Lives Saved by Vehicle Safety Technologies and Associated Federal Motor Vehicle Safety Standards, 1960 to 2012 – Passenger Cars and LTVs

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ABSTRACT

NHTSA began in 1975 to evaluate the effectiveness of vehicle safety technologies associated with the Federal Motor Vehicle Safety Standards (FMVSS). By June 2014, NHTSA had evaluated the effectiveness of virtually all the life-saving technologies introduced in passenger cars, pickup trucks, SUVs, and vans from about 1960 up through about 2010. A statistical model estimates the number of lives saved from 1960 to 2012 by the combination of these life-saving technologies. Fatality Analysis Reporting System (FARS) data for 1975 to 2012 documents the actual crash fatalities in vehicles that, especially in recent years, include many safety technologies. Using NHTSA's published effectiveness estimates, the model estimates how many people would have died if the vehicles had not been equipped with any of the safety technologies. In addition to equipment compliant with specific FMVSS in effect at that time, the model tallies lives saved by installations in advance of the FMVSS, back to 1960, and by non-compulsory improvements, such as pretensioners and load limiters for seat belts. FARS data has been available since 1975, but an extension of the model allows estimates of lives saved in 1960 to 1974. A previous NHTSA study using the same methods estimated that vehicle safety technologies had saved 328,551 lives from 1960 through 2002. The agency now estimates 613,501 lives saved from 1960 through 2012. The annual number of lives saved grew from 115 in 1960, when a small number of people used lap belts, to 27,621 in 2012, when most cars, light trucks, and vans were equipped with numerous modern safety technologies and belt use on the road achieved 86 percent.

INTRODUCTION

The National Highway Traffic Safety Administration began in 1975 to evaluate the effectiveness of vehicle safety technologies associated with the Federal Motor Vehicle Safety Standards (FMVSS). By 2004, NHTSA had evaluated virtually all of the life-saving technologies introduced in passenger cars and in LTVs (light trucks and vans – i.e., pickup trucks, SUVs, minivans and full-size vans) from about 1960 through the mid-1990s. These were retrospective evaluations with estimates of fatality-reducing effectiveness based on statistical analyses of the actual crash experience of production vehicles equipped with the technologies. In October 2004, the agency issued a report estimating the number of lives saved from 1960 to 2002, year-by-year, by the combination of those life-saving technologies and by each individual technology; the estimates added up to 328,551 lives saved through 2002.[1]

Since 2004, NHTSA has evaluated nine additional life-saving technologies, such as electronic stability control (ESC) and curtain air bags and has acquired 10 additional years of crash data (through 2012). Although some of these technologies, including ESC and curtain air bags were already available in production vehicles by 2002, they could not be included in the previous report because the vehicles had not yet accumulated enough on-the-road experience for statistical analyses. NHTSA has issued a report updating the 2004 study and estimating 613,501 cumulative lives saved from CY 1960 through 2012. The update includes not only new estimates of 281,042 lives saved from CY 2003 through 2012 (the years not included in the earlier report), but also a slight upward revision from the previous report's estimate of 328,551 to 332,459 for CY 1960 through 2002 to account for the technologies that had begun to appear in production vehicles by 2002 but had not yet been evaluated by 2004.[2]

METHOD

Past evaluation reports estimated the **effectiveness** of a safety technology – a percentage reduction of fatalities – by statistically analyzing crash data. An initial evaluation is based on production vehicles produced just before versus just after a make-model received that technology. Effectiveness might subsequently change over time if vehicles and/or the crash environment changes; when feasible, NHTSA tracks effectiveness with follow-up evaluations of crash data based on later vehicles. These follow-up analyses show that effectiveness has remained quite stable for key safety technologies such as seat belts, frontal air bags, and ESC. But the **benefits** of a technology – the absolute number of lives saved in a year – readily change from year to year depending on the number of vehicles equipped

with the technology, their vehicle miles travelled (VMT), and the crash-involvement rate of the driving population (exposure). NHTSA has:

- Reviewed the effectiveness estimates in past evaluations of safety technologies for cars and LTVs, describing how the technologies work and the history of the FMVSS that regulate them.[3]
- Developed a model that uses Fatality Analysis Reporting System (FARS) data and these past effectiveness estimates to calculate how many lives the following technologies have saved, individually and in combination, in each year from 1960 to 2012:[4]

FMVSS: Safety Technologies	Cars	LTVs	Heavy Trucks
105/135: Dual master cylinders & front disc brakes*	X	X	
108: Conspicuity tape for heavy trailers			X†
126: Electronic stability control‡	X	X	
201: Voluntary mid/lower instrument panel improvements	X	X	
Head-impact upgrade	X	X	
203/204: Energy-absorbing steering assemblies	X	X	
206: Improved door locks	X	X	
208: Lap belts	X	X	
3-point belts	X	X	
2-point automatic belts**	X		
Voluntary NCAP-related improvements for belted occupants††	X		
Belt pretensioners and load limiters	X	X	
Frontal air bags (barrier-certified, sled-certified, advanced)	X	X	
212: Adhesive windshield bonding	X	X	
213: Child safety seats	X	X	
214: Side door beams	X	X	
Structure and padding to meet a dynamic side-impact test	X		
Curtain and side air bags	X	X	
216: Roof crush resistance (eliminate true hardtops)	X		
226: Ejection mitigation (rollover curtains)	X	X	
301: Fuel system integrity: rear-impact upgrade	X	X	

*Applies to cars and LTVs, but also saves pedestrians, bicyclists and motorcyclists not hit by these cars and LTVs.
†Applies to heavy trailers, but also saves occupants of cars and LTVs that avoid collisions with these trailers.
‡Applies to cars and LTVs, but also saves motorcyclists not hit by these cars and LTVs.
**LTVs were not equipped with 2-point automatic belts.
††NCAP testing, the dynamic side-impact test of FMVSS No. 214, and FMVSS No. 216 apply to LTVs as well as cars, but NHTSA evaluations have not identified a life-saving effectiveness for the LTVs.

In addition to safety equipment compliant with a specific FMVSS in effect at that time (and perhaps even excelling the performance requirements of that FMVSS), the model tallies lives saved by installations in advance of the FMVSS and by non-compulsory improvements shown in the preceding list, such as belt pretensioners and load limiters. The model includes car/LTV occupants saved by car/LTV technologies or child safety seats (99 percent of the total) plus pedestrians/bicyclists/motorcyclists saved by car/LTV brake improvements, motorcyclists saved by ESC, and car/LTV occupants saved by conspicuity tape on heavy trailers.

The model does not include technologies so recent that NHTSA has not yet evaluated them based on statistical analysis of crash data, such as tire pressure monitoring systems (phased in during MY 2006 to 2008). The study is limited to technologies in cars and LTVs or technologies that save lives of car/LTV occupants; for example, motorcycle helmets are not included. It is limited to vehicle technologies. It does not estimate the effects of behavioral safety programs such as the reduction of impaired driving – except to the extent that buckle-up programs have contributed greatly to the number of lives saved by belts and child safety seats. It does not include effects of roadway and traffic engineering improvements (such as rumble strips), shifts in the vehicle fleet – e.g., between large and small cars or between cars and LTVs, or improvements in EMS or follow-up medical care. The model is

limited to estimating fatality reduction by the safety technologies; NHTSA does not have sufficiently complete evaluation results to develop comparable estimates for the numbers of nonfatal injuries prevented.

Consider 1,000 cases of driver fatalities in directly frontal multivehicle crashes in cars with 1960 technology: no energy-absorbing steering columns, all drivers unbelted, and no air bags. A NHTSA evaluation estimates that energy-absorbing steering columns reduce fatalities of drivers in frontal crashes by 12.1 percent. Thus, if these cars had been equipped with them, there would have been only 879 fatalities, a saving of 121 lives. Another evaluation estimates that 3-point belts, in cars with energy-absorbing steering columns, reduce drivers' fatality risk by 42 percent in these types of crashes. If the cars had been equipped with 3-point belts in addition to energy-absorbing steering columns and the drivers had buckled up, the 879 fatalities would have diminished to 510, saving another 369 lives. A third evaluation estimates that frontal air bags reduce fatality risk by 25.3 percent for belted drivers in these types of crashes, in cars with energy-absorbing steering columns. Frontal air bags would have cut the 510 fatalities down to 381, saving another 129 lives.

The model uses 1975-to-2012 FARS data and performs the same calculations in reverse order: e.g., there might be 381 actual FARS cases of 3-point-belted driver fatalities in directly frontal multivehicle crashes in MY 1999 cars, all of which were equipped with frontal air bags and energy-absorbing steering columns. If frontal air bags, the most recent (1990s) of these three safety technologies, had been removed from the cars, fatalities would have increased to an estimated 510. In other words, we surmise there must have been 129 potentially fatal collisions of these MY 1999 cars that did not become FARS cases because frontal air bags saved the driver's life. If the 3-point belts, a 1970s technology, had also been removed from the cars and all the drivers had been unbelted, the fatalities would have increased to 879. Finally, if the energy-absorbing steering columns, a 1960s technology, had been replaced by rigid columns, downgrading these cars all the way back to a 1960 level of safety, fatalities would have increased to 1,000. The three technologies, in combination, saved an estimated 619 lives: 129 by air bags, 369 by 3-point belts and 121 by energy-absorbing columns. In summary, FARS cases of fatalities in vehicles equipped with modern safety technologies constitute evidence of an even larger hypothetical number of fatalities that would have occurred without those technologies. This approach "removes" the technologies in reverse chronological order; alternative approaches removing them in some different order would still have estimated 619 overall lives saved from 1960 to 2012, but might have allocated that total differently among the individual safety technologies. FARS data has been available since 1975, but the FMVSS date back to January 1, 1968, and some technologies were introduced even before that. An extension of the model allows estimates of lives saved from 1960 to 1974.

FINDINGS: LIVES SAVED FROM 1960 TO 2012

Safety technologies saved an estimated 613,501 lives from 1960 through 2012. Table 1 shows that the annual number of lives saved grew from 115 in 1960, when a small number of people used lap belts, to 27,621 in 2012, when most cars and LTVs were equipped with numerous modern safety technologies and belt use on the road achieved 86 percent. This is a large increase from the previous NHTSA study, which estimated 328,551 lives saved from 1960 through 2002. Table 1 shows that vehicle safety technologies had great benefits during the decade from 2003 through 2012, saving between 26,000 and 31,000 lives each year.

Fewer than 1,000 lives per year were saved during 1960 to 1967. Starting in 1968, vehicles incorporating most of the safety improvements of the 1960s superseded older vehicles; lives saved reached 4,000 in 1978, but remained at that level for 6 years as belt use temporarily declined. The greatest increase, from 4,835 in 1984 to 11,265 in 1988, came with buckle-up laws in the States. From 1988 until 2007, continued increases in belt use; air bags, ESC, and other recent technologies; and an expanding "base" of more vehicles and more VMT helped the fatality reduction grow, exceeding 15,000 in 1994 and 20,000 in 1999, reaching a peak of 30,312 in 2007. From 2007 until 2011, however, even though safety technologies continued to save a growing share of the potential fatalities, a shrinking "base" of VMT, especially the high-risk VMT, contributed to a decrease in the absolute number of lives saved, down to 26,098 in 2011, but then rebounding to 27,621 in 2012.[5]

Table 1: **Lives Saved by Vehicle Safety Technologies, 1960 to 2012**
(Car and LTV Occupants Saved, Plus Non-Occupants and Motorcyclists Saved by Car/LTV Brake Improvements or ESC)

CY	LIVES SAVED
1960	115
1961	117
1962	135
1963	160
1964	203
1965	251
1966	339
1967	509
1968	816
1969	1,179
1970	1,447
1971	1,774
1972	2,226
1973	2,576
1974	2,518
1975	3,058
1976	3,240
1977	3,671
1978	4,040
1979	4,299
1980	4,540
1981	4,455
1982	4,057
1983	4,248
1984	4,835
1985	6,389
1986	8,531
1987	9,992
1988	11,292
1989	11,522
1990	11,761
1991	12,250
1992	12,573
1993	13,902
1994	15,263
1995	16,265
1996	17,956
1997	18,751
1998	19,613
1999	20,256
2000	22,280
2001	23,364
2002	25,691
2003	27,174
2004	28,253
2005	29,936
2006	30,242
2007	30,312
2008	27,941
2009	26,770
2010	26,695
2011	26,098
2012	27,621
	==========
	613,501

Car/LTV occupants: actual fatalities, potential fatalities and percent saved
Among the 613,501 lives saved in 1960 to 2012, 610,566 were occupants of cars and LTVs. (The remaining 2,935 were pedestrians, bicyclists, and motorcyclists who avoided fatal impacts by cars or LTVs because dual master cylinders, front disc brakes, or ESC improved the car or LTV's braking or handling performance.) The sum of the

actual fatalities and the lives saved is the number of fatalities that potentially might have happened if cars and LTVs still had 1960 safety technology and nobody used seat belts. Table 2 shows 1,712,855 actual car/LTV occupant fatalities from 1960 through 2012; without the 610,566 lives saved, there would have been 2,323,421 potential fatalities. Actual car and LTV occupant fatalities decreased from 28,183 in 1960 to 21,696 in 2012. Without the vehicle safety technologies and increases in belt use, the model estimates that fatalities would not have declined but would have substantially increased, from 28,298 in 1960 to 49,214 in 2012.

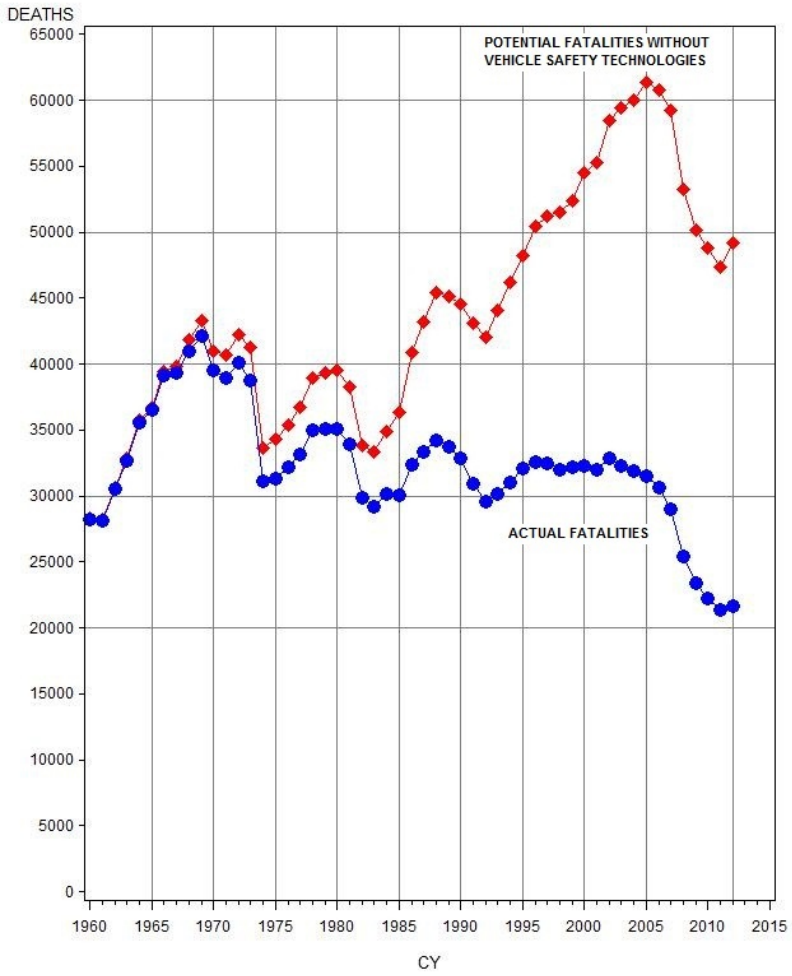
Figure 1 compares the trends in actual and potential fatalities. Up to the early 1980s, both trend lines were fairly close together. Both moved up or down in response to the large cohort of baby boomers starting to drive in the 1960s; the same cohort in the 1970s turning 25, an age when fatal-crash involvement rates are already substantially lower than in adolescence; plus transient reductions in the mid-1970s and early 1980s, perhaps triggered by events such as an energy crisis, high fuel prices, or an economic slowdown. From the mid-1980s, vehicle safety made a big difference. Potential fatalities have historically continued to rise as the number of registered vehicles and VMT increased in an affluent society – with transient interruptions from 1989 to 1992 and 2006 to 2011. But increased belt use, air bags, ESC, and other vehicle safety technologies held the line on actual fatalities at about 32,000 a year during the two decades of generally rising potential fatalities and then helped bring them down to levels not seen since the 1940s, such as 21,331 in 2011 and 21,696 in 2012.[6]

Table 2: **Actual Occupant Fatalities, Potential Fatalities without the Vehicle Safety Technologies, and Lives Saved in Cars/LTVs**

	CAR+LTV OCCUPANT FATALITIES			
CY	ACTUAL	W/O SAFETY TECHS.	LIVES SAVED	PERCENT SAVED
1960	28,183	28,298	115	0.40
1961	28,087	28,204	117	0.41
1962	30,544	30,679	135	0.44
1963	32,664	32,823	159	0.49
1964	35,603	35,805	202	0.56
1965	36,518	36,767	249	0.68
1966	39,130	39,465	334	0.85
1967	39,327	39,826	499	1.25
1968	41,019	41,818	799	1.91
1969	42,117	43,273	1,156	2.67
1970	39,556	40,972	1,415	3.45
1971	38,916	40,651	1,735	4.27
1972	40,103	42,281	2,178	5.15
1973	38,739	41,258	2,520	6.11
1974	31,145	33,608	2,463	7.33
1975	31,361	34,355	2,995	8.72
1976	32,222	35,398	3,176	8.97
1977	33,173	36,772	3,599	9.79
1978	34,988	38,951	3,964	10.18
1979	35,108	39,325	4,217	10.72
1980	35,097	39,554	4,456	11.27
1981	33,911	38,284	4,373	11.42
1982	29,855	33,834	3,979	11.76
1983	29,209	33,384	4,176	12.51
1984	30,177	34,935	4,758	13.62
1985	30,044	36,357	6,314	17.37
1986	32,394	40,849	8,454	20.70
1987	33,334	43,251	9,916	22.93
1988	34,245	45,461	11,216	24.67
1989	33,725	45,177	11,452	25.35
1990	32,844	44,534	11,690	26.25
1991	30,939	43,126	12,187	28.26
1992	29,557	42,071	12,514	29.75
1993	30,192	44,033	13,840	31.43
1994	30,995	46,200	15,204	32.91
1995	32,067	48,271	16,204	33.57
1996	32,541	50,438	17,897	35.48

1997	32,515	51,208	18,693	36.50
1998	31,955	51,512	19,557	37.97
1999	32,171	52,373	20,202	38.57
2000	32,241	54,465	22,225	40.81
2001	32,021	55,327	23,306	42.12
2002	32,872	58,506	25,634	43.81
2003	32,297	59,411	27,114	45.64
2004	31,871	60,064	28,193	46.94
2005	31,539	61,408	29,869	48.64
2006	30,633	60,804	30,171	49.62
2007	29,009	59,246	30,236	51.04
2008	25,423	53,287	27,864	52.29
2009	23,417	50,115	26,698	53.27
2010	22,235	48,852	26,617	54.49
2011	21,331	47,342	26,011	54.94
2012	21,696	49,214	27,518	55.92
	1,712,855	**2,323,421**	**610,566**	

FIGURE 1: ACTUAL VERSUS POTENTIAL CAR/LTV OCCUPANT FATALITIES, 1960 TO 2012



The overall, combined **effectiveness** of the vehicle safety technologies is the percentage of potential fatalities that were saved, as shown in the right column of Table 2. The effectiveness grew in **every** year from 1960 to 2012, from a humble 0.40 percent in 1960 to a very substantial 55.92-percent fatality reduction in 2012. The trend shows:

- Not much effect before the FMVSS;
- Steady growth in the early-to-mid 1970s as the early FMVSS phased in;
- A slowdown in 1978 to 1982, when belt use declined prior to national buckle-up campaigns;
- The largest gains coming with the buckle-up laws in the mid-to-late 1980s; and
- Steady progress since the late 1980s thanks to continued increases in belt use, air bags, ESC, and other recent technologies.

Figure 2 tracks a **vehicular fatality-risk index** for occupants of cars or LTVs that isolates the effects of vehicle safety improvements. The index is obtained by subtracting from 100 the percentage of potential fatalities saved. The index was 100 in 1955 and had declined to 44 by 2012. In other words, given the same mileage by the same driver on the same roads, the average vehicle on the road in 2012 would have 56 percent lower fatality risk for its occupants than the average vehicle on the road in 1955.

FIGURE 2: VEHICULAR FATALITY-RISK INDEX BY CALENDAR YEAR (1955 = 100)
BASED ON PERCENT OF POTENTIAL FATALITIES SAVED BY VEHICLE SAFETY TECHNOLOGIES

Estimates of lives saved by individual technologies (grouped by FMVSS)
Car/LTV safety technologies saved an estimated 27,621 lives in 2012. That total includes 14,018 car occupants and 13,500 LTV occupants. It also includes 103 pedestrians, bicyclists and motorcyclists saved by car/LTV braking improvements or by ESC. Table 3 apportions how many of those lives were saved by the various individual technologies and groups those technologies according to the FMVSS with which they appear to be most closely associated:[7]

Table 3: **Estimates of Lives Saved by Safety Technologies in 2012**

FMVSS & Associated Safety Technologies	Car Occupants	LTV Occupants	Pedestrians Bicyclists Motorcyclists	TOTAL
105/135: Dual master cylinders & front disc brakes	217	201	65	482
108: Conspicuity tape for heavy trailers	90	70		161
126: Electronic stability control for cars and LTVs	500	824	38	1,362
201: Instrument panel improvements & head impact protection	778	573		1,350
203/204: Energy-absorbing steering assemblies	1,323	1,084		2,407
206: Improved door locks	486	641		1,127
208: Seat belts – all types, all seating positions*	7,169	8,316		15,485
208: Frontal air bags*	1,738	1,193		2,930
212: Adhesive windshield bonding	177	95		271
213: Child safety seats*	213	145		357
214: Side impact protection & curtain/side air bags	1,196	315		1,512
216: Roof crush resistance (eliminate true hardtops)	122			122
226: Curtains that deploy in rollovers	3	41		43
301: Fuel system integrity – rear impact upgrade	5	4		9
TOTAL	14,018	13,500	103	27,621

* Estimates in this table for seat belts, frontal air bags, and child safety seats do not supersede NHTSA's official annual estimates in *Traffic Safety Facts 2012 Data – Occupant Protection* of the lives **directly** saved by those technologies. The estimates in this table, which also include estimates of lives **indirectly** saved by those technologies (discussed below), are meaningful primarily in this report's context of computing the overall effect of the FMVSS and the comparing the effects of various FMVSS.

- Seat belts are by far the most important occupant protection, saving an estimated 15,485 lives: over half the total of 27,621. The estimate includes seat belts of all types (3-point, lap-only, automatic), at all designated seating positions. Seat belts are designed to keep occupants within the vehicle and close to their original seating position, provide "ride-down" by gradually decelerating the occupant as the vehicle deforms and absorbs energy, and, if possible, prevent occupants from contacting harmful interior surfaces or one another (however, NHTSA recommends correctly-installed, age-appropriate safety or booster seats for child passengers until they are at least 8 years old, unless they are at least 4'9" tall). Seat belts are especially important in LTVs, where a large proportion of unrestrained fatalities are ejections and/or rollover crashes; belts saved 8,316 lives in LTVs, over 60 percent of the 13,500 LTV occupants saved.

  (NHTSA's official estimate is that belts directly saved 12,174 lives in 2012 – i.e., fatalities would have increased by 12,174 if nobody had buckled up, but otherwise the cars and LTVs on the road had remained unchanged.[8] This report's estimate, 15,485 lives saved in 2012, is higher because it also includes some indirect savings: this report estimates how many additional fatalities would have occurred if all safety technologies had been removed, not just the belts, and it then apportions the total among the various individual technologies. Accounting for the lives directly saved by recent technologies such as ESC, by this report's computational method, also indirectly augments the estimates of lives saved by earlier technologies such as seat belts.[9] The estimates here do not supersede the agency's official estimates of lives directly saved by seat belts, frontal air bags, and safety seats. They are primarily meaningful within the context of this report: estimation of the overall effect of all the vehicle safety technologies and apportionment of the overall effect among the individual technologies.)

- Frontal air bags saved 2,930 lives in 2012, when 95 percent of cars and 91 percent of LTVs on the road were equipped with dual or driver-only frontal air bags. (NHTSA's official estimate in *Traffic Safety Facts 2012 Data – Occupant Protection* is 2,213 lives saved directly by air bags in 2012.) Frontal air bags have significant benefits in frontal and partially frontal impacts for nearly all occupants 13 and older, including the oldest drivers and passengers, by providing energy absorption and ride-down and by preventing head contacts with the windshield or windshield header. However, a deployed frontal air bag, especially some of the pre-2007 designs without the advanced features of current models, can present risks to child passengers 12 and younger. The risk can be eliminated if the child rides in the rear seat, correctly restrained – or by

turning off the manual on-off switch in pickup trucks or other vehicles where children cannot ride in a rear seat correctly restrained.

- Energy-absorbing steering assemblies meeting FMVSS Nos. 203 and 204 are an important "built-in" safety technology that saved an estimated 2,407 lives in 2012. In the 1960s, they were the first basic protection for drivers in frontal crashes, designed to cushion their impact into the steering assembly. Today, the combination of energy-absorbing steering columns, seat belts and frontal air bags provides far better protection for the driver in frontal crashes.

- Three groups of technologies associated with FMVSS No. 214, "Side impact protection," saved an estimated 1,512 lives in 2012. The technologies are: (1) Side door beams in cars and LTVs meeting the original static crush test of FMVSS No. 214, which are primarily effective in side impacts with fixed objects, such as trees or poles; (2) Structures and padding added to passenger cars before or after FMVSS No. 214 was upgraded in the 1990s with a dynamic test requirement, which are primarily effective in near-side impacts by other vehicles (i.e., left-side impacts for drivers and right-side impacts for right front passengers); and (3) Curtain and side air bags, which further enhance protection in near-side impacts.

- Electronic stability control (now required in new cars and LTVs by FMVSS No. 126) saved 1,362 lives in 2012, the first year when all new cars and LTVs had ESC – but in 2012 only 20 percent of cars and 22 percent of LTVs on the road were ESC-equipped. Benefits can be expected to grow substantially in future years as the on-road fleet approaches 100 percent ESC-equipped. ESC detects when a vehicle is about to lose traction and automatically applies the brakes to individual wheels and/or reduces engine torque to help the driver stay on course. It is a highly effective crash avoidance technology.

- Two groups of technologies associated with FMVSS No. 201, "Occupant protection in interior impact" saved an estimated 1,350 lives in 2012. The technologies are: (1) Improvements to the materials and contours of middle and lower instrument panels in the late 1960s and 1970s, not specifically required by FMVSS No. 201 but historically and functionally associated with that standard to some extent; instrument panels were redesigned, using energy-absorbing materials, to decelerate occupants at a safe rate and keep them in an upright position during frontal crashes. (2) The head-impact upgrade of FMVSS No. 201, phased in during MY 1999 to 2003, which added energy-absorbing padding to pillars, roof headers, roof side rails, and other components that were sources of life-threatening head injuries.

- Improvements to door locks, latches, and hinges, generally implemented by manufacturers in the 1960s and regulated by industry standards subsequently incorporated into FMVSS No. 206, saved 1,127 lives in 2012. They reduce the risk of occupant ejection by keeping doors closed in rollover crashes.

- Car/LTV braking improvements directly or indirectly associated with FMVSS Nos. 105 and 135 include dual master cylinders and front disc brakes. By eliminating brake failure or helping cars and LTVs stop more effectively, they saved 482 lives in 2012, including 65 pedestrians, bicyclists or motorcyclists.

- Child safety seats or booster seats meeting FMVSS No. 213 saved an estimated 357 young passengers in 2012. (NHTSA's official estimate is 284 lives saved directly by child safety seats in 2012.) Child safety seats and booster seats are the basic protection system for passengers who are too small to obtain full benefits from seat belts. Newborns should start with rear-facing seats and stay in them until their weight or height reaches a point where they should graduate to forward-facing seats, subsequently to booster seats and, finally, when they are at least 9 years old or 4'9" tall, to adult seat belts.

- Adhesive windshield bonding saved 271 lives in 2012 by keeping the windshield attached to the vehicle in severe impacts and preventing occupant ejection via the windshield portal. FMVSS No. 212 regulates windshield retention for cars and LTVs.

- FMVSS No. 108 requires red-and-white conspicuity tape on heavy truck trailers. The tape reflects another vehicle's headlights strongly and it is highly visible in the dark. Although this device is furnished on heavy

trailers, not cars or LTVs, it is the occupants of cars and LTVs who primarily benefit by avoiding collisions with the trailers. The tape saved an estimated 161 car and LTV occupants in 2012.

- FMVSS No. 216, "Roof crush resistance" is associated with the redesign of true hardtops as pillared hardtops or sedans during the 1970s. True hardtops had no B-pillars to support the roof, making it more susceptible to crush in a rollover. If cars were still built that way there might have been 122 additional fatalities in 2012.

- FMVSS No. 226, "Ejection mitigation" began to phase in during MY2014. Curtain air bags that deploy in rollover crashes are the key technology for meeting the standard. Rollover curtains have already been available in some production vehicles since 2002. They are effective in preventing ejection and mitigating interior impact. They saved an estimated 43 lives in 2012.

- The rear-impact test of FMVSS No. 301, "Fuel system integrity" was substantially upgraded during the past decade. The upgrade saved an estimated 9 lives in 2012: people who otherwise would have died of burns in post-crash fires.

Table 4 shows cumulative lives saved from 1960 through 2012: 385,408 car occupants and 225,158 LTV occupants, plus 2,936 pedestrians, bicyclists and motorcyclists saved by car/LTV braking improvements or ESC, for an estimated total of 613,501. Seat belts (329,715) accounted for more than half the total. Frontal air bags had saved 42,856 lives by the end of 2012 and child safety seats, 9,891. The "built in" non-belt technologies regulated by or associated with the remaining 13 FMVSS in Table 4 (Nos. 105/135, 108, 126, 201, 203/204, 206, 212, 214, 216, 226, and 301) sum to 231,039 lives saved; energy-absorbing steering assemblies, improved door locks, occupant protection in interior impact, and side impact protection have cumulatively saved the most lives.

Table 4: **Estimates of Cumulative Lives Saved by Safety Technologies from 1960 through 2012**

FMVSS & Associated Safety Technologies	Car Occupants	LTV Occupants	Pedestrians Bicyclists Motorcyclists	TOTAL
105/135: Dual master cylinders & front disc brakes	10,559	5,001	2,790	18,350
108: Conspicuity tape for heavy trailers	1,524	1,136		2,660
126: Electronic stability control for cars and LTVs	2,420	3,604	146	6,169
201: Instrument panel improvements & head impact protection	24,779	9,698		34,477
203/204: Energy-absorbing steering assemblies	57,112	22,877		79,989
206: Improved door locks	25,377	16,758		42,135
208: Seat belts – all types, all seating positions	187,442	142,274		329,715
208: Frontal air bags	27,765	15,091		42,856
212: Adhesive windshield bonding	7,268	2,585		9,853
213: Child safety seats	7,257	2,634		9,891
214: Side impact protection & curtain/side air bags	28,971	3,317		32,288
216: Roof crush resistance (eliminate true hardtops)	4,913			4,913
226: Curtains that deploy in rollovers	8	171		178
301: Fuel system integrity – rear impact upgrade	14	13	___	26
TOTAL	385,408	225,158	2,936	613,501

DISCUSSION

The fatality-reducing effectiveness estimates used in the model are all derived from published NHTSA evaluation reports. The model includes a technology only if its estimate of fatality reduction in NHTSA evaluations is statistically significant. As stated above, the estimates are based on statistical analyses of crash data. An initial evaluation report usually compares fatality risk in vehicles built just before and just after make-models became equipped with the technology, statistically controlling for factors other than the technology by using double-pair comparison, control groups, logistic regression, or other techniques. For some technologies, including seat belts,

frontal air bags, ESC, and curtain and side air bags, the agency has performed follow-up evaluations of crash data involving later vehicles to see if effectiveness might have changed over time.

The basic assumption of the model is that any group of FARS fatality cases involving vehicles equipped with a safety technology known to be effective in that type of crash may be considered evidence that there were additional crashes where that technology saved lives: these additional crashes are not in FARS because the technology made them nonfatal crashes. For example, if there are 100 belted fatality cases in FARS in a type of crash where statistical analysis shows 50-percent belt effectiveness, we surmise that there must have been another 100 people in potentially fatal crashes who were saved by the belt. This is a leap of faith to the extent that we cannot identify those 100 specific occupants who were "saved by the belt" – we assume they must exist, based on our effectiveness estimate.

The model simulates "removing" safety equipment from a modern vehicle one piece at a time, starting with the most recent technology and working backward. Some of these technologies were introduced at about the same time, and it is not always obvious which was first: for some of the earliest ones, limited information is available about their introduction dates. Changing the order in which the technologies are "removed" would still produce the same estimate of overall lives saved, but the allocation among the individual technologies could change.

The model assumes that the belt use of **fatally injured** occupants (not survivors) in FARS is accurately reported. NHTSA has long believed this to be true, based on statistical analyses comparing FARS data with belt use observed in surveys. In the future, conceivably, event data recorders could provide additional evidence on belt use in crash data files.

Finally, when the model says vehicle safety technologies saved 613,501 lives, it estimates that this number of additional fatalities might have occurred from 1960 through 2012, without those technologies, if all other factors had stayed the same: the same increase in VMT from 1960 to 2012, the same driving behaviors. It is a hypothetical estimate. If seat belts and the other modern vehicle safety technologies had never been invented and if occupant fatalities had continued climbing toward 61,000 instead of remaining near 32,000, as shown in Table 2, the public might have demanded much stronger regulation of drivers (e.g., licensing) or the infrastructure (e.g., speed limits). Consumers might have purchased a different mix of vehicles and some people might have been more reluctant to travel during the riskiest hours (e.g., weekend nights). Those measures might have prevented at least some of the additional 613,501 fatalities – but surely not as efficiently and with as little impairment of driving enjoyment and mobility as the vehicle safety technologies.

CONCLUSIONS

- Vehicle safety technologies and their associated FMVSS have greatly reduced fatality risk for car and LTV occupants over the past decades in the United States. Given the same mileage by the same drivers on the same roads, the average vehicle on the road in 2012 would have an estimated 56 percent lower fatality risk for its occupants than the average vehicle on the road in 1955 to 1960.

- These technologies have saved an estimated cumulative 613,501 lives since 1960, including 27,621 in calendar year 2012.

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[3] *Ibid*., pp. 14-213.
[4] *Ibid*., pp. 1-13 and 214-226.
[5] *Ibid*., pp. 227-232.
[6] *Ibid*., pp. 233-244.
[7] *Ibid*., pp. 244-252.

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[9] Kahane (2014, September), pp. 244-249.