EVALUATING CRASH AVOIDANCE COUNTERMEASURES USING DATA FROM FMCSA/NHTSA'S LARGE TRUCK CRASH CAUSATION STUDY

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ABSTRACT

Real world crash data are used to estimate the size of crash populations addressable by crash avoidance countermeasures. Until the release of the data from the Large Truck Crash Causation Study (LTCCS) that was conducted from 2001 to 2003 by the Federal Motor Carrier Safety Administration (FMCSA) and the National Highway Traffic Safety Administration (NHTSA), only coarse estimates of those target populations were possible using data from the Fatality Analysis Reporting System (FARS) and the National Automotive Sampling System's General Estimates System (NASS GES). Both of these databases contain limited information that is coded from police reported data.

The LTCCS conducted on-scene investigations of real world crashes that resulted in a database of 1070 cases rich in detail, specifically related to precrash conditions and factors associated to why the crash occured. The detail in the data was enough to make clinical (case by case) estimations of the applicability of crash avoidance countermeasures for each crash, based on our knowledge of these systems and how effective they are in certain scenarios. Final benefit estimates would take into account the applicable target populations and the effectiveness of a system, as determined through field operational tests or some other measure.

This study presents the results of clinical reviews of truck crashes from the LTCCS to determine which target populations of crashes could be candidates for prevention given the multiple factors that came into play. Countermeasures related to the truck, truck driver, or trucking industry might have prevented 61 percent of the crashes in LTCCS, including 50 percent that might have been prevented by advanced technologies that are currently available for trucks. The newly coded data from these clinical reviews can be used to further refine the applicable crash populations estimated from FARS and GES. This research indicates that only a portion of applicable crash scenarios identified through FARS and the NASS GES are candidates for prevention by crash avoidance countermeasures.

The results present an option for a more accurate methodology for estimating the size of crash populations addressable by crash avoidance countermeasures. Using these results it is possible to prioritize research on crash avoidance countermeasures.

BACKGROUND

In 2007, an estimated 413,000 heavy vehicles were involved in crashes which resulted in 4,808 deaths and 101,000 injuries. Of the fatalities that resulted from heavy truck crashes, 75 percent were occupants of a light vehicle, 8 percent were nonoccupants, and 17 percent were occupants of a large truck [1]. Crashes involving heavy vehicles are severe events. Due to the nature of crashes which involve heavy trucks and another vehicle (extreme differences in mass and energy), the greatest potential to save lives and reduce injuries comes from crash avoidance countermeasures. Advances in crashworthiness aim to protect motor vehicle occupants given that a crash occurs. Advances in crash avoidance technologies present the opportunity to prevent these crashes from occurring in the first place. Preventing heavy vehicle crashes can result in a big impact by focusing on a specific population of crashes, whose prevention would result in a significant number of lives saved and injuries avoided.

INTRODUCTION

The first step to prevent crashes is to gain a complete understanding of how and why they happen. Through a joint effort by the Federal Motor Carrier Safety Administration and the National Highway Traffic Safety Administration, a major on-scene data collection effort was undertaken to identify events leading up to crashes and factors that contribute to them. It was called the Large Truck Crash Causation Study.

The LTCCS data were collected on-scene by trained crash researchers at 24 representative locations throughout the United States. The on-scene nature of the study allowed for richer and more accurate data than a study based on after-the-fact investigations would have.

Data collected on-scene and from follow-on investigations were compiled for each case and a crash event assessment was made using all of the available information. The crash event assessment for a crash occurrence consists of three elements for each vehicle involved in the crash: the “critical precrash event”; the “critical reason for the critical event”; and “associated factors”.

The “critical precrash event” is the action or event that placed the vehicle on a collision course such that the collision was unavoidable given reasonable driving skills and vehicle handling. In other words, the “critical precrash event” makes the crash inevitable. The “critical precrash event” is typically coded in relation to a pedestrian, nonmotorist, object, other motor vehicle, or animal that the subject vehicle was attempting to avoid. It is important to note that culpability/fault is not considered when making the “critical precrash event” determination.

The “critical reason for the critical event” is the immediate reason for this event and is often the last failure in the causal chain (i.e., closest in time to the “critical precrash event”). This variable establishes the critical reason for the occurrence of the critical event. Although the critical reason is an important part of the description of the crash event, it is not the cause of the crash nor does it imply the assignment of fault. The primary purpose for the “critical reason for the critical event” is to enhance the description of crash events and allow analysts to better categorize similar events [2].

While there is only one critical reason coded per crash, this variable is documented at the vehicle level. Therefore, for each multiple-vehicle crash, there is at least one vehicle for which the critical reason is coded as “No driver error,” which means the critical reason was coded to another vehicle in the crash. Table 1 shows the results from the LTCCS for the “critical reason for the critical event” codes. A general level of detail is shown, but each level contains several more detailed elements.

Table 1 [3].
Weighted Number of Involved Vehicles
By Critical Reason (General Level), Crash Type, and Involved Vehicle Type

Critical Reason (General Level)	Single-Vehicle Crash		Multivehicle Crash						Total					
	Truck		Truck		Vehicle		Total		Truck		Vehicle		Total	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%
No Driver Error	1447	4	61913	60	58252	58	120164	59	63360	45	58252	58	121612	50
Physical Driver Factor	7744	20	1377	1	6214	6	7590	4	9121	6	6214	6	15335	6
Driver Recognition Factor	6309	17	15883	15	12421	12	28304	14	22193	16	12421	12	34613	14
Driver Decision Factor	12621	33	16886	16	11106	11	27992	14	29507	21	11106	11	40612	17
Driver Performance Factor	4425	12	2758	3	7617	8	10375	5	7182	5	7617	8	14800	6
Vehicle Related Factor	4831	13	2956	3	1577	2	4533	2	7787	6	1577	2	9364	4
Environment - Highway	599	2	950	1	510	1	1460	1	1549	1	510	1	2059	1
Environment - Weather	127	0	114	0	541	1	655	0	241	0	541	1	782	0
Unknown Reason	23	0	238	0	1591	2	1829	1	261	0	1591	2	1852	1
Total	38127	100	103047	100	99829	100	202902	100	141200	100	99828	100	241028	100

Source: NHTSA, NCSA, LTCCS. Study time span: April 1, 2001 - December 31, 2003.

Associated factors can be related to the drivers involved in the crash, the vehicles, and/or the environment. The NASS researcher collected as much data as possible related to factors present prior to the crash. Factors were coded when present; no determination was made as to whether or not they contributed to the crash. These factors are important to provide more detail for each crash and to set the stage for relative risk analyses using the entire data set. Relative risk analyses will determine whether the presence of certain factors increases the risk of a crash occurrence. For example, in the LTCCS, alcohol would still be coded for a drunk driver stopped for a red light who got rearended even though alcohol did not play a role in this crash. Statistical analysis in the end would show if alcohol was more prevalent in striking or struck vehicles in similar crash scenarios.

ANALYSIS

Heavy vehicle research must be focused to have the highest impact to prevent crashes involving large trucks. To accomplish this, crash types must be accurately quantified and mapped to potential countermeasures. This results in the identification of the largest crash problems and identifies possible solutions to them. Analysis of LTCCS data can play an important role in this process by improving the accuracy of crash population estimates for specific countermeasures.

A Volpe study shows that 90 percent of crashes are caused by driver error (see Figure 1) [4]. LTCCS data also shows that more than 80 percent of associated factors are coded as driver-related factors.

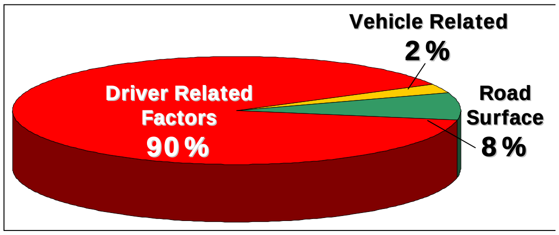

Figure 1. Crash Causal Factors [5].

Until we had the rich precrash data from the LTCCS, we relied solely on estimates from FARS (for fatalities) and GES (for injuries). Crash scenarios were coded, technologies were mapped to the scenarios they may be able to prevent, and then populations were defined to feed into effectiveness estimates. But, for example, how many run-off-road scenarios might actually be prevented by lane departure warning systems, if a portion of those are due to a physical inability to control the vehicle (i.e. heart attack or seizure). We can't get this information from FARS and GES. But we can get it from LTCCS.

Findings from the LTCCS analysis show that regardless of which vehicle or the types of factors that contributed more to the crash, in 52 percent of truck vs. light vehicle crashes, countermeasures on the truck may have helped to prevent the crash. And in 70 percent of the truck vs. nonmotorist crashes, countermeasures on the truck may have helped to prevent the crash. These are the target populations which would then be multiplied by system effectiveness estimates to give overall benefits estimates of each countermeasure.

As for individual countermeasures – how do we prioritize them? Which are applicable to largest target populations and present us with an opportunity to prevent the most crashes and save the most lives?

The objective of the analysis presented in this paper is to estimate the size of crash populations addressable by crash avoidance countermeasures using very detailed real world crash data. NHTSA uses multiple data sources to prioritize research on advanced technologies, to support regulatory activities, and to provide information to consumers. The precrash data from each of these resources, thus far, has been extremely limited, with details focused on crash configurations and injury mechanisms. The detailed precrash data from the LTCCS can explain how and why crashes occurred which leads to more accurate target population estimates, which in turn will lead to more accurate benefits estimates.

There are different ways to analyze a data set such as the LTCCS. One can perform relative risk analyses to determine whether the presence or absence of certain factors increases the likelihood of a crash. Another method, which was used in the analysis this paper presents is a clinical method.

In depth, clinical reviews of each case were completed to make individual determinations as to what happened in each crash and what could have prevented each crash.

New data elements were coded for each case, specifically whether the crash should be included in the target population of crashes that may be prevented by a countermeasure. The list of countermeasures included was identified using several factors. Only advanced technologies that are newly penetrating the commercial vehicle market or are soon to penetrate were included. They had to have a reasonable expectation to be successful in preventing crashes or mitigating injuries by reducing crash severity. The following advanced technologies, from warning systems to active vehicle interventions, were included in the analysis:

Augment Driver Performance

- Lane Departure Warning (LDW)/Lane Keeping Assist(LKA)
- Forward Collision Warning (FCW)
- Blind Spot Detection (BSD)/Lane Change Warning
- Drowsy Driver Detection
- Backover Crash Prevention
- Night Vision
- Tire Pressure Monitoring System (TPMS)

Augment Vehicle Performance (intervene when driver action would be insufficient to prevent a crash

- Roll Stability Control (RSC)
- Electronic Stability Control (ESC)

In addition to the technologies listed here, non-technological countermeasures were considered, such as:

- Stricter Vehicle Maintenance Requirements
- Enhanced Conspicuity
- Driver Training and Education
- Stricter Driver Licensing Requirements
- Alcohol and Drug Enforcement
- Miscellaneous Others

With these countermeasures in mind each case was reviewed using the following clinical review process. First, by reviewing case summaries, then scene diagrams, pictures, the crash event assessment forms and any other coded data identified as necessary, a determination was made as to whether or not each crash should be included in the target population for each countermeasure considered.

In the case example illustrated in Figure 2, a truck was traveling in the center lane next to a light vehicle in lane 1. The truck initiated a lane change maneuver to the right and impacted the car. The crash event assessment form shows the critical event, critical reason for the critical event and all of the associated factors in the crash. The case data (Shown in Figure 3) includes separate tabs for different kinds of factors. Drugs and alcohol are rarely coded as critical reasons for the critical event, but if they are present, they are included as associated factors.

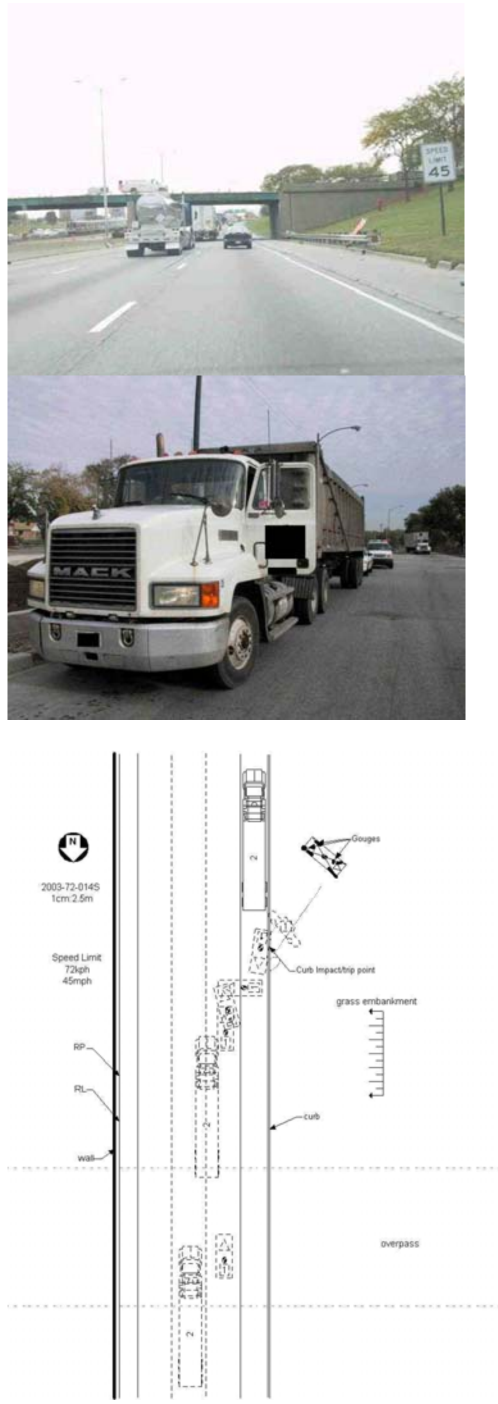

Figure 2. Photos and Scene Diagram from Example Case 2003-72-014.

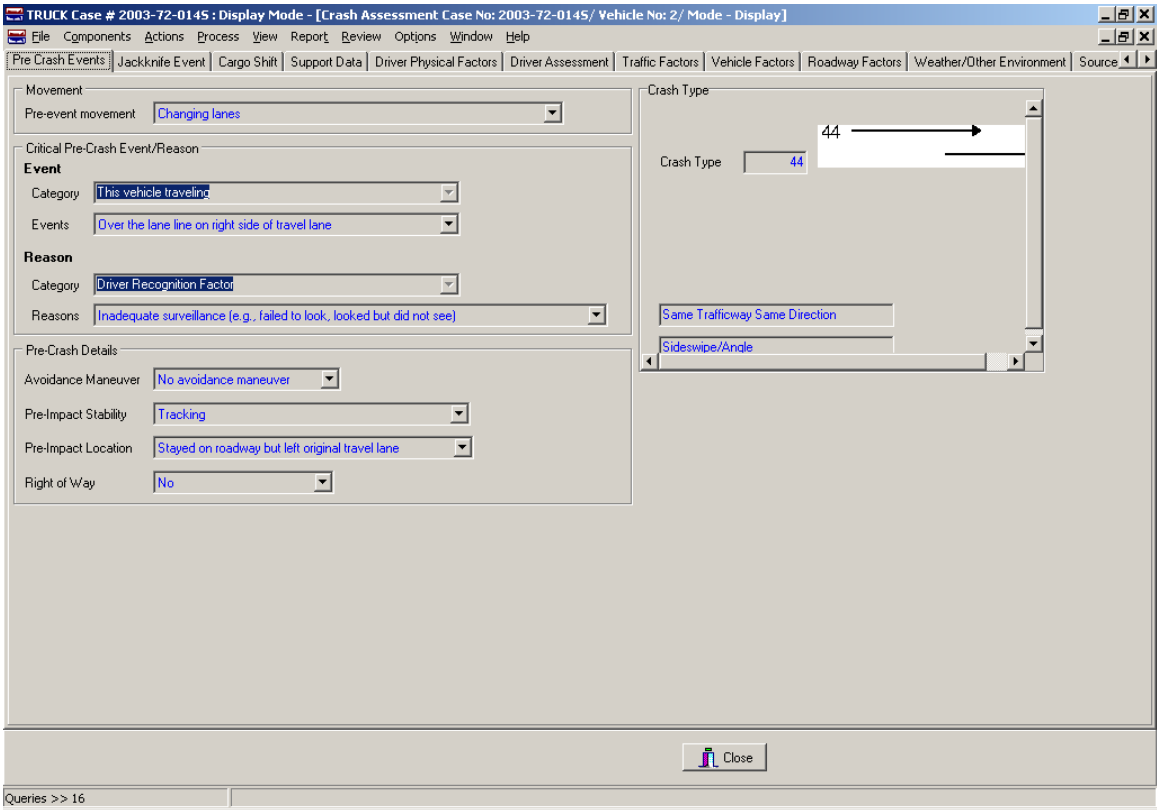

Figure 3. Screen Capture of Case Data from Example Case 2003-72-014.

In this case, the critical reason was coded as inadequate surveillance (See Figure 3). The car was in the truck's blind zone. This case was fairly straightforward because the countermeasure that could have prevented this crash was some kind of blind zone detection system or lane change assist. There could be confounding factors that would exclude a case from the target population (such as when a driver suffered a heart attack that precipitated the crash), but this case was kept in because there were no such factors. For many other cases in the LTCCS countermeasures were coded not only for the truck, but for the light vehicles and the environment as well.

RESULTS

The advantage of such a clinical review is to gain a better understanding of what kinds of crashes define the target populations that are preventable by crash avoidance technologies and what percentage of the applicable population of crashes could actually be mitigated. In addition, we can identify crashes that may be prevented by advanced technologies that otherwise would have gone unnoticed based solely on the data in a police report. This increases our target population and gives better benefits estimates.

Only 10 percent of the LTCCS crashes could be considered unpreventable with the rest having a reasonable expectation of being included in target populations that have the potential to be prevented by some countermeasure on either the heavy vehicle or a passenger vehicle, if one was involved. Countermeasures include advanced technologies, stricter vehicle maintenance requirements, alcohol enforcement, etc. If you go far enough back in the chain of events, almost everything is preventable.

A breakdown of the unpreventable crashes is shown in Table 2 including some reasoning as to why countermeasures would not have been able to address each.

Table 2.
Unpreventable Crash Types from the LTCCS

Unpreventable Crash Types	Number of LTCCS Crashes Applicable
Medical Condition	25
Intersection Crash	19
Poor Driving Skills/Bad Decisions	16
False Assumption of Other Road User's Actions	14
Caused by Previous Event	10
Blew Red Light/Stop Sign	8
Unpredictable Pedestrian Behavior	8
Vision Obscured	5
Rare Occurrence	1
Total*	106
Source: LTCCS Analysis, Kingsley, 2009.	

*The total in the table represents 10 percent of all crashes in the LTCCS.

A surprising number of crashes in the LTCCS involved some kind of medical condition which precipitated the physical inability to act. There were seizures, heart attacks and diabetic episodes.

Many of the crashes occurred at intersections and may only be prevented by technologies that are further off into the future, such as vehicle to infrastructure or vehicle to vehicle communications.

There were a number of crashes that happened because of poor driving skills or poor decisions made on the part of one of the drivers. For example, a truck backed into a bicyclist after ignoring the audible warning from the vehicle's rear object detection system. One of the codes in the LTCCS is "False Assumption of Other Road User's Actions." Many of these may be preventable, depending on the crash type, but an example of the type that are unpreventable is crashes occurring at an intersection controlled by a 2-way stop sign. Five of the cases in the LTCCS involved a driver stopping at the stop sign, viewing the crossing vehicle, but continuing ahead anyway because of the assumption that the other driver also had a stop sign.

An unpreventable crash was one where a driver swerved to avoid another vehicle or another crash, but ended up in their own crash. Other examples are crashes that involved erratic pedestrian behavior (e.g. one pedestrian who was under the influence climbed under a truck who stopped briefly at an intersection unbeknownst to the truck driver).

The unpreventable crashes are only a small percentage of the crash population as a whole. This leaves a large target population that has the potential to be addressed by countermeasures. Countermeasures for trucks may have prevented 61 percent of these crashes, regardless of who was at fault, and regardless of who was assigned the critical reason for the critical event.

In order to prioritize individual countermeasures, to have the greatest impact, new codes were added to each LTCCS case. These codes were queried and then tallied to provide the results.

Analysis shows the technologies ranked in order by their potential to prevent the largest number of crashes (See Table 3). Unweighted data were used and pilot study cases were included. The total number of cases reviewed was 1070.

Table 3.
Advanced Technologies and Their Potential to Prevent Crashes from the LTCCS

Advanced Crash Avoidance Technologies	Percentage of LTCCS Crashes Applicable
FCW	23.8%
ESC	19.3%
RSC	10.2%
LDW	6.1%
BSD	5.9%
Drowsy Driver Warning	4.1%
TPMS	1.7%
Backover Prevention	0.3%
Night Vision	0.5%
Total*	49.9%
Source: LTCCS Analysis, Kingsley, 2009.	

*The total value in the chart takes into account overlap among the systems. It is not the sum of the percentage of crashes applicable for each technology. Most of the crashes may be included in target populations of more than one advanced technology. See the drowsy driver warning example below.

Forward collision warning (FCW) systems have the potential to prevent the most crashes, based on in-depth clinical reviews of LTCCS cases. Although not included in this analysis, some form of automatic braking technology (e.g. collision mitigation braking) would likely address similar crashes in addition to those in the target population for FCW. The most common crash scenario for heavy vehicles is rear-end crashes (23 percent) as can be seen in the chart below. Figure 4 shows the most common accident types, which total 75 percent of all of the LTCCS crashes. An additional 25 percent of crashes are miscellaneous accident types and are not included.

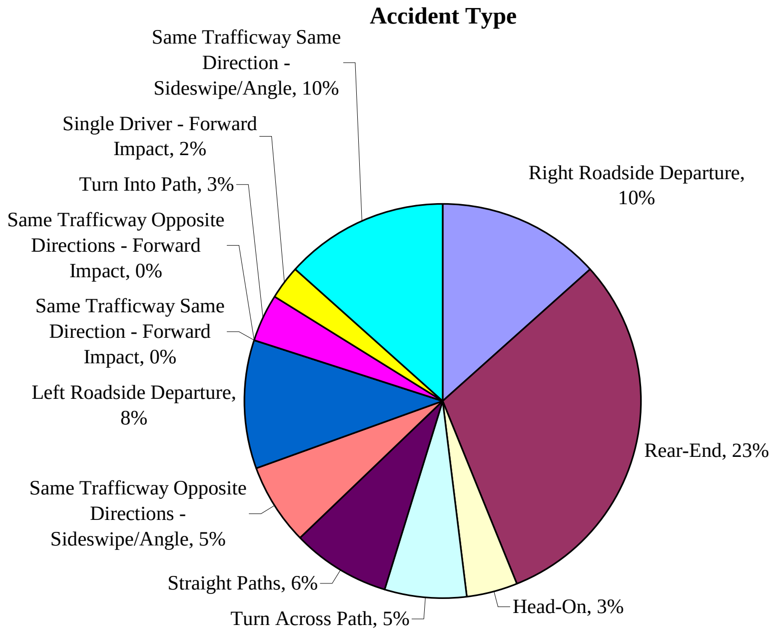

Figure 4. LTCCS Accident Types (Most Common Types Included – 75 percent of Cases).

Understanding that there is an incremental benefit to a crash imminent breaking system in addition to FCW, those target populations were not broken out in this analysis. Results shown here define the target population for FCW, the difference coming into play based on the driver's response to the warning, which is outside of the scope of this analysis.

An example of the type of crash that LTCCS would shed enough light on to exclude from an FCW target population is one in which the heavy vehicle driver is aware of the danger of the situation and makes the conscious decision to "follow too closely" in traffic.

Another technology with significant potential, because of its large target population, is electronic stability control. Cases were reviewed separately for yaw stability and roll stability and it was found that the target population for a combined system was two times the size of the target population for roll stability alone. While ESC and RSC target populations would include rollover crashes some of the accident types these technologies map to in Figure 4 include Right and Left Roadside Departures.

Notable were the crashes that may have been prevented by a drowsy driver warning system. All of them in LTCCS could have benefited from either a lane departure warning system or a forward collision warning system as well. See Table 4.

Table 4.
Drowsy Driver Crashes
Also Addressable by LDW or FCW

Advanced Crash Avoidance Technologies	Number of Crashes in Drowsy Driver Population	Percentage of Drowsy Driver Population
DDWS	**44**	**100.0%**
LDW	33	75.0%
FCW	8	18.0%
LDW or FCW	3	7.0%
Source: LTCCS Analysis, Kingsley, 2009.		

Although only LDW and FCW systems were considered in the analysis above, if one assumes that a drowsy driver warning system (DDWS) would have alerted the driver at a point earlier in the pre-crash timeline, a DDWS would potentially offer the driver more of an opportunity to avoid a crash. For example, for cases in which a driver was actually asleep at the wheel and awoke to either the sound of rumble strips, or the jar of a road departure, it can be assumed that an LDW system might not give the driver sufficient warning to avoid that crash. In these types of crash imminent cases, it was assumed that even if a person were awakened by an LDW (or FCW system in the case of a rear-end crash scenario), the driver would not be able to successfully correct in time.

Another interesting countermeasure, though limited in crash population, was the TPMS. Each of those crashes that would be in a target population for TPMS would also be in a target population of crashes that have the potential to be prevented by some other non-technological countermeasure, such as stricter vehicle maintenance or better driver training. Advanced driver training courses teach drivers to handle blowouts and tread separations in such a way that they are non-events. And TPMS is not a replacement for regular vehicle maintenance, including checking tire pressures and tread depth.

Surprisingly, a significant impact can be made with non-technological countermeasures. See Table 5. Though vehicle-related factors rank well below driver error, as a causal factor in just 2 percent of crashes [6], almost 30 percent of the trucks in the LTCCS were coded with some vehicle deficiency. Based on this analysis, better vehicle maintenance could have prevented 13 percent of the crashes.

Table 5.
Additional Countermeasures and Their Potential to Prevent Crashes from the LTCCS

Additional Crash Avoidance Countermeasures	Percentage of LTCCS Crashes Applicable
Vehicle Maintenance	12.5%
Conspicuity	2.7%
Driver Training	1.1%
Stricter Licensing	0.8%
Alcohol and Drug Enforcement	1.4%
Misc.	0.6%
Total*	17.9%
Source: LTCCS Analysis, Kingsley, 2009.	

*The total value in the chart takes into account overlap among the countermeasures. It is not the sum of the percentage of crashes applicable for each countermeasure. Most of the crashes may be included in target populations of more than one advanced countermeasure.

Alcohol and drug involvement do not play as big of a role for truck drivers in heavy vehicle crashes as it does for crashes involving passenger vehicles. The percentage of large-truck drivers involved in fatal crashes who had a blood alcohol concentration (BAC) of .08 grams per deciliter (g/dL) or higher was 1 percent in 2007. For drivers of other types of vehicles involved in fatal crashes in 2007, the percentages of drivers with BAC levels .08 g/dL or higher were 23 percent for passenger cars, 23 percent for light trucks, and 27 percent for motorcycles[7].

Overall, 61 percent of the crashes in the LTCCS are represented in target populations of crashes that may be avoided by trucks equipped with advanced technologies or truck drivers who have the benefit of other non-technological countermeasures.
The total of 61 percent represents the sum of the totals from Tables 3 and 5, minus the crashes that were included in both tables (e.g. crashes where either advanced technologies or some other non-technological countermeasure may have prevented the crash).

CASE EXAMPLES

There are several cases in the LTCCS where the truck and its driver did nothing to contribute to the crash, but a countermeasure on the truck could have prevented it from happening. An example is CASEID 820003685. A heavy truck impacted a pedalcyclist who was riding in the middle of the lane down the highway. The impact occurred late at night on an interstate highway. It is not reported whether the pedalcyclist was under the influence of alcohol or drugs at the time. The critical reason for the critical event was coded to the pedalcyclist, but advanced technologies on the truck (such as forward collision warning with object detection, collision mitigation braking, and/or night vision) may have helped to prevent this crash and others like it (there are also two similar cases in LTCCS where alcohol was a factor for the nonmotorist).

There are several cases in the LTCCS which, based solely on police reported data, might be included in effectiveness estimates for advanced crash avoidance technologies. But upon clinical review of the cases, it is clear that the scenario would not have been applicable. An example is CASEID 333006978. Other data sources would show that a truck rear-ended another truck. This should be a prime candidate for forward collision warning. But upon further review of this case, one can ascertain that the driver of the striking truck was following too closely when a car suddenly cut off the truck in front of him. A forward collision warning system would not have helped, but some form of automatic braking technology (e.g. collision mitigation braking systems) may have mitigated the severity of the crash.

The last example is CASEID 342006805. The truck departed the roadway in the curve of an exit ramp. One might conclude that the truck was traveling too fast for the curve and either electronic stability control or roll stability control would have slowed the vehicle sufficiently to prevent this crash. The LTCCS data shows that this driver lost control of his vehicle due to a heart attack, and therefore no advanced technologies could have helped in this situation. There were many cases in the LTCCS like this.

FUTURE WORK

It is envisioned that the refinement of target population estimates from FARS and GES would be conducted using the following steps:

1. Define pre-crash scenarios from FARS and GES like the 37-crashes typology [8], but specific to trucks (this is currently being done by NHTSA).
2. Map crash avoidance technologies to each of the scenarios to estimate target populations.
3. Identify the same scenarios in the LTCCS data.
4. Refine target population by:
    a. Calculating the percentage of those LTCCS cases which were coded during the analysis presented in this paper as being a candidate for inclusion in the target population of the countermeasure being studied.
    b. Identifying other cases in the LTCCS which were coded as being a candidate for inclusion in the target population of the countermeasure, but were not pulled out using the query based on crash scenarios.
5. Apply those proportions back to the FARS and GES estimates for a more robust target population.

CONCLUSIONS AND CURRENT STATUS REPORT

Clinical reviews of the cases from the Large Truck Crash Causation Study show that 90 percent of those crashes could be prevented by highly effective countermeasures and programs. Sixty-one percent of the crashes have the potential to be prevented by some countermeasure related to the truck, truck driver, or trucking industry. An additional 29 percent could be prevented by countermeasures related to light vehicles, light vehicle drivers or the environment. The truck-related countermeasures include vehicle maintenance and driver training in addition to advanced technologies. Almost 50 percent of the crashes in the LTCCS have the potential to be prevented by advanced technologies that are currently available for trucks.

The in-depth cases reviews and analysis conducted in this paper can be used to prioritize research, refine effectiveness estimates from FARS and GES, and to define crash scenarios that can be used in follow-on research (e.g. simulation studies) to estimate the effectiveness of advanced technologies.

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