# STABILITY CONTROL SYSTEMS FOR SINGLE UNIT TRUCKS: EVALUATION OF SAFETY BENEFITS


Graduate of the University of Ottawa, Canada. Completed MSc. in 1979. Currently Director of the Commercial Vehicle Research and Policy Program and Head of Vehicle Safety Analytics UMTRI.

Graduate of the University of Michigan, Ann Arbor, Michigan. Completed Ph.D. in 1984. Currently Director of the Center for National Truck and Bus Statistics, UMTRI.

JOHN WOODROOFFE
University of Michigan Transportation Research Institute USA

DANIEL BLOWER
University of Michigan Transportation Research Institute USA

Graduate of the University of Michigan. Completed a Ph.D. degree in 1995 in biostatistics. Developed statistical models for the analysis of crash rates for vehicles involved in nonfatal and fatal crashes. Assistant research scientist UMTRI.

PAUL E. GREEN
University of Michigan Transportation Research Institute USA



Abstract

This paper contains an analysis of the potential safety benefits of electronic stability control systems (ESC) for single unit trucks without trailers within the U.S.A. This research is based on the analysis of crash datasets using engineering and statistical techniques to estimate the probable safety benefits of the technology. The crash population that could likely benefit from the technologies was identified by reviewing a random sample of fatal and nonfatal crash involvements, covering all crash types. Fatal crashes were sampled from a national census file of fatal crashes and nonfatal crashes from two states. Track testing of the technology was conducted using maneuvers characteristic of loss of control crashes. The probable outcome estimates were based on the track test experience and expert panel assessment and were applied to the national crash population. Assuming ESC was fitted to all single units trucks, savings from LOC and rollovers prevented by ESC are estimated at $1.2 to 1.5 billion annually.



**Keywords:** Electronic Stability Control, Single Unit Trucks, Benefit Estimates, Loss of Control, Heavy Vehicles, Freight Transport.

## 1. Introduction

Stability-enhancing technologies sense when a loss of control or rollover is imminent and take action to reduce the likelihood of a crash. This technology is capable of sensing the early stages of loss of control and effect countermeasures without driver involvement before it is too late for typical driver corrective action.[1] Countermeasures consist of selective braking to counteract understeer or oversteer. The ESC system can also sense vehicle lateral acceleration in a curve and intervene to slow the vehicle to prevent rollover in accordance with an algorithm that accounts for vehicle load state. The deceleration interventions for rollover prevention are graduated in the following order: de-throttling; engine brake; and foundation brake application.

Single unit trucks included in this study are defined as non-articulated vehicles without trailers. This study is specifically designed to estimate the potential benefit of electronic stability control (ESC) within the context of the single unit truck population operating in the U.S.

This paper documents part of a study conducted by the University of Michigan Transportation Research Institute (UMTRI) under a Cooperative Agreement between National Highway Traffic Safety Administration (NHTSA) and Meritor WABCO to examine the performance of electronic stability control systems (ESC) single unit trucks and motorcoaches [2].

## 2. Study Design and Approach

The conventional approach for assessing the safety benefits of vehicle technologies is to analyze crash datasets containing data on the safety performance of vehicles equipped with the technology of interest. Since deployment of the stability technologies for single unit trucks is in its infancy, national crash databases do not include information that can be used to identify trucks equipped with ESC; moreover, even if they could be identified, in the current stage of deployment it is unlikely that there would be sufficient data to evaluate the safety performance of the technology. In light of these limitations, this study used an indirect method of predicting the safety performance of stability technologies based on an understanding of the technical function of the technology relative to crash types that would likely benefit from the technology.

The technical function of the technology was determined through rigorous analysis based on knowledge of the performance attributes and control systems, vehicle intervention strategies, and vehicle corrective response. Additional knowledge was gained through independent study and track tests.

Linking the performance of the stability technologies to benefits based on estimates of national crash reduction was achieved by a three step process similar to a previous study on tractor semitrailers [3].

1. Identify the population of crashes that can be addressed by the ESC technology by a survey of fatal and nonfatal crash reports.
2. Estimate the effectiveness of the stability technology in preventing the candidate crashes through track testing and engineering judgment.
3. Apply those effectiveness estimates to the crash population.

The population of crashes that can be addressed by ESC was developed through a comprehensive survey of crash reports on fatal and nonfatal crashes. Crash reports from the Trucks Involved in Fatal Accidents (TIFA) [4] survey were used for fatal single unit truck crashes. Crash reports on nonfatal crashes were sampled from two states (Florida and Louisiana) for nonfatal crashes. [9, 10]

Track tests of the technology were conducted using maneuvers characteristic of loss of control crashes. These tests provided a detailed understanding of how the technology responds under conditions similar to those identified in the crashes, as well as a demonstration of how ESC extends the performance envelope of the vehicles.

Probable effects of the stability technologies were then developed using the well-documented cases in the Large Truck Crash Causation Study (LTCCS). The LTCCS crash data which formed the backbone for this study provided the high quality and consistent detail contained in the case files. Included in this resource are categorical data, comprehensive narrative descriptions of each crash, scene diagrams, and photographs of the vehicle and roadway from various angles. This information allowed the researchers to achieve a reasonable level of understanding of the crash mechanics for particular cases.[5, 6, 7]

Once the technology effectiveness estimates were completed for the LTCCS cases, scaling the benefits to the national population was achieved by mapping the LTCCS effectiveness ratio to the corresponding crash populations identified in TIFA for fatal crashes and in the General Estimates System [8] for nonfatal crashes. The mapping was achieved by aggregating the candidate crash involvements into common crash characteristics (roadway alignment and road surface condition) that can be identified identically in each of the three crash files (LTCCS, TIFA, and GES).

Engineering judgment was used to estimate benefits in the national crash population. The crash selection algorithm in the national data was applied to the LTCCS data to produce a sample of the types of crashes identified in the national data by the algorithm. The effectiveness of the ESC technology was estimated separately. The effectiveness was estimated for each crash using expert judgment informed by track tests and experience. Since the LTCCS cases were selected using the same algorithm developed in the national crash files, each crash could be linked to the national data to produce overall estimates of the effectiveness of the technologies in reducing crashes.

## 3. Identification of Target Crashes

Several crash data sets and sets of crash investigations were used in this project. The National Highway Traffic Safety Administration’s (NHTSA’s) General Estimates System (GES) file and UMTRI’s Trucks Involved in Fatal Accidents (TIFA) file are used to define the universe of crashes involving single unit trucks. In addition, the NHTSA/Federal Motor Carrier Safety Administration’s (FMCSA’s) Large Truck Crash Causation Study (LTCCS) data file is used to identify candidate crashes and to provide example crashes with enough information to support an expert judgment as to the effectiveness of the ESC technology in mitigating crashes.

Crash data from Florida and Louisiana were used to sample cases from the population of nonfatal crashes. A survey of these crashes provides an estimate of the incidence of crashes relevant to the ESC technology in nonfatal crashes, just as TIFA provided cases to review of fatal crashes. [9, 10]

### 3.1 ESC-relevant Fatal Crash Involvements, using the TIFA Crash File

The TIFA cases were classified into different types, based on the geometry of the crash, and by road surface condition in preparation for sampling. Some of the crash types in the classification were designed to aggregate crashes which were judged to be more likely to be relevant to the ESC technology. An example is the “control loss, off road” crash type. Other types were judged less likely to include ESC-relevant crashes, such as rear-end crashes, or same direction crashes, but were aggregated into those types because they capture the primary geometries of crashes. Within each crash type, the crashes were classified by road surface condition, coded as either dry or not dry, on the assumption that yaw or other loss of control (LOC) events would be more likely on low friction surfaces. Cases were sampled from each cell of the matrix formed by the cross-classification of crash type and road surface condition, to ensure that the entire population of single unit truck crashes would be represented. Crash types which seemed more likely to contain ESC-relevant crashes were oversampled. Sample weights were calculated to weight the sampled data back to the full population. A total of 388 crashes were sampled, reviewed, and coded as to whether the ESC technology would have activated prior to the crash.

Table 1 shows the overall distribution of involvements in fatal crashes by the type of crash and whether the ESC technology was relevant. The cell frequencies include all single unit trucks involved in a fatal crash. The top half of the table shows the weighted frequencies and the bottom shows the row percentages of ESC-relevance for each crash type. The data cover the period from 2003-2007 and are not annualized. In the period, almost 1,100 single unit trucks were involved in a fatal crash that may have been mitigated by ESC. This amounts to 13.7 percent of all single unit truck fatal involvements.

ESC-relevant crash involvements are found in almost all of the crash types shown, which validates the strategy of surveying all crash types. The incidence of ESC-relevant crashes varies by crash type. The “control loss, off road” and “1st event rollover” types have the highest percentages of ESC relevant involvements, with 63.4 percent and 60.8 percent respectively. About 20-25 percent of “other 1 vehicle,” “ran off road,” and “opposite direction” crashes were found to be potentially addressable with the ESC technology as well. In these crashes, there were events where ESC intervention may help. For example, a common scenario in the opposite direction crashes was truck LOC while evading another vehicle, resulting in either a head-on collision or opposite direction sideswipe. If ESC had helped the truck driver maintain control, the truck may not have struck the other vehicle. In any case, ESC would likely have activated in these crashes when the truck lost directional control during the evasion, which is what makes the crash ESC relevant. Only the rear-end crash type had a negligible proportion of ESC relevant involvements.

Table 2 shows the distribution of ESC relevance by rollover condition. This table uses the FARS rollover variable, which classifies rollover as either the first harmful event or a subsequent event. Almost 60 percent of first event rollovers were deemed relevant to the ESC technology, while only 12.0 percent of subsequent event rollovers were relevant. In many of the subsequent event rollovers considered relevant, the truck lost control prior to striking another vehicle or object, which precipitated the rollover. However, if ESC had enabled the truck to maintain control in those situations, the collision and therefore the rollover may have been averted. Again, the judgment of ESC relevance at this stage was that the technology would likely have activated and have some effect. It is not that the technology would have prevented the crash.

**Table 1 - Fatal Crash Type by ESC-Relevance, Single Unit Trucks, TIFA 2003-2007**

| Crash type | ESC relevant | | |
|---|---|---|---|
| | No | Yes | Total |
| Ran off road | 217 | 59 | 276 |
| Control loss, off road | 87 | 150 | 237 |
| Hit object in road | 947 | 62 | 1,009 |
| Other 1 vehicle | 20 | 7 | 27 |
| Rear-end | 1,092 | 6 | 1,098 |
| Opposite direction | 1,582 | 413 | 1,995 |
| Same direction | 166 | 11 | 177 |
| Turning/intersection | 1,780 | 222 | 2,001 |
| 1st event rollover | 75 | 117 | 192 |
| Other/unknown | 852 | 32 | 884 |
| Total | 6,817 | 1,079 | 7,896 |
| | Row percentages | | |
| Ran off road | 78.8 | 21.2 | 100.0 |
| Control loss, off road | 36.6 | 63.4 | 100.0 |
| Hit object in road | 93.8 | 6.2 | 100.0 |
| Other 1 vehicle | 73.5 | 26.5 | 100.0 |
| Rear-end | 99.4 | 0.6 | 100.0 |
| Opposite direction | 79.3 | 20.7 | 100.0 |
| Same direction | 93.7 | 6.3 | 100.0 |
| Turning/intersection | 88.9 | 11.1 | 100.0 |
| 1st event rollover | 39.2 | 60.8 | 100.0 |
| Other/unknown | 96.4 | 3.6 | 100.0 |
| Total | 86.3 | 13.7 | 100.0 |

**Table 2 - Fatal ESC Relevance by Rollover, Single Unit Trucks, TIFA 2003-2007**

| | ESC relevant | | |
|---|---|---|---|
| Rollover | No | Yes | Total |
| None | 5,880 | 747 | 6,627 |
| First Event | 152 | 225 | 377 |
| Subsequent Event | 785 | 107 | 892 |
| Total | 6,817 | 1,079 | 7,896 |
| | Row percent | | |
| None | 88.7 | 11.3 | 100.0 |
| First Event | 40.4 | 59.6 | 100.0 |
| Subsequent Event | 88.0 | 12.0 | 100.0 |
| Total | 86.3 | 13.7 | 100.0 |

### 3.2 Florida

Florida was one of the two states selected for review to estimate the incidence of single unit truck crashes that might be addressed by ESC in nonfatal crashes. Crashes were categorized by crash type, using the same (or as close as possible) crash types as were used in the TIFA file. A total of 343 crash reports involving medium or heavy single unit trucks were sampled using a stratified random sampling procedure. The strata used were the cross-classification of the crash type variable and road surface condition, categorized as dry/not dry. Approximately 25 percent of single unit trucks sampled as medium duty trucks proved to be light vehicles (verified by decoding the VIN). There were 282 crash reports for medium or heavy single unit trucks in the final set of cases reviewed. Case weights were calculated so that correct population estimates could be computed.

Overall, the percentage of involvements in the Florida data that were judged ESC relevant was only 2.3 percent. This is significantly lower than the 13.7 percent rate observed in the TIFA review. It was expected that the rate of crashes relevant to ESC in nonfatal crashes would be lower than in fatal crashes, though prior to the review we had no particular expectation as to how much lower the rate would be. But it is reasonable that the rate is lower, since in nonfatal crashes, vehicle speeds are typically lower, and present a much lower risk of loss of control prior to the collision.

However, in the review of Florida rollovers, in contrast to crashes that did not include rollover, a much higher proportion included the sort of yaw or lateral acceleration that would trigger the ESC. The result of the review was that over 60 percent of the single unit truck rollovers in Florida appeared to include events that would activate the ESC technology. A small number of distinct scenarios predominated. One common scenario was the truck entering a curve too fast, going partially off the roadway before overcorrecting back on, followed by one or more corrections as the driver attempted to regain control. In another common scenario, the driver allowed the truck to drift off the road partially and then overcorrected back on the road, followed by one or more corrections before rolling over. As shown in Table 3, the proportion of rollovers judged ESC-relevant in Florida is very similar to that of first-event rollovers in the TIFA data.

**Table 3 - Nonfatal ESC-relevance for Rollover by ESC-Relevance for Single Unit Trucks in Florida, 2008**

| | ESC relevant | | |
|---|---|---|---|
| Rollover | No | Yes | Total |
| No rollover | 8,568 | 83 | 8,651 |
| Rollover | 77 | 122 | 199 |
| Total | 8,645 | 205 | 8,850 |
| | Row percentages | | |
| No rollover | 99.0 | 1.0 | 100.0 |
| Rollover | 38.7 | 61.3 | 100.0 |
| Total | 97.7 | 2.3 | 100.0 |

Though the raw incidence of ESC-related crashes is lower in the Florida nonfatal crash population, the relative ranking of the association of roadway curvature and not dry roads is similar to that observed in the population of fatal crashes, as captured in the TIFA data. The combination of curved, not dry roads had the highest percentage of crashes that were judged ESC-relevant at over eight percent, compared with the overall rate in Florida of 2.3 percent.

### 3.3 Louisiana

The same procedure used for TIFA and Florida was implemented to sample Louisiana crash reports for review. Two hundred and two crashes were sampled; and crash reports were obtained for 136. Overall, 6.5 percent of the involvements had characteristics and events consistent with the activation of the ESC technology. The expected crash types tended to be overrepresented. The ESC technology was determined to be applicable to almost 56 percent of crashes where the truck lost control and went off the road, and to 18.2 percent of crashes where the vehicle just exited the roadway. Over 57 percent of first event rollovers were ESC-relevant. On the other hand, no rear-end crashes occurred in a way that ESC could potentially address, and only very small proportions of opposite direction or same direction type crashes. Though the magnitudes differ, the results for Louisiana parallel the results of the TIFA and Florida reviews.

The estimate of 6.5 percent of involvements being ESC-relevant is somewhat higher than the 2.3 percent observed in the Florida, but the two estimates are not out of line. The crash reports reviewed were not equivalent in terms of detail and completeness. In particular, Louisiana crash reports tend to have more detailed diagrams and are more likely to include skid and other crash-related marks. The review process was intentionally conservative, which would have the effect of making it more difficult to identify ESC-relevant events in the Florida data.
As with the Florida and TIFA reviews, a high proportion of crashes in which the truck rolled over included events that suggest ESC might be able to help the driver maintain control of the truck. Table 4 shows that the ESC technology might activate in almost 40 percent of rollover crashes compared with only about five percent of crashes that did not result in rollover. A common scenario was road excursion, followed by one or more over-corrections as the driver attempted to regain control of the vehicle. Excessive speed in curves was a frequent precursor.

**Table 4 - Nonfatal ESC-relevance for Rollover Involvements Single Unit Trucks, Louisiana 2008**

| | ESC relevant | | |
|---|---|---|---|
| Rollover | No | Yes | Total |
| No roll | 3,584 | 201 | 3,785 |
| Rollover | 81 | 54 | 135 |
| Total | 3,665 | 255 | 3,920 |
| | Row percentages | | |
| No roll | 94.7 | 5.3 | 100.0 |
| Rollover | 60.3 | 39.7 | 100.0 |
| Total | 93.5 | 6.5 | 100.0 |

As in the results from the reviews discussed above, roadway curvature and surface condition are both strongly associated with pre-crash LOC. Over two-thirds of crashes on curved/not dry roads are ESC-relevant, compared with only about six percent of crashes on straight/dry roads. Table 5 shows the estimated incidence of ESC-relevant crash involvements by roadway alignment and surface condition, weighted to the whole population.

**Table 5 - Percentage of Single Unit Truck ESC-Relevant Fatal Involvements by Roadway Alignment and Surface Condition Louisiana 2008**

| Roadway alignment | Surface condition | | Total |
|---|---|---|---|
| | Dry | Not dry | |
| Straight | 6.4 | 1.7 | 5.9 |
| Curved | 10.5 | 67.3 | 16.6 |
| Total | 6.7 | 5.1 | 6.5 |

### 3.4 LTCCS

All 310 trucks classified as single unit truck trucks with no trailers were selected for review. The purpose of the review was primarily to identify ESC-relevant cases that could be used as examples in a clinical review to estimate the effectiveness of the ESC technology in helping a driver maintain vehicle control and avoid crashes. As part of that process, each single unit truck crash in the LTCCS was reviewed to determine its suitability for use in generating the effectiveness estimates. Those effectiveness estimates were generated in a separate process, in which reviewers evaluated each case and rendered a judgment as to the likelihood that the ESC technology would mitigate the collision.

For each case, the reviewers set flags for rollover, yaw, and skidding. The rollover flag indicated whether the vehicle experienced any type of rollover, whether first event or following an impact with a vehicle or object. The yaw flag captured whether there were indications of pre-crash yaw. The skidding flag captured any type of skidding, whether longitudinal (as in hard, straight line braking) or lateral (as in yaw). In addition, each reviewer recorded comments pertinent to the pre-crash events for the vehicle, with particular focus on events that bear on vehicle control. Finally, the reviewers set the flag for "ESC relevant" for those cases that, in their judgment, included events and conditions in which ESC might activate.

Each reviewer independently evaluated all 310 LTCCS single unit truck cases, though they discussed the review procedure prior to initiating the review and also occasionally consulted to clarify ambiguous cases. Following the review, the results of each reviewer were compared, to identify those cases where they agreed and, more importantly, where their coding differed. Each case where there were differences was then discussed by the two reviewers and a joint classification was made.

At this stage of the review, the judgment made was whether the conditions were such that ESC would activate, not that it would be effective in intervening. Effectiveness ratings were reserved to the clinical review by the expert panel. Again, this initial review was just to identify cases that were relevant to the ESC technology.
In total, crashes involving 54 single unit truck cases were identified as relevant to the ESC technology. Overall, about 17.4 percent of single unit truck crashes in the LTCCS data were judged relevant to the ESC technology. This proportion is reasonably close to that observed in the TIFA data, which it matches the best in terms of crash severity.

## 4. Engineering Evaluation of Relevant Crashes in LTCCS

One of the more complex challenges faced during this study was establishing a reliable estimate of the proportion of crashes that could be addressed by these technology. There is an inherent uncertainty in estimating how ESC will behave in real-world crashes. This is true of any analysis method open to the research team, since, however accurately the method is applied, key inputs, such as vehicle speed and orientation, vehicle loading conditions, and the vehicle path (driver input), have to be assumed. The vehicles involved in crashes were of course not instrumented, so the crash analyst was dependent on the evidence preserved by the crash investigators. With knowledge of how the technology functions and influences vehicle behavior, an expert panel reviewed each crash in detail to derive the effectiveness estimates.

### 4.1 Track Testing

To develop a better understanding of the ability of the technology to influence single unit truck loss of control, a limited winter test program was conducted on low friction surfaces at the Smithers Scientific Services Winter Test Center located in Northern Michigan. The facility consists of large open test areas with packed snow or polished ice surfaces. The polished ice surface is rectangular in shape approximately two travel lanes, 7.9 m wide and 0.55 km long. The adjoining surface was densely packed snow. The packed snow area was very large allowing for complex vehicle maneuvers with homogeneous road friction. Split friction tests are accomplished by straddling the ice surface and the packed snow surface.

The test program was split into two distinct activities both conducted at the same facility in parallel with each other. One test activity was a subjective demonstration of vehicle handling and response variability as a function of wheelbase. This demonstration test consisted of a “J” turn initiated from a split friction surface of polished ice and packed snow and transitioning to packed snow. The friction differential was intended to roughly represent driver drift off road onto the gravel shoulder followed by aggressive steering to return to the roadway. Compared to the longer wheelbase vehicle, the short wheelbase vehicle showed a higher tendency to oversteer when the technology was off and showed marked improvement in handing when the technology was active.

One of the test vehicles was fitted with NHTSA’s robot steer device. The vehicle was put through three separate maneuvers, two of which utilized the robotic steer and a third used human steer input for split friction vehicle response analysis. The tests were designed to provide technical insight into vehicle performance envelope improvements from ESC. Each maneuver was conducted with the ESC technology activated (“on”) and immediately repeated with the technology disabled (“off”). For each condition, vehicle speed was increased until loss of control occurred.

For the sine with dwell maneuvers, with the identical vehicle, load and road conditions and the same speed of 65 km/h, tests were conducted with increasing hand wheel steer angle limits with the ESC system “on” and “off”. For these tests, the hand wheel steer angle of the steering robot was increased incrementally until loss of control became evident through the yaw rate measure. With the system enabled (“on”), the vehicle remained under control with hand wheel steer inputs of 145, 155 and 165 deg. with some evidence of yaw rate response decline between 155 and 165 deg. However with the system disabled (“off”), vehicle control was maintained at a hand wheel steer angle of 55 degrees but was not achievable at 75 degrees as evident by the divergent yaw rate. These results suggest that ESC significantly alters the characteristics of the vehicle such that it can cope with much more aggressive steer input prior to loss of control. For the test conditions and vehicle examined, the presence of ESC more than doubled the amount of hand wheel steer input that the vehicle could absorb prior to loss of control. Because excessive steer input was found to be a common factor in single unit truck loss of control crashes, the test results provide strong evidence that ESC can address this frequently occurring loss of control scenario.

## 5. Estimated Reduction in Fatalities and Injuries

Effectiveness estimates from the review of LTCCS crashes were applied to the national single unit truck crash population to estimate the potential reduction in fatal and other injuries that might be obtained if ESC were installed in all single unit trucks. Separate estimates of the reduction in nonfatal crashes were made based on the results of the evaluation of the Florida and Louisiana nonfatal crashes. The benefit from reduction of fatal and nonfatal crashes is summed and presented in Table 6. The results for fatal crashes are based on the TIFA review and remain constant. If the result from the review of Louisiana nonfatal crashes is applied to the whole population of single unit truck crashes, it is estimated that 136 fatal injuries and 2,011 nonfatal injuries would be saved. The number of nonfatal injuries saved is more than twice the 785 estimated injuries saved based on Florida evaluation.

**Table 6 - Benefit from Reduction of ESC Relevant Fatal and Nonfatal Crashes**

| | Nonfatal injury reduction based on: | |
|---|---|---|
| Injury severity | Review of Florida | Review of Louisiana |
| Fatal | 136 | 136 |
| A-injury | 139 | 323 |
| B-injury | 237 | 533 |
| C-injury | 409 | 1,155 |
| No injury | 4,260 | 10,717 |
| Injury Unknown | 12 | 26 |

Benefit estimates in terms of dollars were calculated using estimates of the costs of highway crashes involving large trucks (updated report by Zaloshnja and Miller, 2006). [11] Since costs were reported in 2005 dollars, they were adjusted to 2009 dollars using the CPI inflation factor of 1.10 as reported by the Bureau of Labor Statistics [12]. The benefits were applied specifically to single unit trucks with no trailer. The total cost per fatal victim is $6,302,605 and is by far the largest amount compared to other injury severities.

**Table 7 - Estimated Societal Costs by Injury Severity from Zaloshnja and Miller**

| Injury severity | Total cost per victim |
|---|---|
| Fatal | $6,302,605 |
| A-injury | 523,532 |
| B-injury | 310,784 |
| C-injury | 86,187 |
| No injury | 5,596 |
| Unknown injury | 43,727 |
| Unknown | 15,599 |

Table 8 shows the estimated cost benefits in 2009 dollars that result by applying the societal crash costs by injury severity from Zalshnja and Miller to the counts of fatalities and injuries saved in the tables above and multiplying by the CPI inflation factor 1.10. A $864,328,000 benefit is estimated for reduced fatalities. For injuries, the amount is $183,987,000 for the Florida review and 441,549,000 for the Louisiana review.

**Table 8 - Estimated ESC Benefit in 2009 Dollars**

| | Benefit related to nonfatal crashes based on | |
|---|---|---|
| Injury severity | Review of Florida | Review of Louisiana |
| Fatal | $864,328,000 | $864,328,000 |
| A-injury | 74,340,000 | 172,500,000 |
| B-injury | 74,575,000 | 168,992,000 |
| C-injury | 35,072,000 | 100,057,000 |
| No injury | 24,000, | 61,195,000 |
| Injury Unknown | 189,000 | 1,164,000 |
| Total | 1,072,390,000 | 1,368,236,000 |

## 6. CONCLUSIONS

This paper presents a method for estimating benefits of electronic stability control systems for single unit trucks operating within the U.S. Because these technologies are not yet widely used, the analysis did not have the benefit of examining representative crash datasets that would show how the technology performs in the real world. Therefore the analysis was based on probable outcome estimates derived from expert panel assessment informed by track test experience. The analysis was only able to examine pre-crash loss of control cases and did not consider cases where subsequent event loss of control may have been relevant to the technology; therefore any benefits associated with subsequent event loss of control have not been accounted for. The study did not examine unintended consequences that may be relevant to this technology although the likelihood of negative unintended consequences appears to be small. Finally the study team believes that the functional characteristics of the technology that result in autonomous brake intervention near the limits of stability may provide an additional safety benefit in the form of constructive driver behavior modification. While it was not possible to address this issue in the course of the research, it is believed that the role of driver feedback from the technology may produce a secondary benefit of significant proportion particularly if the interventions are stored and cataloged for review by fleet safety personnel within the context of a driver education and improvement program.

The research project resulted in the following conclusions:

1. The findings of the study indicate that stability control systems provide substantial safety benefits for single unit trucks. Assuming that all existing single unit trucks operating on U.S. roads were fitted with ESC, the expected annual safety benefit is a reduction of about 2,000 to 5,000 crashes and 1,000 to 2,000 injuries (ranges based on estimates calculated from Florida and Louisiana). Based on TIFA review the annual reduction in fatalities is estimated at 136. Since TIFA is the best source of available data on fatal truck crash involvements, and given that it is a census file, there is a high degree of confidence in the fatal estimate and therefore a range of values is not reported.

2. Assuming ESC was fitted to all single units trucks, savings from LOC and rollover crashes prevented are estimated at $1.2 to 1.5 billion annually.
3. The benefit estimates are limited to single unit trucks without trailers operating within the U.S. The study was not able to assess benefits attributable to less obvious crash types that may nevertheless have an unforeseen connection to the technology. Nevertheless, the analysis did consider all crash types coded in the data using a sampling procedure.
4. The study could not account for secondary benefits such as driver awareness benefits from intervention experience, directed driver performance modification from company initiatives derived from technology intervention records, or any post-crash benefits attributable to the technologies.

## 7. References


1. Winkler, C.B. and Ervin, R.D., "Rollover of Heavy Commercial Vehicles." The University of Michigan Transportation Research Institute, Ann Arbor, MI. 1999.
2. Woodrooffe J., Blower D., Green P.E. (2011) "Safety Benefits of Stability Control Systems for Single Unit Trucks and Buses" NHTSA, U.S. Department of Transportation.
3. Woodrooffe J., Blower D., Green P.E. (2011) "Tractor Trailer Rollover Prevention: The Effectiveness of Electronic Stability Control Systems". TRB Record.
4. 2006 Trucks Involved in Fatal Accidents Codebook (Version August 5, 2008). Anne Matteson, Linda Jarossi, Leslie Pettis, John Woodrooffe. 2008.
5. Large Truck Crash Causation Study Codebook. FMCSA, NHTSA, U.S. Department of Transportation, June 2006.
6. Large Truck Crash Causation Study Analytical User's Manual. FMCSA, NHTSA, U.S. Department of Transportation, June 2006.
7. Large Truck Crash Causation Survey search interface, NHTSA, accessed at **http://www-nass.nhtsa.dot.gov/LTCCS_PUB/SearchForm.aspx**
8. National Automotive Sampling System (NASS) General Estimates System (GES) Analytical User's Manual, 1988-2005. National Highway Traffic Safety Administration, US. Department of Transportation, National Center for Statistics and Analysis, Washington, DC n.d.
9. Instructions for Completing the Florida Uniform Traffic Crash Report Forms, State of Florida, Department of Highway Safety and Motor Vehicles, January 2002.
10. State of Louisiana Uniform Motor Vehicle Traffic Crash Report, [January 1, 2005], no author.
11. Zaloshnja, E. and Miller, T. (2006). Unit Costs of Medium/Heavy Truck Crashes, Pacific Institute.
12. Bureau of Labor Statistics, U.S. Department of Labor, Inflation Calculator, accessed at **http://www.bls.gov/home.htm**