The definition of a lane departure "event" is particularly important if the data are transmitted for real-time evaluation and potential intervention. From a safety perspective, this capability might have the highest benefit for both individual drivers and companies. One of the most frequently cited benefits of LDWS is to reduce the potential for accidents associated with fatigue or drowsiness. Even the less complex LDWS that only warn the driver of a lane departure can help the driver understand that it might be beneficial to stop and rest. However, if lane departure events can be reliably used to detect, in real-time, that an individual driver's behavior is degraded, it might be possible for company personnel to intervene and contact the driver to recommend that the driver take a break. The potential of this type of interactive system is dependent upon the ability to effectively detect degraded performance while ensuring that there are few false alarms.

One of the issues related to a real-time intervention system is the personnel required to download, analyze and interpret the data if it is either stored or transmitted to the back office in real time. One model would have the dispatchers, who are already in contact with the drivers interact with the driver if there is an indication that their performance is degraded. Another model is to have safety personnel either with the dispatchers, or at a separate location be responsible for the evaluation. The advantage of using safety personnel is that it would allow the dispatcher to deal with conflict resolution related to scheduling, route changes, customer communications, etc. rather than driver discipline issues. The cost of personnel to document, analyze, interpret and act upon the data from a LDWS should be included in the cost analysis when deciding whether and/or how to implement the systems.

Analysis of the Large Truck Crash Causation Study Data

The Large Truck Crash Causation Study (LTCCS) studied 963 fatal and injury crashes involving trucks at 24 sites in 17 states from 2001 to 2003. The LTCCS has provided databases that are available on the internet from the Federal Motor Carrier Safety Administration (http://www.fmcsa.dot.gov). The data from the internet consists of 43 separate SAS or excel files. The excel data sets were combined into one file that could be used for the comprehensive analysis. Due to the same variables being included in many of the various data sets, it was necessary to eliminate the redundancy. The total number of columns (variables) in the resulting data set was 406. There were a total of 2284 vehicles that were included in the study. However, of those, only 2078 were involved in crashes that the LTCCS researchers considered to have sufficiently valid to include in the data analysis. The questionable data were labeled in the data set (RATWeight = 0) and were eliminated from the analysis. The resulting data set included a total of 1123 trucks (GVEBodyType = 60 to 64 and 66 to 78). This definition of heavy truck was adopted for this study to be consistent with the definition in the LTCCS (gross weight rating > 10,000 lb.).

The LTCCS Summary Tables provide a number of estimates of lane departure and run-off-roadway crashes. For example from the sample observed in the LTCCS, the estimates of the percentage of crashes associated with being over the lane line on the left and right were 13 and 11 percent, respectively. These estimates are related to the critical pre-crash event (see Appendix A) and included all roadways, independent of travel speed.

The data from the LTCCS crash data set were further analyzed to evaluate the potential for crash avoidance with LDWS. The data included in the current report were selected to be representative of crashes involving lane departures that LDWS might impact. Two roadway groups were included. The first grouping was all “non-local” roads based on the LTCCS variable, *Trafficway Functional Class*. The data for non-local roads included all crashes that did not occur on Trafficway Functional Class 6 (rural local) or Class 13 (urban local). There were a total of 1924 vehicles of which 1036 were trucks involved in these crashes. The second roadway grouping included rural interstates and rural U.S. highways. Another restriction was that only highways with posted speed limits of 50 mph or greater were included. The LTCCS variable *Route Signing* was used for this classification, in combination with the variable *ADAPostedSpeed*. There were a total of 886 vehicles, of which 569 were trucks, that were involved in crashes on these highways. This group represented rural highways where LDWS potentially provide the most benefit. In addition, most LDWS operate only at higher (e.g., highway) speeds.

Table 1 indicates the percentages of crashes in the LTCCS separated into the following variable classifications according to the *Large Truck Crash Causation Study (LTCCS) Analytical Users' Manual* (http://ai.volpe.dot.gov/ltccs/documents/LTCCS_Manual_Public.pdf) and the *Large Truck Crash Causation Study Codebook*. (http://ai.fmcsa.dot.gov/ltccs/data/documents/LTCCS_Codebook.pdf).

- Pre-Event Movement
- Critical Event
- Location
- Crash Code
- Accident Type

The definitions, sources, cross references and variable name for these variables are presented in Appendix A. The codes that are related to lane departures (either intentional or unintentional) are listed in the table. The crash codes that might be reduced by the implementation of LDWS are indicated by shading (▭). It I important to note that the table presents the empirical percentages observed from the LTCCS sample. The data have not been weighted to represent the nation-wide estimates. It is the relative values, as opposed to the absolute proportions or inferences to a population that are of interest in the current study.

One item that stands out from the table is the ***Location*** variable that indicates that a relatively high percentage of both light vehicles and trucks in the LTCCS sample of crashes "stayed on the roadway, but left the original travel lane" (19.4 to 23.1 percent). Similarly, the percentage of vehicles that left the roadway ranges from 8.8 percent to 13.1 percent. The percentage of trucks that left the roadway was higher than the percentage of all vehicles (9.3 and 8.8 versus 13.1 and 12.2). This could be related to the vehicle weight and the lack of maneuverability of heavy trucks.

The variable, ***Critical Event***, is used to identify the "event which made the crash imminent." The values for this variable that relate to leaving the travel lane or leaving the roadway range from 1.8 percent to 6.2 percent. From the values in the table, it appears that for "all vehicles" more crashes were coded as traveling "over the lane line on left side of the travel lane" than "over the lane line on right side of travel lane." For heavy trucks, this same

Code Number and Meaning	All Vehicles		Trucks	
	Non-local	Hwy >50	Non-local	Hwy >50
Location				
2 - stayed on roadway but left original travel lane	23.08	20.73	22.39	19.40
4 - departed road way	9.25	8.82	13.13	12.17
6 - returned to roadway	1.14	1.31	0.87	1.23
7 - entered roadway	0.52	0.75	0.48	0.71
Critical Event				
10 - over lane line on left side of travel lane	5.72	4.78	3.76	3.53
11 - over lane line on right side of travel lane	2.60	3.75	2.80	4.06
12 - off the edge of the road on the left side	1.82	2.16	2.51	3.17
13 - off the edge of the road on the right side	3.48	3.75	5.60	6.17
60 - from adjacent lane (same direction) -over left lane line	3.79	5.16	3.96	6.00
61 - from adjacent lane (same direction) -over right lane line	4.47	6.00	5.12	7.76
62 - from opposite direction-over left lane line	4.78	1.50	6.08	2.29
63 - from opposite direction-over right lane line	0.05	0.00	0.10	0.00
Crash Code				
1 - right roadside departure, drive off road	2.86	2.91	4.63	4.76
6 - left roadside departure, drive off road	1.72	1.88	2.32	2.65
4 - sidewipe/angle-changing lanes to the right	2.23	3.28	2.32	3.53
47- sidewipe/angle-changing lanes to the left	2.60	3.85	2.41	3.88
48 -sidewipe/angle-specifics other	2.49	3.19	2.03	2.82
49- sidewipe/angle-specifics unknown	0.00	0.00	0.00	0.00
64- sidewipe/angle-lateral move (left-right)	1.87	1.03	0.48	0.18
65- sidewipe/angle-lateral move (going straight)	1.92	1.03	2.61	1.59
66- sidewipe/angle-specific others	0.62	0.75	0.48	0.53
67- sidewipe/angle-specifics unknown	0.00	0.00	0.00	0.00
68- turn across path-initial opposite directions (left/right)	1.61	0.28	1.16	0.18
69- turn across path-initial opposite directions (going strait)	1.61	0.28	1.74	0.35
70- turn across path-initial same directions (turning right)	0.31	0.09	0.48	0.00
71- turn across path-initial same directions (going straight)	0.31	0.09	0.19	0.18
72- turn across path-initial same directions (turning left)	0.47	0.09	0.48	0.00
73- turn across path-initial same directions (going straight)	0.47	0.09	0.58	0.18
74- turn across path-specifics others	0.10	0.00	0.10	0.00
75- -turn across path-specifics unknown	0.00	0.00	0.00	0.00
76- turn into same direction (turning left)	0.16	0.00	0.29	0.00
77- turn into same direction (going straight)	0.16	0.00	0.10	0.00
78- turn into same direction (turing right)	0.26	0.19	0.19	0.00
79- -turn into same direction (going straight)	0.26	0.19	0.29	0.35
80- turn into opposite directions (turning right)	0.10	0.00	0.19	0.00
81--turn into opposite directions (going straight)	0.21	0.00	0.10	0.00
82- turn into opposite directions (turning left)	0.83	0.09	0.29	0.00
83- turn into opposite directions (going straight)	1.40	0.09	1.93	0.18
84- turn into path-specifics others	0.00	0.00	0.00	0.00
85- turn into path-specifics unknown	0.00	0.00	0.00	0.00
Pre-Event Movement				
6 - passing or overtaking another vehicle	2.29	2.44	1.06	1.23
15 – changing lanes	3.90	4.88	3.19	3.35
16 - merging	0.68	0.84	0.68	0.71
Accident Type				
1 - right roadside departure	4.94	4.50	8.20	7.23
4 - turn across path	4.89	0.94	4.73	0.88
6 - same trafficway opposite direction-sidewipe/angle	4.42	2.81	3.57	2.29
7 - left roadside departure	4.37	4.22	6.27	5.82
10- turn into path	3.38	0.56	3.38	0.53
12- same trafficway same direction-sidewipe/angle	12.58	18.01	11.49	17.64

Table 1. LTCCS Percentages for Lane Departure Crashes

relationship appears to hold for non-local roadways. However, for the trucks on highways that have posted speed limits at or above 50 mph the results were more similar; although there were more coded as "over lane line on right side of travel lane" was somewhat higher (4.1 versus 3.5 percent). For both all vehicles and trucks on non-local roadways and highways with higher speed limits, the proportions that were coded as "off the edge of the road on the right" was greater than "off the edge of the road on the left." For trucks, the percentage of crashes that were coded as departing the right side (6.2 percent) was nearly twice the percentage of those departing the left side (3.2 percent).

These data are consistent with the ***Crash Code*** variable that indicates that more crashes were involved with right roadside departure than left roadside departures, particularly for trucks. With respect to this variable, Table 1 illustrates that the total of the coded values that involved roadside departure and/or sideswipe ranged from 16.3 percent to 19.9 percent. For trucks, the totals for these classifications were 17.3 percent and 19.9 percent, respectively for non-local roadways and highways with posted speed limits of 50 mph or above.

The ***Pre-Event Movement*** variable shown in Table 1 indicates actions that represent intentional lane departures (passing, changing lanes and merging). These activities accounted for approximately 5 to 7 percent of the observed crashes in the LTCCS sample.

The last variable in Table 1 is ***Accident Type***. The definition of accident type in the LTCCS study refers to the categorization of collisions. A collision was defined as "the first harmful event in a crash between a vehicle and some object, accompanied by property damage or human injury." The data in the table illustrate that for all vehicles, there was not a large difference between the number of left and right roadside departures (approximately 4 to 5 percent). However, for trucks the proportion of right roadside departures was higher than the proportion of left roadside departures (8.2 and 7.2 percent versus 6.3 and 5.8 percent). This is consistent with the other variable codes that documented left and right roadway departure. The other category within accident type that could pertain to LDWS is the "same trafficway, same direction - sideswipe/angle." This category represents 11 to 12 percent of the non-local accidents and 17 to 18 percent of the crashes on highways with posted speed limits equal to or above 50 mph.

The LTCCS also addresses the specific issue of "inattention" in their data. The LTTCS Summary Tables indicate "inattention" was approcimately 9 percent of the crashes for both trucks and light vehicles on all roadways. For one-vehicle truck accidents, the LTCCS Summary Tables indicated that "inattention" was an associated factor for 12 percent of the crashes. Table 2 indicates the data for all non-local roadways for all posted speed limits and interstates and U.S. highways with posted speed limits of 50 mph or above. The percentage of trucks which were coded as inattention was much lower for interstates (4.7 percent) compared to either non-local roadways (8.1 percent) or US highways (9.1 percent).

	Non-local Roadways		Interstates		US Highways	
	Vehicles	Trucks	Vehicles	Trucks	Vehicles	Trucks
Inattentive	7.10	8.12	6.15	4.71	8.02	9.10
Attentive	67.33	80.74	71.51	82.35	55.31	64.82
Unknown	25.57	11.14	22.35	12.94	36.67	26.09

Table 2. LTCCS Percentages for Crashes Associated with Inattention

Analysis of Commercial Fleet Data

Eight commercial fleets participated in this portion of the study. Each company provided safety data for at least three years (ending in 2007). The data sets were in excel format. The different fleets use different variables in their accident data. In addition, the same or similar variables are sometimes referred to using different terms. Some characterize only the accident type (e.g., run-off-road), while others include additional information documenting the cause (driver inattention). Table 3 illustrates the set of variables used in the data analysis for one fleet. The data were filtered (using location values) to exclude accidents that did not occur on highways or interstates and would not apply to LDWS (e.g., location of truck stop, terminal, etc.).

The accidents were classified based on the “cause code.” Table 4 illustrates a sample of the cause codes from one of the fleets. The accidents for each fleet were filtered by the cause codes in an attempt to separate those cases for which a LDWS might have an impact and those for which it would not (e.g., mechanical failure, hit overhead, etc.).

Table 5 presents a set of tables that show the cause codes that were analyzed for each of the eight fleet. The cause codes for all of the “driving” accidents on the selected roadways are included to allow a relative comparison of the accidents that a LDWS might impact compared to the other highway accidents. The data given in the tables is proportion (as a percentage) of the total “driving” accidents that was documented for each cause code.

Table 5 indicates that, for Fleet 1, the percentage of the “driving” accidents that were associated with “Left Roadway” was 0.8 percent. This value is consistent with the data from Fleet 2 (1.0 percent). The values for the category, “Run-off-Road,” ranges from a low of 0.3

Tractor Number
Accident Number
Accident Date
DOT Accident
Preventable/Non preventable
Cause Code
Claim Description
Total Service Miles of driver
Accident Location Street Address
Accident Location City
Accident Location State
Accident Location Zip Code
Location S= Street, T=truckstop,
Intersection
Following too Closely
Day of the Week Accident Occurred
CFI Driver Seat Belt in Use
Co-Driver Seat Belt in Use
Weather Conditions
Road Conditions
Highway Divided or Undivided
Number of Traffic Lanes
Lights On
Hazardous Material
Hazardous Material Spilled
Number of Vehicles Involved
Number of Vehicles Towed
Number of Persons Involved
Number of Fatalities
Direction of Vehicle One
Speed of Vehicle One
Tractor Number
Driver Injured
Load Number
Load Damaged
Number of Witnesses
Lawsuit Filed
Police Report Issued
Police Report Filed Date
Tickets Issued
Who Received Ticket
Charges Filed
Adjuster Called (Blank or X = No)
Adjuster Called Date (YYMMDD)
Hours Driven since Eight-Hour Break
Driving Time between Required Breaks

Table 3. Sample Variables in Feet Accident Data

Hit Other in Rear
Intersection/Driveway
Left Roadway
Rollover
Evading Rear End Collision
Head-On Collision
Side Swipe
Pedestrian Impact (Includes Bicycle)
Left Turn Squeeze
Right Turn Squeeze
Lane Change (Left)
Lane Change (Right)
Hit in Rear By Adverse
Jackknife (braking-trailer swing out)
Trailer Breakaway (On Roadway)
Rollaway (Unattended)
RR-Xing (any accident related to RR-Xing)
Forward Collision/Parked Vehicle on Shoulder
Animal Hit
Mechanical Failure (Other than Tire/Wheel)
Tire/Wheel Failure
Forward/Collision with Adverse (if not appl
Forward/Hit Overhead Object
Forward/Hit Fixed Ground Object
Forward/Jackknife (Off FXF Yard)
Road Hazard
Cargo Falling Onto Roadway
Backing/Collision with Adverse
Backing/Hit Overhead Object
Backing/Hit Fixed Ground Object
Backing/Jackknife
Unsecured Load/Cargo Shift
Pulled TLR/Dropped F-lift/Other
Stuck---Towed Out
Parked/Stopped---Hit by Other
Trailer/Customer Damage
Trailer/Chemical Release
Trailer/Customer Injury
Trailer/ Forklift Operator Damage
Pintle Hook Release
Fire (cargo/vehicle)
Non Vehicular 3rd party injury
Potential Bio/Chemical Exposure
Damaged by Freight Handling Proc.
Inside Delivery Damage
Vandalism
N.O.C. (Not Otherwise Coded)

Table 4. Sample of Cause Codes for Fleet Data

Cause Codes - Fleet 1	%
Hit Other in Rear	2.2
Left Roadway	0.8
Rollover	0.6
Evading Rear End Collision	0.2
Head-On Collision	0.1
Sideswipe	1.3
Lane Change (Left)	.03
Lane Change (Right)	.05
Hit in Rear By O/V	3.5
Jackknife (braking-trailer swing out)	0.5
Forward Collision/O/V on Shoulder	0.1
Animal Hit	14.8
Tire/Wheel Failure	6.2
Forward/Collision with O/V	11.2
Forward/Hit Overhead Object	23.9
Forward/Hit Fixed Ground Object	12.1
Forward/Jackknife	5.2
Road Hazard	16.4

Cause Codes - Fleet 2	%
Hit Animal	16.6
Hit By O/V	30.0
Hit Overhead Object	5.0
Hit Parked O/V	2.5
Hit Stationary Object	14.4
Jackknife	1.0
Lane Change Left	1.5
Lane Change Right	2.9
Misc. Avoidable	4.0
Misc. Unavoidable	2.5
Overhead (Not Bridge)	2.4
Passing	0.1
C/V Rearended O/V	4.8
Run Off Road	1.0
Run Under/Side Impact	0.0
Sideswipe - Merge	10.1
Sideswipe - Opposing	0.8
Road Debris	0.3
Turnover	1.1

Cause Codes - Fleet 3	%
Road Hazard	
C/V Struck O/V	7.4
O/V Struck C/V	22.2
Stationary Object	
Weather Related	0.3
Overturn	
Weather Related	1.9
Driver (Inattention)	6.2
Too Fast	7.1
Struck Object In Roadway	1.2
Avoid Collision	4.3
Misc.	3.7
Jackknife	
Weather Related	2.5
Panic Stop/Avoiding Collision	0.6
Object in Roadway	
Struck Animal	2.2
Sideswipe	
C/V Merging Into Traffic	3.4
O/V Merging Into Traffic	5.2
C/V Crossed Traffic Lane	1.2
O/V Crossed Traffic Lane	4.9
C/V Completing Pass	0.6
O/V Completing Pass	2.2
Ran Off Roadway	
To Avoid Collision	0.6
Driver Illness	0.9
Driver Inattention	3.1
Misc.	0.3
Vehicle In Roadway	
Uncontrolled/Spinning	15.4
Parked	0.6
Head-On Collision	
O/V Struck C/V	1.9

* C/V – Company Vehicle

O/V – Other Vehicle

Cause Codes - Fleet 4	%
Damaged Equipment	1.2
Damaged Property	0.3
C/V Forced O/V Off Road	0.5
C/V Forced Off By O/V	0.4
C/V Hit O/V Head-On	0.1
Hit Animal	8.5
C/V Hit By O/V	25.7
Hit By Object	1.6
Hit By Unknown	0.2
Hit Fixed Object	2.7
C/V Hit Headon By O/V	1.4
C/V Hit Moving O/V	7.8
Hit Object In Road	1.3
Hit Overhead	0.2
C/V Hit Stopped O/V	3.0
Jackknifed	2.9
C/V Jackknifed, Hit O/V	0.2
C/V Jackknifed, Hit By O/V	0.1
Jackknifed, Hit Object	1.0
Lane Change	0.3
C/V Changed Lanes, Hit O/V	2.5
Lost Wheels	0.5
Merging	0.1
Overturn	6.7
C/V Rearended Moving O/V	4.3
C/V Rearended Stopped O/V	2.7
C/V Rearended By O/V	16.0
C/V Sideswiped By O/V	4.6
Went/Ran Off Road	3.1

Cause Codes - Fleet 5	%
Adverse Vehicle	32.3
Following Too Close	2.8
Improper Lane Change	7.4
Improper Turn	8.2
Inattention	14.3
Other	29.9
Too Fast for Conditions	3.6
Unknown	1.5

Table 5. Proportions for Cause Codes for Different Fleets

Cause Codes - Fleet 6	%
C/V Rearended O/V	6.3
O/V Rearended C/V	6.7
C/V Wrong Side of Road	0.4
O/V Wrong Side of Road	0.7
Disputed Center Line	0.6
C/V Ran Sign or Signal	0.2
O/V Ran Sign or Signal	0.5
Disputed Sign or Signal	0.2
C/V Left Turn Squeeze on O/V	0.8
O/V Left Turn Squeeze on C/V	0.6
C/V Right Turn Squeeze on O/V	0.7
O/V Right Turn Squeeze on C/V	0.3
C/V Passing O/V	0.8
O/V Passing C/V	5.2
C/V Changing Lanes	7.5
O/V Changing Lanes	10.2
C/V Into Stationary Object	9.7
C/V Ran Off Road	2.9
Tire Blowout	0.2
Jackknife	1.4
Overturn	3.4
C/V Driver (DWI, asleep, drugs)	0.1
O/V Out of Control	5.3
Miscellaneous	8.9
Hit Animal	26.2

Cause Codes - Fleet 7	%
Angle Collision	1.6
Struck Animal	23.8
Head-on Collision	0.1
Jackknife	0.2
Load Shift	3.0
Miscellaneous	15.0
Driver Negligence	0.2
Off Roadway	1.0
O/V hit C/V	17.7
Road Debris	23.0
C/V rearended O/V	2.8
Rollover/Upset	1.3
Sideswipe	5.4
Struck Stationary Object	4.9

* C/V – Company Vehicle

O/V – Other Vehicle

Cause Codes - Fleet 8	%
C/V Into Rear Of O/V	4.3
O/V Into Rear Of C/V	5.6
C/V Wrong Side Of Road	0.1
O/V Wrong Side Of Road	1.3
C/V Left Turn	0.9
O/V Left Turn	0.2
C/V Right Turn	0.8
O/V Right Turn	0.1
C/V Passing O/V	0.6
O/V Passing C/V	4.2
C/V Changed Lanes	4.0
O/V Changed Lanes	12.8
C/V Into Stationary Object	1.9
Hit Viaduct/Underpass	0.6
C/V Ran Off Road	0.3
Tire Blowout	0.6
Overturn	0.9
Jacknife	0.5
Hit By Unknown Vehicle	1.6
Hit Animal	28.3
Miscellaneous	5.8
C/V Hit Object In Roadway	13.5
O/V Hit Object In Roadway	0.1
C/V Out Of Control	5.2
O/V Out Of Control	5.8

Table 5 (continued). Proportions for Cause Codes for Different Fleets percent (Fleet 8) to a high of 4.9 percent (Fleet 3). It is beneficial that Fleet 3 divides "Ran-off-Road" into components (avoid collision, driver illness, driver inattention, misc.). As can be seen for Fleet 3, the majority of the "Ran-off-Road" category was accounted for by "driver inattention (3.1 percent of total but 63 percent of "Ran-off-Road"). Turnover (overturn, roll over etc.) accidents are often the result of running off of the roadway. Although Fleets 1, 2, 7 and 8 had roll over percentages of approximately 1 percent, the experiences of other fleets were higher. Fleet 4 categorized 6.7 percent of the accidents as overturn and the combination of the various categories of overturn for Fleet 3 accounted for 24.4 percent.

The other category that has been considered to be very important to the potential of LDWS is "lane change" accidents. As previously discussed, the LTCC found that lane change crashes accounted for approximately 3 to 5 percent of accidents. This is consistent with the data from Fleets 2, 4 and 8. However, Fleets 5 and 6 had higher incidences of lane change accidents (7.4 and 7.5 percent, respectively). This could be due to the fact that neither of these fleets use a "Merge" category and some (or even most) of the lane change accidents could be related to merging behavior. On the other hand, for Fleet ,1 lane change accidents accounted for less than 1 percent of the total. Again, this could be accounted for by the fact that Fleet 1 uses a category of "Sideswipe" that might be used when a truck strikes an object or other vehicle while being out of their lane.

Discussion of LTCCS and Fleet Data Analysis

The first and most important issue in this analysis is that it cannot be determined how many of the accidents discussed in this report could be reduced or eliminated with LDWS. For example, if sideswipe accidents are the result intentional actions by the driver, a LDWS that simply warned the driver of a lane barrier violation might not be effective. However, a LDWS with an integrated side collision warning system (e.g., radar) might be very effective. Similarly, a Run-off-Road accident that is the result of avoiding collision with an object would not be eliminated with either of these systems.

However, the data do provide an upper limit on the possible benefits. That is, the potential for accident reductions is lower if the frequency of that particular type of accident is very low. The analyses of these data also do not address the severity of the accidents. That is, even if a particular category of accident is relatively low, the severity in terms of property loss, personal injury or even fatalities can be very high. This is obviously the case for roll-over accident that resulted from running off of the roadway.

Another aspect of the fleet data that makes it more difficult to interpret is that fact that only one cause code was indicated for each accident. That is, a combination of associated factors such as “Run-off-Road” and “Hit Animal” might be coded in only one category.

The data from the commercial carriers indicates that there is a high amount of variation in the experience of different fleets with respect to the relative frequency of different types of accidents. As previously discussed, this could be somewhat due to the difference in cause code definitions and coding procedures. However, the wide range indicates that trying to establish the potential for accident reductions with LDWS for an individual fleet based on composite data can be misleading. Whereas one fleet might experience significant benefit from implementing a LDWS, another fleet might not find the systems to be cost effective.

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Appendix A.

Variables Descriptions from the Large Truck Crash Causation Study (LTCCS)

Location

Definition: This variable reports the location of the subject vehicle at the point where its pre-impact stability is determined.

Source: Determined by Case Reviewer using all available information inputs. Primary sources include the scaled schematic, police report, driver interviews, witness interviews and vehicle inspection results.

Variable Name: ***ACRLocation***

Critical Event

Definition: This variable identifies the event which made the crash imminent (i.e. something occurred which made the collision inevitable). A precrash critical event is coded for each vehicle in the crash and documents the circumstances leading to this vehicle's first impact in the crash sequence.

Source: Determined by the Case Reviewer using all available information inputs. Primary sources include the scaled schematic, police report, driver interviews, witness interviews, and vehicle inspection results. It should be noted, however, that this may be a subjective decision based on the preponderance of available evidence.

Variable Name: ***OVECriticalEvent***

Crash Code

Definition: This variable is used in categorizing the collisions of drivers involved in crashes. A collision is defined here as the first harmful event in a crash between a vehicle and some object, accompanied by property damage or human injury. The object may be another vehicle, a person, an animal, a fixed object, the road surface, or the ground. If the first collision is a rollover, the impact is with the ground or road surface. The collision may also involve plowing into soft ground, if severe deceleration results in damage or injury. A road departure without damage or injury is not defined as a collision. This variable encompasses the "Configuration" variable, which is a component of this variable. Cases where the crash type is "No Impact" include fire and immersion.

Source: Determined by Case Reviewer using all available information inputs. Primary sources include

Variable Name: ***CrashCode***

Pre-Event Movement

Definition: This variable establishes the subject vehicle's pre-critical event movement pattern. The pre-event movement pattern is usually described as the point that both precedes the critical precrash envelope and that precedes vehicle motions that place the involved vehicle(s) on an imminent collision path.

Source: Determined by the Case Reviewer using all available information inputs. Primary sources include the scaled schematic, police report, driver interviews, and witness interviews. It should be noted, however, that this may be a subjective decision based on the preponderance of available evidence.

Variable Name: ***Movement***

Accident Type

Definition: This variable is used in categorizing the collisions of drivers involved in crashes. A collision is defined here as the first harmful event in a crash between a vehicle and some object, accompanied by property damage or human injury. The object may be another vehicle, a person, an animal, a fixed object, the road surface, or the ground. If the first collision is a rollover, the impact is with the ground or road surface. The collision may also involve plowing into soft ground, if severe deceleration results in damage or injury. A road departure without damage or injury is not defined as a collision. This variable is part of the larger variable "Crash Type." The "Crash Type" variable is actually broken down into three components: the crash category, the crash configuration, and the accident type. This variable only deals with the configuration of the crash.

Source: Determined by Case Reviewer using all available information inputs. Primary sources include the scaled schematic, police report, driver interviews, witness interviews, and vehicle inspection reports.

Variable Name: ***OVEAccidentType***

Inattention

Definition: This variable documents driver inattention (i.e. focusing on internal thought processes) and the nature of the involved thought processes.

Source: Determined by the Case Reviewer using all available information inputs. Primary data sources include the driver interview, carrier records, medical records, and the police report. Secondary sources include other occupant interviews and **Inattention**

Variable Name: ***Inattention***