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Updated Estimates of Fatality Reduction by Electronic Stability Control

By Charles J. Kahane, Ph.D.

Electronic stability control (ESC) has dramatically enhanced drivers' ability to keep vehicles under control in a wide variety of driving situations. ESC systems use automatic computer-controlled braking of individual wheels to assist the driver in maintaining control in critical driving situations. When the system predicts a loss of control it applies braking force to one or more wheels or reduces engine output to assist the driver when the vehicle is beginning to lose directional stability at the rear wheels (spin-out) or directional control at the front wheels (plow-out). Preventing single-vehicle loss-of-control crashes is a most effective way to reduce deaths resulting from rollover crashes. This is because most loss-of-control crashes culminate in the vehicle leaving the roadway, which dramatically increases the probability of a rollover. ESC systems are able to act quickly and discreetly; often the driver is unaware that the system has intervened to prevent a loss of stability or control. Federal Motor Vehicle Safety Standard (FMVSS) No. 126, "Electronic stability control systems," has required ESC on passenger cars, multipurpose passenger vehicles, trucks, and buses with a gross vehicle weight rating (GVWR) of 10,000 pounds or less: 100 percent of new vehicles since MY 2012, after phase-in during MY 2009 to 2011.[1]

NHTSA issued statistical evaluations in 2004, 2007, and 2011, based on the most recent crash data available at the time.[2] They show that ESC significantly reduced fatal rollovers and fixed-

[1] *Federal Register* 72. (April 6, 2007): 17236.

[2] Dang, J. N. (2004, September). *Preliminary Results Analyzing the Effectiveness of Electronic Stability Control (ESC) Systems*. (Report No. DOT HS 809 790). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809790.pdf; Dang, J. N. (2007, July). *Statistical Analysis of the Effectiveness of Electronic Stability Control (ESC) Systems – Final Report*. (Report No. DOT HS 810 794). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/810794.pdf; Sivinski, R. (2011, June). *Crash Prevention Effectiveness of Light-Vehicle Electronic Stability Control: An Update of the 2007 NHTSA Evaluation*. (Report No. DOT HS 811 486). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811486.pdf.

object impacts of cars and LTVs (pickup trucks, SUVs, and vans) as well as culpable involvements in fatal multi-vehicle crashes (at least for LTVs). The 2011 analysis, based on Fatality Analysis Report System (FARS) data for CY and MY 1997 to 2009, estimated that ESC reduced first-event rollovers by 56 percent for cars and by 74 percent for LTVs; collisions with fixed objects dropped by 47 percent in cars, 45 percent in LTVs; ESC helped car drivers avoid 18 percent of culpable involvements in multi-vehicle crashes, LTV drivers, 21 percent. All of the estimated reductions are statistically significant, except for the cars in multi-vehicle crashes.

A NHTSA report, *Lives Saved by the Federal Motor Vehicle Safety Standards, 1960-2002,* estimated that vehicle safety technologies had saved an estimated 328,551 lives through 2002.[3] The agency is currently updating the analysis to 2012 and including the effects of more recent technologies, such as ESC. This research note will supply updated estimates of fatal-crash reduction by ESC, based on FARS data through 2011, for the statistical model that computes lives saved by the FMVSS. It is desirable to update the NHTSA's previous estimates (based on FARS data through 2009) because:

- The previous studies were not based on a representative cross-section of vehicles. Early installations of ESC were concentrated among luxury cars and the more expensive SUVs. Not until MY 2010 was ESC available in the majority of new vehicles, including high-sales, relatively less expensive cars and pickup trucks.
- A new effectiveness analysis provides the opportunity to define the various crash categories exactly as they will be defined in the model to compute lives saved – and assure that the effectiveness estimates match the target populations.
- Rollover curtains are another life-saving technology introduced at the same time or nearly the same time as ESC in many LTVs.[4] It is important to separate the effect of ESC from the effect of rollover curtains when analyzing the reduction of fatal first-event rollovers.
- The 2011 report's estimated effectiveness for cars in fixed-object crashes (47%) was implausibly high (even higher than the 45% in LTVs), probably a consequence of not enough data at that time.
- The 2011 report's estimate for culpable involvements of cars in collisions with other vehicles was not statistically significant, again probably due to insufficient data.

The analysis method is the same as in the 2007 and 2011 reports. For a selected list of make-models that switched from not having ESC to being equipped with ESC, a contingency table compares the numbers of FARS crashes of interest in the first model years with ESC to the last years without it, relative to the numbers of control-group crash involvements on FARS. The control group again consists of non-culpable involvements in multi-vehicle crashes on dry roads. The three primary groups of crashes of interest are: (1) first-event rollovers; (2) single-vehicle crashes that are <u>not</u> first-event rollovers and <u>not</u> collisions with pedestrians, bicyclists, or other non-occupants; and (3) culpable involvements in multi-vehicle crashes. Furthermore, the analysis

[3] Kahane, C. J. (2004, October). *Lives Saved by the Federal Motor Vehicle Safety Standards and Other Vehicle Safety Technologies, 1960-2002*. (Report No. DOT HS 809 833). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809833.PDF.
[4] Kahane, C. J. (2014, January). *Updated Estimates of Fatality Reduction by Curtain and Side Air Bags in Side Impacts and Preliminary Analyses of Rollover Curtains*. (Report No. DOT HS 811 882, Chapter 4). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811882.pdf.

will estimate a combined effect for groups (1) and (2); it will also look at the effect of ESC in collisions with pedestrians, bicyclists, or other non-occupants.

From MY 1998 (when ESC was first offered on BMW 700-series cars) through MY 2011, NHTSA identified 59 make-models of passenger cars and 54 make-models of LTVs that switched from not having ESC to being equipped with ESC. Each model was included in the analysis for up to six MY (the last 3 before and the first 3 after the switch), but often fewer than six. One objective of limiting the range of MY is to minimize the differences between the vehicles of the same make-model with and without ESC – e.g., to avoid the effects of changes in the static stability factor if the model had been redesigned several times over many years; however, even with a limited range of MY it still possible that the SSF or other vehicle features changed to some extent. The range of MY was tailored, if necessary, to "balance" the database to contain, in each make-model, approximately twice as many FARS cases without ESC as cases with ESC. Balancing prevents the database from being skewed toward one type of vehicle or model without ESC and a different type with ESC.

However, for the analysis of rollovers, one of the 59 car models and 19 of the 54 LTV models had to be omitted because they received ESC simultaneously with rollover curtains; data for selected MY in 2 other car models and 11 LTV models was omitted because rollover curtains came in 1 to 3 MY before or after ESC. Although side air bags and curtains are a life-saving technology in near-side impacts, they do not particularly affect the analyses if they were installed at about the same time as ESC, because the control group, the single-vehicle crashes that are not first-event rollovers, and the culpable involvements in multi-vehicle crashes each include approximately the same proportion of near-side impacts (close to 12% of the FARS cases in each group are near-side impacts).

The control group consists of FARS cases of vehicles where ESC would have had no role, or at most a small role in preventing the crash. In this report, they are vehicles involved in multi-vehicle crashes and these vehicles were stopped, parked, entering or leaving a parking space, backing up, or moving at 10 mph or less prior to the collision; were struck in the rear; or the crash occurred on a dry road and the driver was not culpable – i.e., did not engage in any of the possible driving actions listed on FARS that would indicate culpability, such as failing to stay in lane or failing to yield the right of way.[5]

In this report, the first group of crashes of primary interest, "first-event rollovers" includes single-vehicle crashes where FARS says the first harmful event is a rollover <u>or</u> where FARS says the most harmful event is a rollover and the first harmful event is essentially contact with a tripping mechanism such as a curb or ditch. In this report, rather than trying to isolate "fixed-object" or "run-off-road" crashes, the second category of crashes of interest simply consists of all single-vehicle crashes that are <u>not</u> first-event rollovers <u>and</u> the first harmful event is <u>not</u> a collision with a pedestrian, bicyclist, other non-occupant, or animal. The third group, "culpable involvements in multi-vehicle crashes" includes cases where the driver engaged in one or more

[5] Specifically, in FARS up to 2009, if none of DR_CF1, DR_CF2, DR_CF3, or DR_CF4 equaled 3, 6, 8, 26, 27, 28, 30, 31, 33, 35, 36, 38, 39, 44, 46, 47, 48, 50, 51, 57, 58, 79, or 87; and in FARS from 2010 onward if none of DR_SF1, DR_SF2, DR_SF3, or DR_SF4 equaled 6, 8, 18, 26 to 30, 33 to 36, 38, 39, 41, 47, 48, 50, 51, 57, 58.

of the actions that indicate culpability <u>and</u> the vehicle was not stopped, parked, backing up, etc. before the crash.

Table 1 compares passenger cars' involvements in first-event rollovers, relative to control group crashes, before and after ESC (but no change in a make-model's availability of rollover curtains during the MY included in Table 1). The typical first-event rollover of a light vehicle such as a car or LTV involves the vehicle first running off the road (often after the driver loses directional control) and then contacting an off-road tripping mechanism. ESC can prevent these rollovers by maintaining the driver's directional control and helping the driver keep the vehicle on the road.

Table 1: First-Event Rollovers, Passenger Cars, Reduction in Fatal Crash Involvements by ESC (Relative to control group of non-culpable involvements in multi-vehicle crashes on dry roads, 1994 to 2011 FARS, 58 make-models, no change in rollover curtains, ≤ 6 MY per make-model)

Frequency Row Percent	CONTROL GROUP	FIRST-EVENT ROLLOVER	Total
WITHOUT ESC	1437 80.28	353 19.72	1790
WITH ESC	986 90.96	98 9.04	1084
Total	2423	451	2874

Statistic	DF	Value	Prob
Chi-Square	1	58.2087	<.0001
Likelihood Ratio Chi-Square	1	62.2757	<.0001
Continuity Adj. Chi-Square	1	57.4043	<.0001
Mantel-Haenszel Chi-Square	1	58.1885	<.0001

Estimates of the Relative Risk (Row1/Row2)

Type of Study	Value	95% Confidence Limits	
Odds Ratio	0.4046	0.3189	0.5133

While there are 1,437 control-group involvements without ESC and 986 with ESC, first-event rollovers decreased from 353 to 98. That is a 59.54-percent drop in rollovers relative to the control group (i.e., 1 – 0.4046, the odds ratio specified in the last line of Table 1). The reduction is statistically significant, as evidenced by chi-square ranging from 57.40 to 62.28 by the four computational methods shown in the middle of Table 1: All of them far exceed the value of 3.84

needed for statistical significance at the two-sided .05 level.[6] The 95-percent confidence bounds for effectiveness range from 48.67 to 68.11 percent – i.e., from 1 – 0.5133 to 1 – 0.3189, the "95% Confidence Limits" for the odds-ratio in the last line of Table 1.

Table 2 shows that ESC is even more effective in preventing first-event rollovers in LTVs. As in Table 1, the make-models in Table 2 are entirely without rollover curtains throughout the range of MY included in the table or entirely with rollover curtains in those MY. The reduction in rollovers by ESC is an estimated 74 percent, relative to the control group (1 – 0.2600), with confidence bounds ranging from 67.7 to 79.1 percent. Chi-square ranges from 162.16 to 185.96; the reduction is statistically significant.

Table 2: First-Event Rollovers, LTVs, Reduction in Fatal Crash Involvements by ESC
(Relative to control group of non-culpable involvements in multi-vehicle crashes on dry roads, 1994 to 2011 FARS, 34 make-models, no change in rollover curtains, ≤ 6 MY per make-model)

Frequency Row Percent	CONTROL GROUP	FIRST-EVENT ROLLOVER	Total
WITHOUT ESC	1995 69.95	857 30.05	2852
WITH ESC	931 89.95	104 10.05	1035
Total	2926	961	3887

Statistic	DF	Value	Prob
Chi-Square	1	163.2302	<.0001
Likelihood Ratio Chi-Square	1	185.9589	<.0001
Continuity Adj. Chi-Square	1	162.1573	<.0001
Mantel-Haenszel Chi-Square	1	163.1882	<.0001

Estimates of the Relative Risk (Row1/Row2)

Type of Study	Value	95% Confidence Limits	
Odds Ratio	0.2600	0.2091	0.3233

[6] The first computation is the traditional formula for chi-square. The other three use alternative formulas to generate statistics that have the same interpretation as chi-square (namely, 3.84 or more indicates statistical significance at the two-sided .05 level), but are considered more reliable by some statisticians. With plentiful and not too unevenly distributed data, as in all the tables of this report, there is usually little difference between the four methods.

As in NHTSA's 2007 and 2011 reports, ESC in cars and LTVs still does not have a statistically significant effect on fatal collisions with pedestrians, bicyclists, or other non-occupants, relative to the control group, even though there is much more data now. The observed effects are a 5.9-percent reduction of these collisions in cars with ESC and a 10.7-percent increase in LTVs with ESC, both non-significant. A single estimate for cars and LTVs together can be obtained by transforming the two tables into a single logistic regression estimating the effect of ESC while controlling for vehicle type; that effect is a non-significant 4.7-percent increase.[7] In the majority of these crashes, the pedestrian and the vehicle are on the roadway at the moment of contact; the driver did not lose directional control or run off the road before the collision.

Table 3 shows ESC substantially reduces other single-vehicle crashes of passenger cars.

Table 3: Single-Vehicle Crashes Without First-Event Rollovers or Pedestrian/Bicyclists; Passenger Cars, Reduction in Fatal Crash Involvements by ESC
(Relative to control group of non-culpable involvements in multi-vehicle crashes on dry roads, 1994 to 2011 FARS, 59 make-models, up to 6 MY per make-model)

Frequency Row Percent	CONTROL GROUP	OTHER SINGLE-VEHICLE	Total
WITHOUT ESC	1455 52.64	1309 47.36	2764
WITH ESC	988 61.79	611 38.21	1599
Total	2443	1920	4363

Statistic	DF	Value	Prob
Chi-Square	1	34.3996	<.0001
Likelihood Ratio Chi-Square	1	34.6003	<.0001
Continuity Adj. Chi-Square	1	34.0294	<.0001
Mantel-Haenszel Chi-Square	1	34.3917	<.0001

Estimates of the Relative Risk (Row1/Row2)

Type of Study	Value	95% Confidence Limits	
Odds Ratio	0.6874	0.6063	0.7793

[7] Kahane (2014, January), p. 42 describes the method.

Most of these crashes involve running off the road (often after loss of directional control) and then hitting a fixed object. The reduction of fatal crash involvements is 31.3 percent (confidence bounds 22.1 to 39.4%); it is statistically significant (chi-square ranges from 34.03 to 34.60). Effectiveness is not as high as in first-event rollovers (59.5%), but it is still quite substantial.

In these crashes, too, ESC is somewhat more effective in LTVs than cars. Table 4 shows a 45.5-percent reduction of other single-vehicle crashes (confidence bounds 39.2 to 51.1%); it is statistically significant (chi-square ranges from 121.34 to 126.61). Likewise, effectiveness is not as high as in first-event rollovers of LTVs (74.0%), but it is still high.

Table 4: Single-Vehicle Crashes Without First-Event Rollovers or Pedestrian/Bicyclists; LTVs, Reduction in Fatal Crash Involvements by ESC
(Relative to control group of non-culpable involvements in multi-vehicle crashes on dry roads, 1994 to 2011 FARS, 54 make-models, up to 6 MY per make-model)

Frequency Row Percent	CONTROL GROUP	OTHER SINGLE-VEHICLE	Total
WITHOUT ESC	3907 65.91	2021 34.09	5928
WITH ESC	1964 78.00	554 22.00	2518
Total	5871	2575	8446

Statistic	DF	Value	Prob
Chi-Square	1	121.9101	<.0001
Likelihood Ratio Chi-Square	1	126.6095	<.0001
Continuity Adj. Chi-Square	1	121.3402	<.0001
Mantel-Haenszel Chi-Square	1	121.8957	<.0001

Estimates of the Relative Risk (Row1/Row2)

Type of Study	Value	95% Confidence Limits	
Odds Ratio	0.5453	0.4892	0.6078

It is possible to estimate a combined effect of ESC on all single-vehicle crashes that do not involve pedestrians, bicyclists, or other non-occupants. These single-vehicle crashes include first-event rollovers, impacts with fixed objects, and some other types such as running off the road and into a body of water. Because first-event rollovers are included, it is appropriate to limit the analysis to make-models and MY ranges where there was no change in the availability of rollover curtains, exactly as in Tables 1 and 2. The effect of ESC in passenger cars is a statistically significant 37.8-percent reduction (χ^2 = 60.47, confidence bounds 29.8 to 44.8%); in LTVs, the effect is a likewise significant 55.9-percent reduction (χ^2 = 148.73, confidence bounds 49.6 to 61.4%). The effect for cars is between the effects in Tables 1 and 3; the reduction for LTVs is between the effects in Tables 2 and 4.

FARS now has enough data on passenger cars to show a statistically significant reduction of culpable involvements in multi-vehicle crashes. Table 5 shows ESC reduces culpable involvements, relative to the control group, by 16.1 percent (confidence bounds 4.3 to 26.1%). Chi-square ranges from 7.17 to 7.37.

Table 5: Culpable Involvements in Multi-Vehicle Crashes, Passenger Cars, Reduction in Fatal Crash Involvements by ESC
(Relative to control group of non-culpable involvements in multi-vehicle crashes on dry roads, 1994 to 2011 FARS, 59 make-models, up to 6 MY per make-model)

Frequency Row Percent	CONTROL GROUP	CULPABLE MULTI-VEHICLE	Total
WITHOUT ESC	1455 56.75	1109 43.25	2564
WITH ESC	988 60.99	632 39.01	1620
Total	2443	1741	4184

Statistic	DF	Value	Prob
Chi-Square	1	7.3470	0.0067
Likelihood Ratio Chi-Square	1	7.3662	0.0066
Continuity Adj. Chi-Square	1	7.1736	0.0074
Mantel-Haenszel Chi-Square	1	7.3453	0.0067

Estimates of the Relative Risk (Row1/Row2)

Type of Study	Value	95% Confidence Limits	
Odds Ratio	0.8393	0.7393	0.9527

Table 6 indicates ESC reduces culpable involvements of LTVs in multi-vehicle crashes by 16.1 percent, the same as effectiveness observed in cars (Table 5). The reduction is statistically significant (chi-square ranges from 13.02 to 13.29). The confidence bounds extend from 7.8 to 23.7 percent.

Table 6: Culpable Involvements in Multi-Vehicle Crashes, LTVs,
Reduction in Fatal Crash Involvements by ESC
(Relative to control group of non-culpable involvements in multi-vehicle crashes on dry roads, 1994 to 2011 FARS, 54 make-models, up to 6 MY per make-model)

Frequency Row Percent	CONTROL GROUP	CULPABLE MULTI-VEHICLE	Total
WITHOUT ESC	3907 64.81	2121 35.19	6028
WITH ESC	1964 68.72	894 31.28	2858
Total	5871	3015	8886

Statistic	DF	Value	Prob
Chi-Square	1	13.1894	0.0003
Likelihood Ratio Chi-Square	1	13.2850	0.0003
Continuity Adj. Chi-Square	1	13.0158	0.0003
Mantel-Haenszel Chi-Square	1	13.1879	0.0003

Estimates of the Relative Risk (Row1/Row2)

Type of Study	Value	95% Confidence Limits	
Odds Ratio	0.8385	0.7624	0.9222

Summary: With FARS data through 2011, there are statistically significant estimates of fatal-crash reduction by ESC in three types of crash involvements of cars and LTVs:

Fatal-Crash Reduction (%)	Cars		LTVs	
	Estimate	Conf. Bds.	Estimate	Conf. Bds.
First-event rollovers	59.5	48.7 to 68.1	74.0	67.7 to 79.1
Other single-veh (excl ped/bike)	31.3	22.1 to 39.4	45.5	39.2 to 51.1
Culpable involvements in multiveh	16.1	4.3 to 26.1	16.1	7.8 to 23.7

Based on the latest data, these estimates will supersede earlier NHTSA reports and will be used in the forthcoming updated computation of lives saved by the FMVSS. Nevertheless, the estimates remain close to the results in NHTSA’s 2011 report except the fatality reduction for passenger cars in single-vehicle crashes that are not first-event rollovers or collisions with non-occupants. The 31.3-percent reduction here is somewhat lower than the estimate in the 2011 report of 47-percent reduction in impacts with fixed objects. But it is close to the 36-percent reduction of fatal run-off-road crashes estimated for cars in NHTSA's 2007 report.

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