A COMPARATIVE STUDY OF ROLLOVER CRASHES INVOLVING VEHICLES WITH AND WITHOUT ELECTRONIC STABILITY CONTROL (ESC) SYSTEMS

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ABSTRACT

The analysis updates and expands previous research in which rollover critical events were classified based on a detailed review of approximately 500 police-reported single-vehicle rollover crashes of ESC-equipped vehicles. In order to compare the rollover performance of vehicles with and without ESC for the present study, an additional sample of more than 300 police reports on non-ESC single-vehicle rollovers was obtained, and detailed coding of rollover scenarios was performed. The coding effort was undertaken by an engineering team and focused on critical events leading to rollovers (departure from road, loss of directional control, impact with an object, and departure from road with possible driver's input); driver factors (impairment, speeding, inattention, distraction, fatigue, and overcorrection); and environmental factors. A comparison of vehicles with and without ESC was performed to characterize differences in types of critical events leading to rollovers.

Keywords: Accident Analysis, Stability, Safety Devices, Rollover Accidents, ESC

THIS STUDY uses U.S. field accident data to address the effectiveness of Electronic Stability Control (ESC) systems in rollover crashes. Several recent studies of crash performance for ESC-equipped vehicles have indicated that, while ESC is effective in reducing certain types of rollovers, its effectiveness is diminished in others (Padmanaban, 2007; Padmanaban, 2008). To further investigate this finding, the present study performed two analyses:

1. An analysis comparing sequences of events leading to rollovers for vehicles equipped with ESC ("ESC vehicles") to those for vehicles not equipped with ESC (non-ESC vehicles), and
2. A "matched pair" analysis comparing rollover sequences for the same models with and without ESC.

As in the 2008 study, state accident databases with narrative descriptions and scene diagrams were examined to identify critical events leading to rollovers involving ESC and non-ESC vehicles.

BACKGROUND – In 2007, the U.S. National Highway Traffic Safety Administration (NHTSA) established a new Federal Motor Vehicle Safety Standard, FMVSS No. 126, to require ESC systems on all passenger cars, vehicles, trucks, and buses of 10,000 lbs. or less — with 100% installation rate by 2012. ESC is an automatic, computer-controlled braking system designed to help drivers maintain control when their vehicles threaten "to lose directional stability at the rear wheels (spin out) or directional control at the front wheels (plow out)" (NHTSA, 2007). In brief, the system is supposed to detect problems, such as loss of directional control, and apply the appropriate braking (some systems can also reduce engine power, etc.) to the appropriate wheels to counter the problem.

In its Final Rule on FMVSS No. 126, NHTSA estimates that ESC has the potential to prevent 71% of the passenger car rollovers and 84% of the SUV rollovers that would otherwise occur in single-vehicle crashes. NHTSA issued a technical report that found that, for vehicles equipped with ESC, police-reported crashes involving single-vehicle first-event rollovers were reduced by 64% in passenger cars and 85% in light trucks and vans (LTVs) and that *fatal* single-vehicle first-event rollovers were reduced by 70% for passenger cars and 88% for LTVs. The analyses were done using police-reported computerized accident data (Dang, 2007).

To better quantify the types of rollover crashes reduced by ESC presence, it was deemed appropriate to perform a comprehensive review of police reports, scene diagrams and narratives. Hence this study.

CURRENT STUDY – A comprehensive review of police accident reports involving vehicles with and without ESC systems was made. The objectives were to examine and characterize rollover crashes in greater detail than is possible using only the coded information available in electronic accident databases. This included review of engineering issues that relate to ESC effectiveness. In particular, the sequence of critical events leading to rollovers and the interactions between the accident, driver, and environment was examined using the methodology developed to perform the initial study of single-vehicle rollover crashes involving ESC vehicles (Padmanaban, 2008).

METHODS

This study updates and expands previous research in which rollover critical events were classified based on a detailed review of police-reported single-vehicle rollover crashes of ESC-equipped vehicles. In order to compare the rollover performance of vehicles with and without ESC for the present study, police reports on non-ESC single-vehicle rollovers were obtained, and detailed coding of rollover scenarios was performed. As done in the 2008 study, the coding effort was undertaken by an engineering team and focused on critical events leading to rollovers (departure from road, loss of directional control, impact with an object, and departure from road with possible driver input); driver factors (impairment, speeding, inattention, distraction, fatigue, and overcorrection); and environmental factors.

DATA USED – The 2008 study included vehicle models with ESC systems for 1997-2005 model years (Padmanaban, 2008). That study was updated to include 1997-2006 models with ESC systems for the current study by using multiple publicly available sources, including: the NHTSA Safercar.gov website, the Insurance Institute for Highway Safety website, MSN Auto, and information from vehicle manufacturers. The current study also included 1996-2005 model year vehicles without ESC.

A total of about 800 police reports were reviewed (368 passenger cars; 434 light trucks) to perform the analyses. The study included single-vehicle rollover crashes from 11 states (Alabama, Florida, Georgia, Idaho, Kansas, Maryland, Michigan, Missouri, Nebraska, Washington, and Wyoming) for calendar years 1997 to 2006.

APPROACH – The primary objective of this study was to compare the types of critical events leading to rollovers for both ESC and non-ESC vehicles and assess the reduction in certain types of rollovers due to ESC presence.

<u>Coding</u> – Detailed instructions were developed for variables to be coded from the police reports. These included variables that identify:

- The *sequence of critical events,* such as departure from roadway (with or without driver input) and loss of directional control (vehicle is not following the directional path commanded by the driver);
- *Driver actions or decisions* (such as speeding, alcohol/drug involvement, failure to stay in lane, overcorrection, or fatigue/inattention/ distraction) that could have influenced crash occurrence/outcome; and
- Features of the crash *environment* (such as weather, roadway features and surface condition, and lighting) that might have influenced crash occurrence/outcome.

Some variables, such as those identifying occurrence of skidding, yawing, or driver overcorrection, were coded for their occurrence at any time during the accident. Other variables, when examined chronologically, allowed construction of the critical event sequence leading to each of the rollovers. Examples of critical event sequences include:

- Vehicle departure from road; steering; reentering road; second departure from road
- Loss of directional control; departure from road; impact
- Loss of directional control; steering; braking; skidding; departure from road.

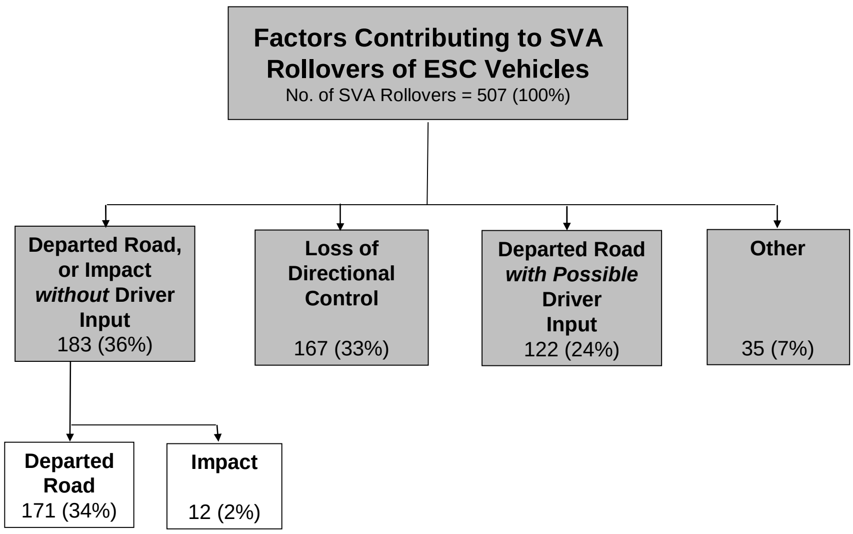
Single-Vehicle Rollover Categories – Review and analysis of the 800 police accident reports resulted in four primary categories of single-vehicle rollovers for ESC and non-ESC vehicles:

1. Departure from roadway without any driver input and prior to loss of directional control. (Example: "Driver reaching for something, departed roadway, impacted an embankment and rolled".)
2. Impacting an object prior to either road departure or loss of directional control.
3. Loss of directional control prior to impact or road departure. This means the vehicle, while on the road, was yawing or rotating such that it did not follow the intended path commanded by the driver (based on narrative descriptions and scene diagrams). Subsequent rollover occurred either on or off the road. (Example: "Vehicle traveling too fast on curve, steered hard, lost control, steered in opposite direction, departed road, struck embankment and rolled".)
4. Departure from roadway with possible driver input. (Example: "Driver steered to avoid deer, departed road, struck trees and rolled".)

Appendix A provides a list of codes used to identify critical events and other factors.

RESULTS

FACTORS CONTRIBUTING TO ESC ROLLOVERS – The single-vehicle rollover results for ESC vehicles, shown in Figure 1, are consistent with those of the 2008 ESC study. Of all ESC vehicle rollovers, 34% involved "departure from road *without* driver input"; 2% involved "impacting an object prior to loss of control or departure from road"; 33% involved "loss of directional control"; and 24% involved "departure from road with possible driver input". Vehicles that departed the road or impacted *without* driver input were at risk prior to the opportunity for ESC engagement.



Source: State Accident Data.

Fig. 1 – Primary Categories of Single-Vehicle Accident (SVA) Rollovers for ESC Vehicles

Of all the ESC cases with "departure from road with possible driver input", 45% included information indicating drivers had attempted to steer or brake prior to road departure. The vehicles in this category demonstrate that, in spite of drivers' attempts to control their ESC-equipped vehicles, these vehicles may still depart the road and roll over.

For the two most common critical event categories for ESC vehicles ("departure from roadway *without* driver input" and "loss of directional control"), driver factors contributing to rollovers were somewhat different. For events in which vehicles departed the road without driver input, fatigue/

inattention/distraction dominated the list, with speeding next. When the loss of directional control occurred prior to departure from road or impact, speeding was the dominant contributing factor and alcohol/drugs was next.

Environmental factors such as snowy/icy/wet road conditions were frequently present in loss of directional control events (50% of the time).

COMPARISON OF ESC AND NON-ESC ROLLOVERS – Figure 2 presents a comparison of critical events leading to rollovers for all vehicles with and without ESC, and Figure 3 presents the corresponding data for light trucks. Figures 2 and 3 also show that the critical event “loss of directional control” is reduced significantly (as shown by statistical significance) for ESC vehicles.

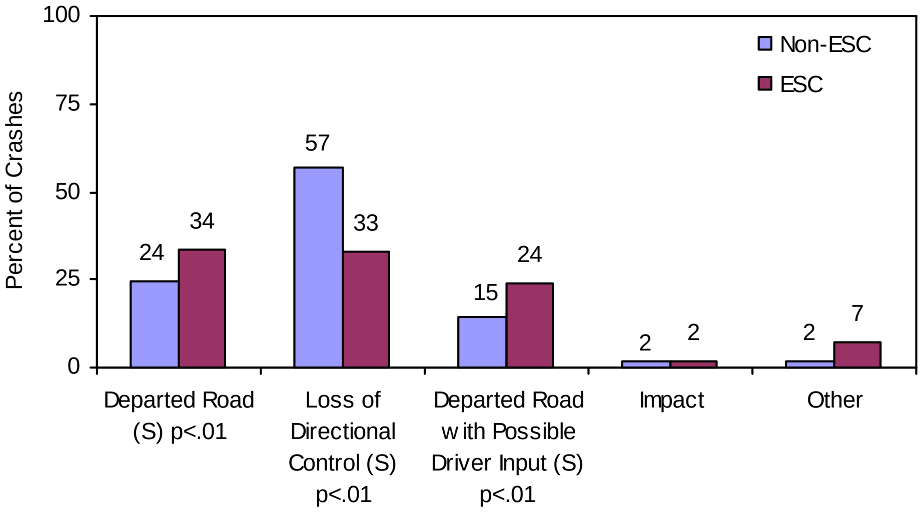


Fig. 2 – Comparison of Critical Events, ESC vs. Non-ESC Vehicles All Light Vehicles in SVA Rollovers

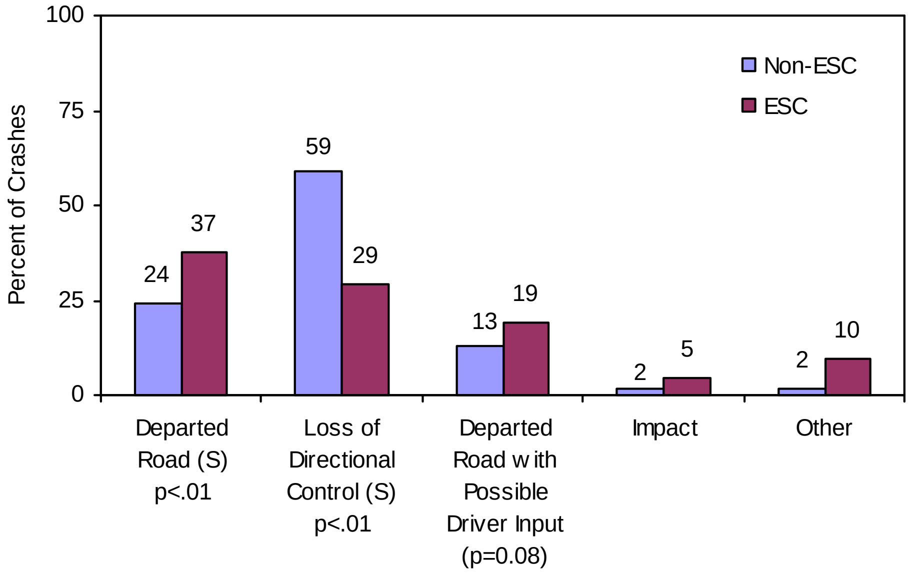


Fig. 3 – Comparison of Critical Events, ESC vs. Non-ESC Vehicles Light Trucks in SVA Rollovers

Other types of single-vehicle rollovers, including "departure from road with possible driver input" and "departure from road *without* driver input" are not reduced with ESC presence. In fact, there was an increase in these types of rollovers for ESC vehicles.

The results also suggest that ESC is 40-50% effective in reducing "loss of directional control" events for all light vehicles (Figure 2) and light trucks (Figure 3). "Fatigue/inattention/distraction" is the primary driver factor associated with the critical event "departure from roadway *without* driver input" for ESC vehicles, with "speeding" as a secondary factor.

MATCHED PAIR ANALYSIS – A study was done comparing matched pairs of vehicles with and without ESC. Data on passenger cars with matched pairs was sparse (since most of the passenger cars with ESC had significant platform changes concurrent with the introduction of ESC). Hence, the matched pair study was restricted to light trucks. Figure 4 presents the comparison of critical events for light trucks with and without ESC included in the matched pair analyses. Figure 4 shows a pattern similar to the one in Figures 2 and 3. There was statistically significant reduction in "loss of directional control" events and a significant increase in "departed from roadway with or without driver input".

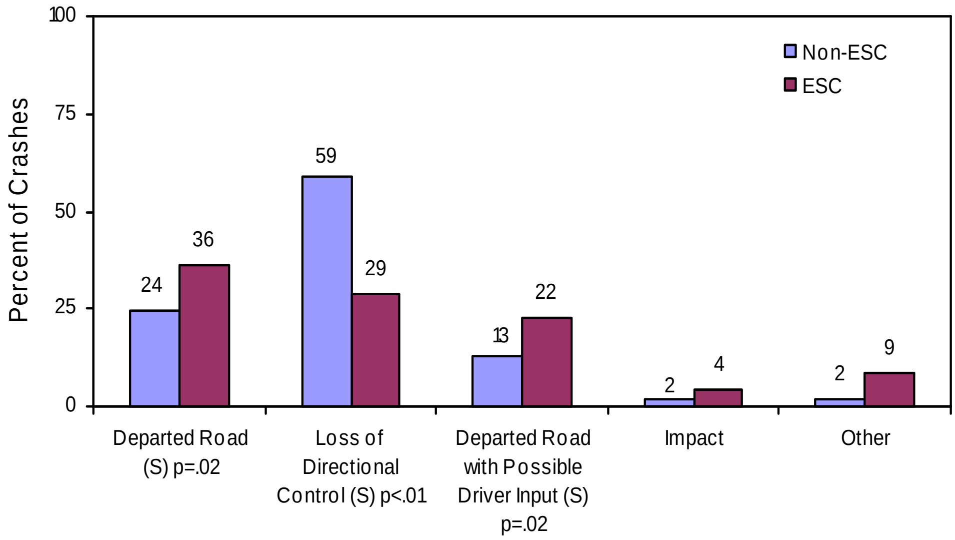


Fig. 4 – Comparison of Critical Events, Matched Pair ESC vs. Non-ESC Vehicles Light Trucks in SVA Rollovers

DISCUSSION

While many studies present high percentages of effectiveness of ESC in reducing rollovers, this study of field data shows that rollovers still occur for ESC vehicles. Direct comparisons of ESC and non-ESC rollover experiences are quantified in our analysis. The results showed that many ESC rollover cases involve situations where ESC has little or no reason or opportunity to intervene, or where its intervening brake and throttle controls are limited by the available friction at the tire/road interface.

Generally, vehicles that depart the road without driver input are "tracking" (not yawing out of control) as they leave the road. Once off the road, the risk of control loss and rollover is compounded by two factors:

1. Driver surprise or anxiety apparently stimulates overcorrective steering maneuvers, which can induce particularly high yaw moments. This is amplified when tires differentially engage relatively high-coefficient road surfaces and low-coefficient shoulders and off-road surfaces.
2. Off-road surfaces are more likely to be irregular, sloping, have areas of soft earth or hazards that can provide momentary and unpredictable yaw forces that would be difficult to avoid or

compensate for, and are more likely to have tripping hazards known to trigger rollover (Viano and Parenteau, 2003).

Factors such as these would explain the continued occurrence of loss of control and rollover for those vehicles departing the road without driver input.

The vehicles that departed the road after driver braking, steering, or change in throttle control were subject to the same two risk factors described above. This category included 57 cases with known driver input and no loss of directional control prior to departure from road; of these there are likely to be some for which ESC was engaged and loss of directional control was successfully avoided prior to road departure. Still, in the presence of the two off-road risk factors, rollover occurred later in the sequence. Likely to be included in this set would be some cases for which ESC was able to prevent loss of directional control but was unable to maintain the driver's chosen path on the road. Of course, ESC is unable to choose the most prudent path for safety, regardless of its effectiveness for maintaining the driver's chosen path.

All 167 cases in which directional control was not maintained involved accidents in which ESC engagement was likely. Of the 122 where the vehicle departed the road with possible driver input, 57 involved the vehicle leaving the road with known driver input (as discussed above). It is likely that many of these also involved ESC activation. Consequently, 44% (224) of the ESC rollover cases still resulted in rollover despite probable ESC activation.

Of the 507 total cases, 58% (293) involved departure from the road prior to known loss of directional control and despite the presence of ESC. The additional risk of rollover after road departure is not currently considered in NHTSA's development of vehicle tests that characterize rollover potential (Forkenbrock et al., 2003). Given the variability of off-road conditions, designing such tests would be difficult. Yet, these results show that road-departure conditions are clearly important, and ESC is unable to eliminate off-road excursions and rollovers.

Plans for future work in this area include an expansion of the passenger car dataset in order to be able to perform a matched pair comparison of the rollover scenarios between the ESC and non-ESC passenger cars.

CONCLUSIONS

While ESC is effective in reducing loss of directional control in certain situations likely to lead to rollover crashes, its effectiveness is diminished in others, particularly when the vehicle departs the roadway or when environmental factors such as slick road conditions or driver factors such as speeding, fatigue/distraction/ inattention, alcohol/drug impairment, or over-correction are present.

Conclusions regarding types of rollover accidents for vehicles with ESC as standard equipment include:

- For about 34% of rollovers, the first critical event was departure from road *without driver input* (i.e., before ESC was engaged).
- Another 33% of rollovers occurred when loss of directional control took place before the vehicle departed the road (likely ESC engagement).
- About 24% of rollovers occurred when vehicles departed the road after possible driver input (likely ESC engagement).
- About 44% had likely ESC engagement, but still rolled.

Conclusions regarding driver factors in ESC rollovers include:

- For those cases where ESC vehicles departed the road without driver input and then reentered the road prior to rollover, 93% of drivers imparted steering overcorrection.
- Speeding, fatigue/distraction/inattention, overcorrection, and alcohol involvement were important driver factors associated with these rollovers.
  - For departure from road without driver input events: fatigue/distraction/ inattention, and speeding were predominant.
  - For loss of directional control events: speeding was predominant.
- Alcohol/drug involvement was also identified as a significant contributing factor.

The two studies that compared field performance of ESC and *non*-ESC vehicles showed similar results:

- ESC was effective in reducing the critical event "loss of directional control". However, for other critical events, including "departure from road with possible driver input" and "departure from road *without* driver input", rollovers are not reduced with ESC presence. These events, which in fact show an increased number of rollovers for ESC vehicles, are associated with the driver factors "fatigue/ distraction/inattention" and "speeding".

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APPENDIX A:
VARIABLES CODED FOR ESC POLICE ACCIDENT REPORT ANALYSIS

1. Critical event sequence
    a. Acceleration, braking, steering
    b. Departure from road
    c. Loss of directional control
    d. Impact
2. Manner of the departure from road (if departure from road was the first critical event)
    a. Wandered off the road
    b. Ran off road in curve
    c. Intentional steer
3. Overcorrection
4. Driver's fatigue, inattention, distraction
5. Exceeding the speed limit or going too fast for conditions
6. Careless driving (other than speeding)
7. Alcohol/drug impairment
8. Lighting conditions
9. Roadway alignment

10. Roadway surface conditions
11. Short summary of the accident