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Effectiveness of Stability Control Systems For Truck Tractors

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This Research Note describes the process of deriving the effectiveness rates of electronic stability control systems (ESC) and roll stability control systems (RSC) in truck tractors that are used by the National Highway Traffic Safety Administration to estimate the benefits of these systems. ESC and RSC are two types of stability control systems that have been developed for heavy vehicles. RSC is designed to mitigate on-road, untripped truck rollovers by automatically decelerating the vehicle by applying the foundation brakes and reducing engine torque output. ESC includes the RSC function described previously but it has added capability that allows it to also mitigate severe oversteer or understeer conditions that can lead to vehicle loss-of-control (LOC), by automatically applying selective brakes to generate a yawing moment that helps the driver maintain directional control of the vehicle. Thus, ESC is designed to mitigate both untripped rollover and LOC crashes. Therefore, the definition of ESC for heavy trucks is different from that specified in Federal Motor Vehicle Safety Standard No. 126 (FMVSS No. 126) for light vehicles with a gross vehicle weight rating (GVWR) of 10,000 pounds or less. For simplicity, hereafter, rollovers represent first event on-road, untripped rollovers.

RSC and ESC became commercially available in the United States primarily for class 8 truck tractors. RSC was introduced first in 2003. ESC was introduced in 2005. Although manufacturers are continuing to equip their truck tractors with RSC-only systems, some have moved towards ESC. The agency estimates that by 2012, about 25 percent of truck tractors will be equipped with ESC. That is about a 15-percentage-point increase from 2007.[1]

For the past several years, both the agency and the Federal Motor Carrier Safety Administration (FMCSA) have examined the performance of these stability systems. In 2008, FMCSA published its study, conducted by the American Transportation Research Institute, on the costs and benefits of RSC (FMCSA, 2008). In 2009, NHTSA published a study on the potential safety effectiveness of stability control systems for five-axle tractor-trailer combination vehicles. The study was conducted by the University of Michigan Transportation Research Institute and Meritor WABCO (UMTRI, 2009) and sponsored by NHTSA. Both studies concluded that ESC and RSC would reduce rollover and LOC crashes. The effectiveness estimates in these two studies serve as the foundation for the effectiveness estimates of RSC and ESC that are used by the agency for estimating the benefits of these two systems. Both studies were based on computer simulation, expert panel assessment of available crash data, input from the trucking industry who had adopted the technology, and laboratory experiments. A statistical analysis of vehicles with and without the technology using real-world crash data was not feasible (even now) since RSC and ESC in truck tractors are relatively new technologies and both were implemented mostly as optional safety features.

The 2008 FMCSA study estimated that RSC is 37 to 53 percent effective against rollovers. The high effectiveness was based on simulation results for rollovers in curved roadways due to excessive speeds. The low effectiveness was based on motor carrier feedback based on 106 rollover cases, of which 39 would have been prevented by RSC. The 2008 FMCSA study only examined the effectiveness of RSC.

The 2009 UMTRI study estimated the effectiveness for both RSC and ESC. The study found that RSC would reduce rollovers by 0 to 71 percent and ESC would reduce rollovers by 0 to 75 percent. The magnitude of the effect varies depending on roadway alignment (straight, curved) and roadway surface conditions (dry, wet). In parallel, for LOC crashes, RSC would reduce these types of crashes by 2 to 14 percent and ESC would reduce these crashes by 18 to 39 percent. These effectiveness estimates were aggregated from the initial

[1] Based on confidential industry product plans

effectiveness rates of these technologies for 159 cases that were identified from FMCSA's large-truck crash causation study (LTCCS). LTCCS contains very detailed crash, environment, and vehicle information for a total of 963 large-truck injury and fatal crashes that occurred between April 2001 and December 2003. Of the 159 cases, 113 were rollovers and 46 were LOC cases. Of the 46 LOC cases, 10 were subsequently rollovers. The impact of RSC and ESC on each of these cases was then determined either by computer simulation or expert panel assessment. The UMTRI estimates are based on a simple aggregation of cases. As such, the occurrence of each case was treated equally.

However, the likelihood of occurrence of each case is not identical as evidenced by the case weight reported in the LTCCS. The aggregated RSC/ESC effects reported in the UMTRI study thus did not reflect the RSC/ESC effects that were derived from a crash population represented by the 159 cases. To address the issue, this research note revises the aggregated effectiveness by calculating the weighted effectiveness with factors representative of each case (i.e., case weight).

The weighted effectiveness can be expressed by the mathematical formula:

$$E = \frac{\sum_{i=1}^{n} w_i * e_i}{\sum_{i=1}^{n} w_i}$$

Where, E = weighted effectiveness of the technology of interest
n = number of cases
e_i = effectiveness of the technology for case i
w_i = weight of the case i.

In addition to using case weight to derive effectiveness, the research note also incorporated some changes for 8 of the 159 cases as result of an NHTSA's independent review of the 159 cases. Based on crash photo evidence and police crash description and diagrams of these cases, NHTSA determined that 2 cases that were categorized as LOC crashes by UMTRI should have been untripped rollover. For the other 6 cases, NHTSA believes that UMTRI overestimated the ESC effectiveness and new effectiveness rates were assigned for these cases. The following summarizes these changes:

- Change of Crash Type
  Case Nos. 81005647 and 815004312 were changed to untripped rollover.

- Change of Effectiveness
  Case 222004325, from (RSC 0%, ESC 70%) to (RSC 0%, ESC 0%)
  Case 333006958, (RSC 0%, ESC 80%) to (RSC 0%, ESC 0%)
  Case 817005748, (RSC 20%, ESC 90%) to (RSC 0%, ESC 90%)
  Case 350007220, (RSC 0%, ESC 90%) to (RSC 0%, ESC 75%)
  Case 801005488, (RSC 0%, ESC 75%) to (RSC 0%, ESC 0%)
  Case 807005712, (RSC 30%, ESC 70%) to (RSC 40%, ESC 60%)

Table 1 shows the revised effectiveness by roadway alignment and roadway surface conditions. The revised effectiveness rates are the weighted effectiveness after incorporating the above changes. For comparison, Table 1 also presents the nonweighted effectiveness of ESC and RSC that were derived by UMTRI. As shown, some discrepancies existed between the revised and nonweighted effectiveness. For rollover crashes, the revised effectiveness of RSC and ESC are lower than those estimated by UMTRI on straight dry roadways but higher on curved, not dry roadway conditions. For LOC crashes, the revised ESC effectiveness is consistent significantly lower than that estimated by UMTRI for the four roadway categories. This is primarily due to the use of a smaller ESC effectiveness for 6 cases and the re-categorization of crash type for two cases. Note the positive effectiveness of RSC against LOC crashes primarily reflects that RSC would benefit LOC crashes where a subsequent rollover occurred.

Table 1
Revised and UMTRI Nonweighted Effectiveness of ESC and RSC

Road Alignment	Surface Condition	# of Cases		ESC Effectiveness		RSC Effectiveness	
First-Event Untripped Rollover Crashes							
		Revised[1]	**UMTRI[2]**	**Revised[3]**	**UMTRI[2]**	**Revised[3]**	**UMTRI[2]**
Straight	Dry	22	22	15.27	21.14	12.50	16.36
Straight	Not Dry	3	3	0.00	0.00	0.00	0.00
Curve	Dry	80	79	75.07	75.05	71.72	71.15
Curve	Not Dry	10	9	61.30	55.56	55.90	45.56
Total		**115**	**113**	**N.A.**	**N.A.**	**N.A.**	**N.A.**
Loss-of-Control Crashes							
Straight	Dry	9	9	6.74	17.78	0.53	0.56
Straight	Not Dry	17	17	18.09	20.59	3.05	1.76
Curve	Dry	6	7	18.70	31.57	6.56	14.00
Curve	Not Dry	12	13	17.90	39.62	1.98	11.54
Total		**44**	**46**	**N.A.**	**N.A.**	**N.A.**	**N.A.**

1. Two LOC cases were recategorized as untripped rollover crashes
2. Nonweighted numbers adopted from the 2009 UMTRI study
3. Weighted effectiveness

To derive an overall effectiveness of ESC and RSC, the four weighted effectiveness rates shown in Table 1 would be further aggregated again using the formula for E. In this process, the weights (wi) are the number (or the proportion) of target crashes that occurred on the four combinations of roadway conditions and n represents the number of categories of crashes (i.e., n = 4). For example, the agency developed the target rollover and LOC crashes using 2006-2008 General Estimates System (GES) and Fatality Analysis Reporting System (FARS). GES was used to obtain the nonfatal target crash population and FARS was used for the fatal target crash population. The criteria that were used for establishing the target crashes generally matched those defined by UMTRI. However, crashes where tire, brake, and transmission were coded as contributing factors were excluded. Furthermore, the agency limited LOC crashes to cases where the truck tractors were the striking vehicles. Table 2 shows the annual average target crash population (fatal and nonfatal) from 2006 to 2008.

Table 2
Annual Average Target Crash Population for ESC and RSC

Road Alignment	Surface Condition	Crash Type: Rollover[1]	LOC[2]	Combined
Straight	Dry	1,722	1,936	3,658
Straight	Not Dry	662	1,241	1,903
Curve	Dry	2,882	991	3,873
Curve	Not Dry	244	635	879
Total		**5,510**	**4,803**	**10,313**

1. First event on-road non-tripped rollovers
2. Truck tractors as the striking vehicles
Source: 2006-2008 GES, 2006-2008 FARS

Substituting wi and ei in the formula for E respectively using the number of crashes (Table 2) and the weighted effectiveness (Table 1) derives the overall effectiveness. For rollover crashes, ESC is 47-percent effective and RSC is 44-percent effective against these crashes. For LOC crashes, ESC is 14-percent effective and RSC is 3-percent effective. These results show that the performance difference between ESC and RSC primarily occurs in the prevention of LOC crashes. In addition, ESC is slightly more effective in reducing rollover crashes than the RSC only system – a reflection of the ESC design which would intervene to prevent the crash earlier than the RSC only systems.

The weighted RSC effectiveness of 44 percent built upon the UMTRI study for rollovers is close to the midpoint between the 37 and 53 percent estimated by the FMCSA study. To reflect the variation and the uncertainty of the study methodologies, FMCSA decided to adopt the range of 37 to 53 percent as the effectiveness of RSC for rollover crashes. The effectiveness against rollover crashes for ESC would range from 40 to 56 percent, which is the RSC effectiveness plus the 3 percent incremental difference between the RSC and ESC effects that were derived based on the UMTRI study. However, for LOC crashes, the UMTRI study is the only available source. Therefore, the revised point estimates of 14 and 3 percent are used as the effectiveness for ESC and RSC, respectively. Table 3 lists the effectiveness rates by crash type that will be used for the benefit analysis of RSC and ESC.

Table 3 also lists the combined effectiveness rates of rollover and LOC crashes for ESC and RSC. The combined rates were derived again using the above formula for E. In this case, n is equal to 2 (i.e., rollover and LOC crashes) and weight is the total number of corresponding crashes (i.e., 5,510 for rollovers and 4,803 for LOC crashes). As shown, the combined effectiveness for ESC ranged from 28 to 36 percent and from 21 to 30 percent for RSC.

Table 3
Effectiveness Rates for RSC and ESC by Target Crashes (Current NHTSA Estimates)

Technology	Target Crashes	Low	High
RSC	Rollover[1]	37	53
	LOC[2]	3	3
	Combined	21	30
ESC	Rollover[3]	40	56
	LOC[2]	14	14
	Combined	28	36

1. Based on the 2008 FMCSA study
2. Revised estimates from the 2009 UMTRI study
3. Based on the 2008 FMCSA study and the revised estimates from the 2009 UMTRI study

Finally, Table 4 lists the 159 cases used by the UMTRI study along with the case weight. This allows readers to verify the process of deriving weighted estimates. In Table 4, crash type "1" indicates rollover, "2" indicates "LOC, no subsequent rollover", and "3" indicates "LOC, subsequent rollover". In addition, the bold-faced cases are those cases for which changed values were used for deriving the revised estimates. Their initial values are in parenthesis.

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Table 4
The 159 LTCCS Cases Used in the UMTRI Study

Case Id	Crash Type*	Roadway Alignment	Surface Condition	Effectiveness**		Case Weight
				RSC	ESC	
153006977	1	curve	dry	95	95	127.287
329006101	1	straight	dry	0	0	34.364
331005867	1	curve	dry	0	0	29.901
331006249	1	curve	dry	0	0	46.473
331006250	1	straight	dry	90	90	29.901
331006312	1	curve	dry	0	0	19.812
332006211	1	curve	dry	95	95	206.963
332006696	1	curve	dry	97	99	206.963
332006697	1	curve	dry	48	96	137.133
332006751	1	curve	not dry	5	25	206.963
333006294	1	curve	dry	62	62	468.821
335006545	1	curve	dry	95	95	125.127
337006323	1	straight	dry	0	35	69.365
337006565	1	straight	dry	0	0	69.365
338007508	1	curve	dry	95	95	127.503
338007582	1	curve	dry	95	95	127.503
339006276	1	curve	dry	97	99	131.148
339006316	1	curve	dry	95	95	131.148
339006771	1	curve	dry	80	95	211.494
339006971	1	curve	not dry	0	20	60.692
340006826	1	curve	dry	5	15	426.863
340007050	1	straight	dry	0	0	688.372
348006225	1	curve	dry	95	95	64.704
348006445	1	curve	dry	95	95	179.933
348006908	1	curve	dry	0	10	179.933
350006669	1	curve	dry	48	96	12.701
350006975	1	curve	dry	96	99	2.424
352006482	1	curve	not dry	80	95	33.237
620006525	1	curve	dry	95	95	38.971
620006805	1	curve	dry	10	40	73.431
800003927	1	curve	dry	95	95	93.511
800004246	1	curve	dry	95	95	93.511
800004865	1	curve	dry	95	95	93.511
802005383	1	curve	dry	95	95	53.409
803004433	1	straight	not dry	0	0	58.657
803004492	1	curve	dry	97	99	32.201
803004652	1	curve	dry	95	95	58.657
805005055	1	curve	dry	0	0	206.963
807004925	1	straight	dry	0	0	125.127
807005712	1	straight	dry	40 (30)	60 (70)	125.127
807005713	1	curve	not dry	20	45	125.127
808004226	1	curve	dry	95	95	292.312
808005621	1	curve	dry	30	50	292.312

Case Id	Crash Type*	Roadway Alignment	Surface Condition	Effectiveness**		Case Weight
				RSC	ESC	
808006003	1	straight	dry	0	0	49.52
808006301	1	straight	dry	0	0	160.472
808006705	1	curve	dry	97	99	292.312
811005442	1	curve	dry	97	99	127.503
811005582	1	curve	dry	62	62	127.503
811006302	1	curve	dry	0	20	127.503
812004411	1	curve	dry	97	99	131.148
812004756	1	curve	dry	95	95	131.148
812005915	1	straight	dry	0	0	211.494
812006131	1	curve	dry	48	96	131.148
813003907	1	curve	dry	96	99	426.863
813004026	1	straight	dry	60	60	426.863
813004046	1	straight	dry	10	20	426.863
813004191	1	curve	dry	95	95	426.863
813004526	1	curve	dry	95	95	426.863
813004546	1	straight	dry	0	0	426.863
813004667	1	curve	dry	0	0	426.863
813004966	1	curve	not dry	95	95	426.863
813005190	1	curve	dry	95	95	688.372
813005530	1	straight	dry	0	0	197.543
813005655	1	curve	dry	95	95	426.863
813006119	1	curve	dry	95	95	426.863
813006120	1	curve	dry	95	95	426.863
814000341	1	straight	dry	0	20	50.061
814000361	1	curve	not dry	95	95	23.167
815004232	1	curve	dry	95	95	58.657
815004252	1	curve	dry	95	95	58.657
815005814	1	curve	dry	95	95	58.657
816004041	1	curve	dry	0	0	356.366
816004201	1	curve	dry	97	99	356.366
816004261	1	curve	dry	95	95	356.366
816006201	1	curve	dry	97	99	356.366
817003933	1	curve	dry	0	0	34.412
817004510	1	straight	dry	80	80	34.412
817005908	1	curve	dry	95	95	18.891
817006509	1	straight	not dry	0	0	34.412
818004012	1	straight	dry	0	0	127.287
818004112	1	curve	dry	95	95	127.287
818004792	1	curve	dry	100	100	127.287
818004912	1	curve	dry	95	95	67.552
818005452	1	curve	dry	95	95	127.287
818005992	1	curve	dry	80	80	127.287
819004045	1	curve	dry	0	0	339.044
819004185	1	curve	dry	62	62	179.933
819004425	1	curve	dry	95	95	179.933

Case Id	Crash Type*	Roadway Alignment	Surface Condition	Effectiveness**		Case Weight
				RSC	ESC	
819005086	1	curve	dry	95	95	179.933
819005325	1	curve	not dry	20	30	339.044
819005527	1	curve	dry	10	15	339.044
819005585	1	curve	not dry	0	0	339.044
819005627	1	curve	dry	95	95	339.044
819005808	1	curve	dry	10	30	179.933
819005865	1	curve	dry	96	99	339.044
819006125	1	curve	dry	97	99	339.044
820003962	1	straight	dry	0	0	260.223
820004422	1	curve	dry	97	99	260.223
820004783	1	curve	dry	0	0	138.103
821005449	1	curve	dry	96	99	12.701
821005769	1	straight	dry	0	0	6.74
823005982	1	straight	dry	90	90	62.628
828004080	1	curve	not dry	95	95	790.707
864004267	1	curve	dry	0	0	29.901
864004488	1	straight	not dry	0	0	29.901
864004907	1	curve	dry	95	95	29.901
870004688	1	straight	dry	0	0	80.73
884003927	1	curve	dry	97	99	73.431
884004325	1	curve	dry	95	95	73.431
884005168	1	curve	dry	95	95	73.431
884005169	1	straight	dry	0	0	14.014
884005425	1	curve	dry	95	95	73.431
884005486	1	curve	dry	0	0	73.431
207004905	2	straight	dry	0	15	49.662
222004325	2	straight	not dry	0	0 (70)	33.237
333006958	2	straight	dry	0	0 (80)	756.035
339006411	2	curve	not dry	0	0	211.494
339006915	2	straight	not dry	0	10	211.494
340006566	2	straight	dry	0	20	426.863
344007015	2	curve	not dry	50	70	9.937
350007220	2	straight	not dry	0	75 (90)	12.701
495005661	2	curve	not dry	0	50	133.902
800006415	2	curve	not dry	0	0	145.338
801003890	2	curve	not dry	10	30	148.42
801005488	2	curve	not dry	0	35	63.274
801005488	2	curve	not dry	0	0 (75)	63.274
803004794	2	curve	not dry	10	35	9.937
803005076	2	straight	not dry	0	0	58.657
810005468	2	straight	dry	0	20	32.101
810005522	2	straight	not dry	10	30	69.365
812004351	2	straight	not dry	0	20	131.148
812004892	2	straight	not dry	0	0	211.494
813004406	2	straight	not dry	5	25	426.863

Case Id	Crash Type*	Roadway Alignment	Surface Condition	Effectiveness**		Case Weight
				RSC	ESC	
813006166	2	straight	not dry	0	0	197.543
816005042	2	straight	not dry	10	50	356.366
816005321	2	straight	not dry	0	0	195.635
817005748	2	curve	not dry	0 (20)	90	5.83
817006028	2	straight	dry	0	0	34.412
821003867	2	curve	dry	0	10	12.701
821005450	2	straight	dry	0	0	2.424
821005589	2	straight	dry	0	10	6.74
821005752	2	straight	not dry	0	0	6.74
821006149	2	straight	not dry	5	25	12.701
823005424	2	straight	not dry	0	0	62.628
864004487	2	straight	not dry	0	0	29.901
864004729	2	straight	not dry	0	10	29.901
870004733	2	curve	not dry	0	30	50.061
870004748	2	curve	not dry	0	30	80.73
884004485	2	straight	not dry	0	20	73.431
339006451	3	curve	dry	30	40	131.148
803004276	3	curve	dry	10	35	58.657
810005647	1 (3)	curve	dry	48	96	69.365
811004362	3	straight	dry	5	15	205.616
812005951	3	curve	not dry	0	0	131.148
813005511	3	straight	dry	0	0	426.863
813005626	3	curve	dry	5	20	688.372
815004312	1 (3)	curve	not dry	60	70	58.657
820003982	3	curve	dry	5	10	260.223
820004643	3	curve	dry	0	10	260.223

* 1 = rollover, 2 = loss-of-control, no subsequent rollover, and 3 = loss-of-control, subsequent rollover
** Percentage that a crash can be avoided based on computer simulation or panel assessment
Note: Bold-faced cases were where discrepancies occurred between NHTSA's and UMTRI's assessments; values in parenthesis were UMTRI's assessment