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Has Electronic Stability Control Reduced Rollover Crashes?

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Abstract

Vehicle rollovers are one of the more severe crash modes in the US - accounting for 32% of all passenger vehicle occupant fatalities annually. One design enhancement to help prevent rollovers is Electronic Stability Control (ESC) which can reduce loss of control and thus has great promise to enhance vehicle safety. The objectives of this research were (1) to estimate the effectiveness of ESC in reducing the number of rollover crashes and (2) to identify cases in which ESC did not prevent the rollover to potentially advance additional ESC development.

All passenger vehicles and light trucks and vans that experienced a rollover from 2006 to 2015 in the National Automotive Sampling System Crashworthiness Database System (NASS/CDS) were analyzed. Each rollover was assigned a crash scenario based on the crash type, pre-crash maneuver, and pre-crash events. The Insurance Institute for Highway Safety ESC availability database was matched to each NASS/CDS case vehicle by the vehicle make, model, and model year. ESC effectiveness was computed using the quasi-induced exposure method.

From 2006-2015, control loss was a factor in 29.7% of the 1,339,407 vehicle rollovers. ESC was standard equipment in 177,644 of vehicles involved in these events. Our study estimated that ESC was effective in reducing the overall number of rollover crashes by 13.3%. ESC was more effective at reducing rollover crashes due to control loss with a reduction of 50.6%. ESC is particularly effective for high center of gravity vehicles such as light trucks, SUVs, and vans. Travelling too fast for the road conditions was the most common reason rollovers due to control loss were not prevented despite the presence of ESC.

Introduction

Vehicle rollovers are one of the more severe crash modes in the US - accounting for 32% of all occupant fatalities in 2015 in passenger vehicles and light trucks and vans (LTVs) despite accounting for less than 1.9% of all crashes [1]. One design enhancement which may prevent some rollover crashes is electronic stability control (ESC). ESC is designed to help keep the driver in control of the vehicle. When the vehicle begins to not follow the direction of the steering due to excessive steering inputs or road conditions such as ice, selective braking is applied to individual wheels, and in some cases power is reduced, which allows the vehicle to help maintain tracking [2]. Previous studies have shown that ESC systems are effective in preventing control loss crashes [3]. ESC has been estimated to prevent up to 50% of all crashes with serious or fatal injuries and could prevent 20% of all non-rear end crashes (Table 1). The purpose of this study was to identify the proportion of the rollover crashes which might benefit from ESC.

Approach

Databases

This study was based on data extracted from the following datasets:

- The National Automotive Sampling System General Estimates System (NASS/GES) is a database containing a weighted sample of all police reported crashes and is nationally representative. It includes basic crash information about the road, vehicles involved, occupants involved, and the surrounding environment.
- The National Automotive Sampling System Crashworthiness Data System (NASS/CDS) is a database of crashes in which at least one passenger vehicle was towed from the scene. Every case in NASS/CDS is assigned a weight to represent all crashes with at least one vehicle towed in the US. NASS/CDS provides detailed information on each crash including a scaled

TABLE 1 Summary of ESC effectiveness values and methods in the literature

Source	Method	Population	ESC Effectiveness (Confidence Interval)
Farmer, 2004 [4]	Induced exposure method in 7 USA states Case years: 2001-2002	All crashes	1% (-4-7%)
		Single Vehicle	50% (39-60%)
		Single Vehicle Rollover	74% (46-88%)
Erke, 2008 [5]	Meta-analysis from many countries Case years: 1995-2006	Single Vehicle	49% (42-55%)
		Loss of control	41% (7-62%)
		Rollover, injuries	69% (45-82%)
		All, non rear-end	22% (-3-41%)
Dang, 2004 [6]	Quasi-induced exposure in 5 USA states Case years: 1997-2003	Single Vehicle Passenger Cars	35% (29-41%)
		Single Vehicle SUVs	67% (60-74%)
		Single Vehicle Passenger Car fatalities	30% (10-50%)
		Single Vehicle SUVs fatalities	63% (44-81%)
Papelis, 2010 [7]	Loss of control Simulator study	180 cases	24.6%
Lie, 2006 [3]	Induced exposure in Sweden Case years: 1998-2004	All, non-rear-end	16.7% (7.4%-26%)
		Serious/fatal, non-rear-end	21.6% (8.8-34.4%)
		Single vehicle, wet roads	56.2% (32.6-79.8%)
		Single vehicle, icy roads	49.2%
		Single vehicle, dry roads	24.8%

scene diagram of the crash and records occupant injury information. The study which follows included 10 years of crashes in NASS/CDS from 2006 to 2015.

- ESC availability for each vehicle was extracted from publically available records maintained by the Insurance Institute for Highway Safety (IIHS).

Characterizing the Target Population

All passenger vehicles and LTVs involved in a rollover crash during calendar years 2011 to 2015 in NASS/GES were analyzed to understand in which crash scenarios rollovers occurred. Every crash was grouped into a crash scenario based on the premove, acctype, and prevent variables consistent with previous studies [8]. Only crashes involving a rollover were selected for the crash scenario analysis.

Case Selection Criteria

The crash scenario for every case in NASS/CDS was determined based on crash type, pre-crash maneuver, and pre-crash event following the methods established by Kusano [8]. The analysis of potential ESC safety benefits was performed on three different populations: all rollover crashes, all control loss crashes, and all rollovers due to control loss. The main focus of the discussion is on the target population of control loss rollover crashes. Although all single vehicle rollovers were considered, scenarios in which control loss was the reason for the crash were of special interest. Thus it was restricted to vehicles in crashes which rolled over. For example, ESC would not be expected to prevent drift out-of-lane crashes into another vehicle, which then lost control and rolled over. However, ESC may help prevent cases where a vehicle lost control and impacted another vehicle before rolling over. The selection of this target population assumes that ESC does not prevent rollover crashes not due to control loss such as drift out-of-lane road departure crashes.

ESC Availability

ESC availability was determined by matching NASS/CDS make and model with IIHS records of ESC availability. Each NASS/CDS vehicle has a 12 digit partial VIN number. The last 5 digits are excluded from NASS/CDS to protect the owner's identity. However, the partial VIN can be used to identify specific vehicle information. The partial VIN was decoded to provide the vehicle specific information using NHTSA's vpic software [9]. The decoded VIN dataset includes 113 variables, however, only the following variables were needed for the matching: make, model, model year, series, trim, body class, cab type, bed type, drive type, four wheel drive, front wheel drive, restraint type, and fuel code.

The IIHS ESC availability dataset has four variables for each row: the model year, make, model information, and ESC availability. The model information variable is a string which contains the model of the vehicle and may contain the trim, body type, number of doors, etc. The model information string was parsed into seven variables: model, cab type, drive type, series, hybrid, number of doors, and body style. Possible ESC availably options included, "Standard", "Optional", and "Not Available".

Several adjustments to both the decoded VIN information and the ESC availability datasets were made for consistency in notation. For example, the model name for the Toyota 4Runner, was changed from 4-RUNNER in the decoded VIN information dataset to 4Runner to match the ESC availability dataset. Once over 150 of these consistency modifications were made, the two datasets were matched. The matching process

TABLE 2 Parameters used to match NASS/CDS vehicles with the vehicles in the IIHS ESC database

Parameter	Example
Make	Toyota
Model	Tacoma
Model Year	2005
Cab Type	Double Cab
Drive Type	Four Wheel Drive
Series	1500
Hybrid	No
Number of Doors	Four Door
Body Style	Truck

first attempted to find the make, model, and model year of the vehicle from the decoded VIN dataset in the ESC availability dataset. If the make, model, and model year was not present, the ESC availability was coded as unknown. If there were multiple options for a vehicle make, model, and model year, but the ESC availability was the same for all models, then that ESC availability was assigned to all. Otherwise, more variables were needed to differentiate between vehicles. The matching was attempted in the order the variables appear in Table 2. This approach successfully matched 99.5% of the unique VINs in NASS/CDS with an ESC availability value from the IIHS database. A summary of the matching procedure is presented in Figure 1. In the following analysis, vehicles with an ESC availability as "Optional" were assumed to not be equipped with ESC.

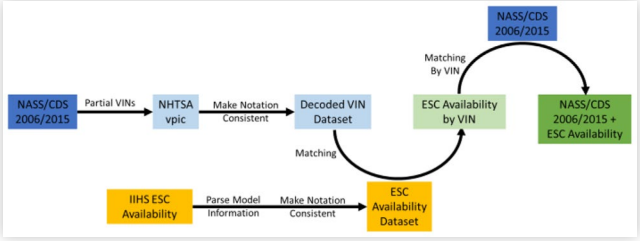
Calculation of Effectiveness

The effectiveness of ESC was defined as the proportion of crashes prevented by the introduction of ESC. The number of crashes must be scaled by either the number of vehicles or the number of miles driven to account for differences in exposure between groups. However, the number of vehicles with or without ESC is unknown. Therefore, the quasi-induced exposure method was used as an alternative method for computing the effectiveness.

The quasi-induced exposure method estimates the change in risk when the actual exposure is unknown based on an independent parameter [10]. Because the number of vehicles with ESC was unknown, the effectiveness of ESC in for all control loss crashes, all rollover crashes, and control loss which resulted in rollovers were estimated using the quasi-induced exposure method (Eq. 1). We assumed that ESC has no effect on rear end crashes. Therefore, rear crashes were used as the comparison population which remains unchanged by the presence of ESC. If the ratio of crashes with ESC is smaller than the ratio of crashes without ESC then some portion of crashes were prevented by the introduction of ESC.

$$Effectiveness = 1 - \frac{(Target_{ESC})(RearEnd_{NoESC})}{(Target_{NoESC})(RearEnd_{ESC})} \quad (1)$$

FIGURE 1 ESC availability matching procedure



Results

ESC Target Population

Only 2.1% of occupants in a police-reported crash were involved in a rollover crash (Table 3). Rollovers represent a small fraction of crashes yet they account for almost one-third of the fatalities each year [1]. Over one-third of all rollover crashes occurred during a control loss scenario (Figure 2) which was the target population for this study.

ESC Effectiveness

The number of crashes we assumed to be preventable with ESC are summarized in Table 4. The quasi-induced exposure method for estimating effectiveness yielded a 50.6% effectiveness of ESC in preventing crashes within the target population of control loss rollovers (Table 5).

TABLE 3 Fraction of rollover occupants in GES 2011-2015

GES 2011-2015	Rollover Occupants	All Occupants	Percent of Occupants
Unweighted	21,973	560,471	3.9%
Weighted	1,350,327	64,142,256	2.1%

FIGURE 2 The distribution of occupants involved in a rollover crash across crash scenarios in GES 2011-2015

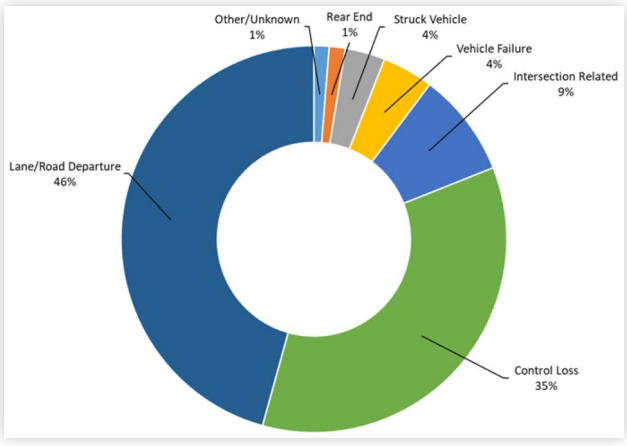


TABLE 4 Data selection criteria for NASS/CDS cases

Criteria	Cases	Weighted Cases	Vehicles	Weighted Vehicles	Occupants	Weighted Occupants
CDS 2006-2015	41,506	16,386,843	41,506	16,386,843	59,210	21,850,193
Rollover	4,944	1,339,407	4,944	1,339,407	7,987	1,947,846
Control Loss	1,428	443,181	1,428	443,181	2,452	670,939
Single Vehicle Crash or Control Loss was Critical Pre-crash Event	1,424	442,989	1,424	442,989	2,446	670,725

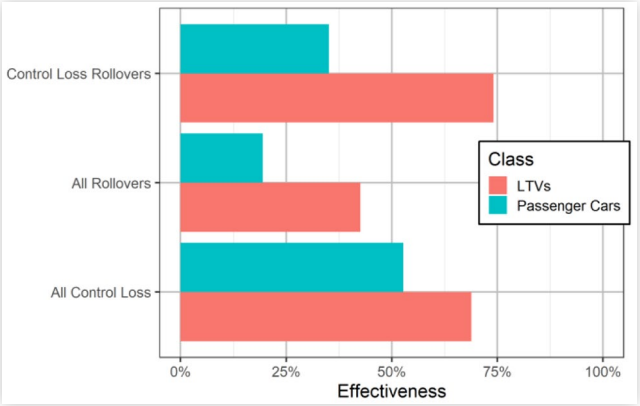
TABLE 5 Estimated Effectiveness of ESC for various populations from NASS/CDS 2006-2015

Population	Crashes with ESC	Crashes without ESC	Rear Crashes with ESC	Rear Crashes without ESC	Effective-ness
All Control Loss Crashes	147,801	1,965,667	547,493	3,539,736	51.4%
All Rollovers	177,644	1,325,431	547,493	3,539,736	13.3%
Control Loss Rollovers	47,641	623,084	547,493	3,539,736	50.6%

ESC Effectiveness by Vehicle Type

Light trucks and vans (LTVs) were involved in more rollover crashes than passenger cars (Table 6 & Table 7). Overall, ESC prevented more control loss rollover crashes in LTVs than in passenger cars with an estimated effectiveness of 74.1% compared to 35.2% for cars (Figure 3).

FIGURE 3 Effectiveness of ESC in LTVs compared to passenger cars from NASS/CDS 2006-2015



Discussion

The vast majority of the vehicles in NASS/CDS 2006-2015 did not have ESC because they were older vehicle models. ESC was required in all light vehicles manufactured after September 1, 2011 by FMVSS 126 [2]. However, as shown in Figure 4 automakers began introducing ESC many years before this required date. The majority of vehicles in NASS/CDS made after 2010 were equipped with ESC.

The prevalence of ESC in vehicles in NASS/CDS has increased almost linearly in each of the case years from 2006-2015 (Figure 5). The increase in ESC prevalence is due to older vehicles without ESC leaving the fleet and the new vehicles with ESC entering the US vehicle fleet. ESC adoption is expected to reach 95% in the US fleet by 2033 [11].

Computing Effectiveness Using Quasi-Induced Exposure Method

The quasi-induced exposure method for estimating effectiveness compared the number of crashes that occurred with ESC with what would have been expected based on the number of crashes that occurred without ESC. For all control

TABLE 6 Estimated Effectiveness of ESC for Passenger Cars from NASS/CDS 2006-2015

Population	Crashes with ESC	Crashes without ESC	Rear Crashes with ESC	Rear Crashes without ESC	Effective-ness
All Control Loss Crashes	87,828	1,116,577	308,526	1,852,902	52.8%
All Rollovers	71,335	531,833	308,526	1,852,902	19.4%
Control Loss Rollovers	22,636	209,634	308,526	1,852,902	35.2%

TABLE 7 Estimated Effectiveness of ESC for LTVs from NASS/CDS 2006-2015

Population	Crashes with ESC	Crashes without ESC	Rear Crashes with ESC	Rear Crashes without ESC	Effective-ness
Control Loss Rollovers	25,004	413,450	227,435	974,801	74.1%
All Rollovers	106,307	793,596	227,435	974,801	42.6%
All Control Loss Crashes	59,025	811,762	227,435	974,801	68.8%

FIGURE 4 ESC prevalence by model year in all NASS/CDS 2006-2015 vehicles based on IIHS ESC availability data

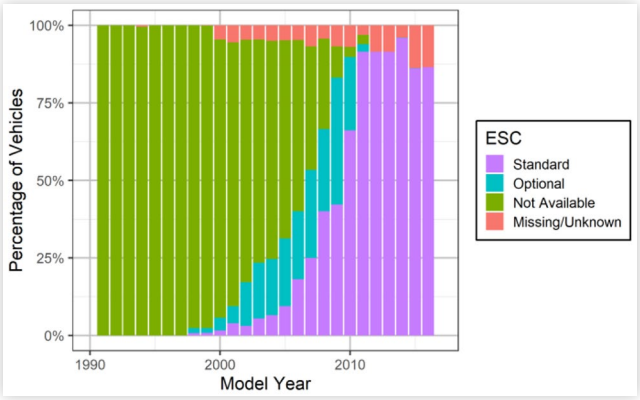


FIGURE 5 ESC prevalence among all vehicles in NASS/CDS 2006-2015 per case year based on IIHS ESC availability data

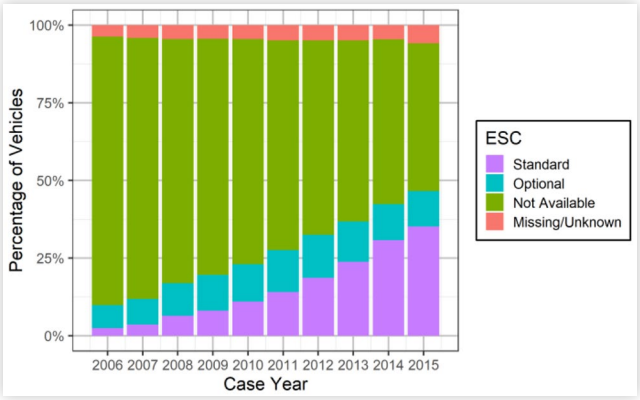


FIGURE 6 Distribution of ESC availability on vehicles which were involved in a rollover crash from NASS/CDS 2006-2015

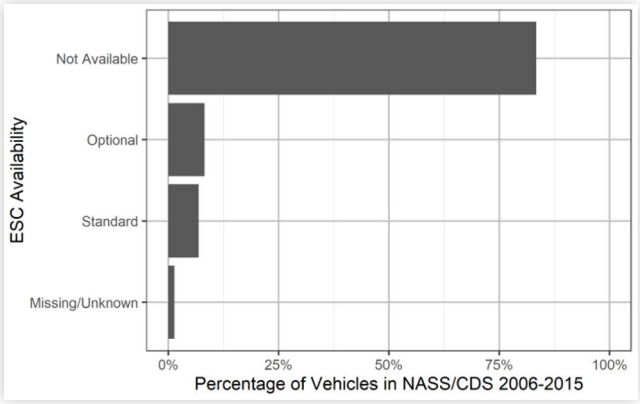


TABLE 8 Distribution of precipitating event which resulted in a control loss crash in vehicles with ESC standard from NASS/CDS 2006-2015

Precipitating Event	Vehicles	Percent Vehicles	Weighted Vehicles	Percent Weighted
Traveling too fast for conditions	69	71.1%	18,929	61.5%
Poor road conditions	10	10.3%	9,265	30.1%
Unknown cause of control loss	9	9.3%	542	1.8%
Other cause of control loss	8	8.2%	1,928	6.3%
Cargo Shift or Jackknife	1	1.0%	96	0.3%
Total	97	100.0%	30,760	100.0%

loss crash scenarios, the estimated effectiveness was 51.4%. This is very similar to the estimated effectiveness of 56.2% on wet roads computed by Lie [3]. ESC was estimated to be able to prevent 50.6% of rollover crashes which were the result of control loss. This is similar to the effectiveness of ESC in preventing all control loss crashes as expected. The effectiveness of ESC among all rollover crashes was 13.3% which is about half of the fraction of rollover crashes due to control loss. (ESC would be expected to have little effect on preventing other crash scenarios, such as drift out-of-lane road departure crashes, which resulted in a rollover). Our estimate for ESC effectiveness in rollovers is lower than the 69% estimated by Erke, and 74% by Farmer [4, 5]. However, our estimate falls within the 95% confidence intervals for both of these studies.

The quasi-induced exposure method does have some limitations as it is an estimate of the effectiveness which does not require the prevalence of ESC to be known. We assumed that ESC had no influence on rear end crashes. ESC tends to be present in newer vehicles. Therefore an assumption was made that there was no difference in newer vehicles which would affect either rollover or rear end crashes. As more active safety systems such as automatic emergency braking systems become more prevalent, the quasi-induced method using rear end crashes as a comparison may become inaccurate.

ESC May Not Always Prevent Rollovers

Our estimate of ESC effectiveness was approximately 50%. While high, this also implies that ESC did not prevent rollovers in all cases resulting from control loss (Figure 6). We examined those cases which were not prevented as potential targets for further improvements to ESC.

Of the 97 cases in which the vehicle was equipped with ESC as standard but still lost control and overturned, the most common precipitating event which resulted in the crash was a vehicle travelling too fast for conditions (Table 8).

Summary/Conclusions

ESC is an effective means of preventing loss of control, and of particular relevance to this study, is highly effective in preventing rollovers caused by loss of control. ESC was estimated to prevent 50.6% of control loss crashes that resulted in a rollover and 13.3% of all rollover crashes. ESC is particularly effective for utility-based vehicles such as light trucks, SUVs, and vans. The vast majority of ESC equipped vehicles that crashed were travelling too fast for the road conditions.

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Definitions/Abbreviations

ESC - Electronic Stability Control

NASS - National Automotive Sampling System

GES - General Estimates System

CDS - Crashworthiness Data System

LTV - Light Truck and Van

IIHS - Insurance Institute for Highway Safety

VIN - Vehicle Identification Number

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