INSTALLATION PATTERNS FOR EMERGING SAFETY TECHNOLOGIES 2000-2015

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ABSTRACT

Motor vehicle consumer information programs promote safety improvements through testing in consumer metrics programs (NCAP programs and IIHS programs) and by providing information to consumers about emerging safety technologies, potential benefits the emerging technologies are expected to provide, and sometimes lists of vehicles that are equipped with the emerging technologies. Motor vehicle manufacturers leverage such consumer information in product promotion through advertising, product descriptions and product announcements.

The success of an emerging safety technology as perceived by consumers can be assessed in part by the extent to which the technology in question increases in application over time. Increased application rates reflect growing consumer adaption, acceptance, or even insistence upon a safety feature or performance element in a new vehicle purchase. Researchers have previously reported upon the installation patterns for various emerging safety technologies through 2010. This paper extends the analysis through 2016 and adds multiple new emerging technologies to the analysis, particularly newly emerging crash avoidance technologies. The information is useful to: safety researchers, regulators, and vehicle manufacturers' safety engineers to plan and execute safety technology integration into the new vehicle fleet.

BACKGROUND

The introduction and applicaton of 28 injury mitigation safety technologies were compilied and reported upon in 2011 [1]. Surveys of the new emerging safety technologies were performed tabulating the technology insertion pattern by: vehicle manufacturer, brand, model, and model year. The technology application as: not available, provided as optional content, or provided as standard equipment was also tabulated. The data reported assists researchers in determining which specific models were offered for sale with an emerging safety technology and the proportion of models in each model year that are offered with that particular technology.

In many technology areas, vehicle manufacturers have exceeded specifications for safety equipment proscribed in Federal Motor Vehicle Safety Standards (FMVSS) and have often implemented safety technologies in advance of any rule. By allowing manufacturers to voluntary exceed the rule based structure, NHTSA encourages and promotes the advancement of motor vehicle safety and continuing progress in motor vehicle collision injury control science. The development of safety improvements have been developed through application of the public health model for injury reduction. The model provides a systematic approach for identifying and prioritizing opportunities for safety needs; research, developing, designing and testing the proposed technology/countermeasure; aligning application and execution in the vehicle development plan (VDP); and survey of effectiveness in injury reduction after sufficient time in the field.

An indication of the success of the injury reduction model can be judged by reviewing fatal injury rates over time. Figure 1 shows the motor vehicle collision fatality rate over the period 1966-2014.

METHODOLOGY

The database created for the 2011 analysis [1] was expanded upon for this study. The vehicle list was increased to include 2013-2015 model year vehicles using databases purchased from Ward's Automotive Yearbooks. The list of brands and models was reduced to one model designation comprising of all various body styles, powertrain, and trim levels. For example there is one designated Ford F150 model that includes the 3 body styles, various drivetrains, powertrains and trim levels. The technologies of interest were surveyed and tabulated indicating whether the technology was optional content, standard equipment, or not available. If there were multiple body styles for one model and the feature was standard for one body style but not the remaining body styles, the feature was characterized as optional equipment. This practice was used for classification of content for all of the technologies we surveyed. Exotic, rare, and very expensive vehicles were excluded from the list of models surveyed; as such vehicle models are not mainstream and present a minimal market profile in terms of sales volumes.

A comprehensive survey of crash avoidance safety technologies of interest and ESC was available through the IIHS website [3, 4]. Although the IIHS tabulated data down drive train level, it was paired down to match the Ward's model list. For example, if a feature was standard for the four wheel drive model but not available for the two wheel drive model, the technology was considered optional for that model.

Ward's Automotive Yearbooks provided details of available rear-facing backup cameras. This data was used to populated the database for the camera feature.

The data tabulated for enhanced head curtain airbags with rollover activation, referred to as rollover curtains, was tabulated manually from various sources. IIHS does list vehicle safety features of the vehicles that are included in their ratings database [5] although not all vehicles are rated. In cases were information was not available on the IIHS website, manufacture sales brochures, owner's manual and shop manuals were consulted. In some cases the information included in those resources was inconclusive and not clear if the side curtain airbags were enhanced for ejection mitigation and deployed in rollover collisions.

Combining the data from these various sources allowed for the creation of brand, model, and model year technology tables; a typical Table is illustrated as **Error! Reference source not found.**. Models surveyed are organized by brand and manufacturer; and color-coded based on the availability of the safety technology. Model cells filled in green are those that have the technology as standard equipment. Model cells filled in white are those that do not offer the technology. Model cells filled in yellow are those that offer the technology as optional equipment. If a technology was dependent on the buyer's selection of: trim level, option packages, engine or drivetrain type, or other factor at the buyer's discretion, the safety technology was registered as "optional", unless of course the technology was not available on the model at all.

Bar charts were also generated to show the year-to-year progression of available models in the U.S. with each specific safety technology surveyed. Bar charts show the installation patterns for the technologies based on the numbers of models for which the technology was standard or optional. An example of such an installation pattern bar chart can been seen in *Figure 2* .

CRASH AVOIDANCE TECHNOLOGIES SURVEYED

Six of the most common collision avoidance technologies identified by the Insurance Institute of Highway Safety (IIHS) were surveyed: Forward Collision Warning, Forward Collision Autobrake, Lane Departure Warning, Lane Departure Prevention, Adaptive Headlights, and Blind Spot Detection. These technologies incorporate sensing, processing, display, and in some cases, actuating systems engineered to assist the driver in reducing the risk of collisions or to mitigate the effects of a collision should one occur.

For the purpose of this study, the crash avoidance technologies were defined based upon automotive manufactures literature as follows:

Forward Collision Warning

By use of range finding radar, laser, or cameras, and other sensors, forward- collision warning

systems monitor driving speed, leading objects (usually another vehicle) and the instantaneous head space between a subject vehicle (equipped with FCW) and a lead vehicle. If a collision is imminent, the system gives the driver an audible and/or visual warning that allows them to take action to avoid or prevent the collision [6, 7, 8, 9].

In some vehicles the system may also detect pedestrians.

Forward Collision Auto-braking
With most manufacturers, the brake-assist functions in conjunction with forward collision warning systems. The braking system assists by providing additional brake force or automatically applies the brakes if the system determines that the possibility of a frontal collision is imminent. In most systems the auto-braking is responsive in specified vehicle speed ranges [7, 8, 9, 10, 11].

In addition, some systems activate seatbelt tensioning devises when the auto-braking function is activated

Lane Departure Warning
Cameras placed in position on the front of the vehicle monitor the lane lines on roads. If the vehicle begins to unintentionally depart from its lane the system alerts the driver through audible, visual and/or vibration of the steering wheel to alert the driver of the deviation [7, 8, 9, 12].

Lane Departure Prevention
In combination with Lane Departure Warning, some manufactures include Lane Departure Prevention which applies steering torque in the direction to keep the vehicle within the lane [7, 11].

Adaptive Headlights
Adaptive headlights adjust atomatically to the direction the vehicle is traveling reacting to in some instances the steering input, speed and elevation of the vehicle. Sensors are placed to detect the speed, steering wheel angle and the yaw of the vehicle activating the headlamps to move to illuminate the road ahead [7, 9, 11, 13, 14].

Blind Spot Detection
Radar sensors located in the rear bumper alongside the vehicle detect adjacent vehicles approaching on the side. The system warns the driver by illuminating a warning icon in the side review mirror and in some systems sounding an alert if a lane change is attempted [7, 9,11].

INFLUENCE OF FMVSS ON SAFETY TECHNOLOGY INSERTION

Electronic Stability Control, Rollover Activated Curtains and Back-up Cameras were all introduced into the stream of commerce well before a regulation was promulgated requiring application.

Electronic Stability Control
Federal Motor Vehicle Safety Standard, FMVSS 126 – Electronic Stability Control Systems; Controls and Displays, was promulgated in April 2007 requiring electronic stability control systems (ESC) to be installed on all passenger cars, multipurpose passenger vehicles, truck and buses with a gross vehicle weight rating of 4,536 Kg (10,000 pounds) or less [15]. The ruling describes ESC systems as "automatic braking of individual wheels to assist the drier in maintain control in critical driving situation in which the vehicle is beginning to lose directional stability at the rear wheels (spin out) or direction control at the front wheels (plow out)." (ibid) The regulation required phase-in of the technology on applicable vehicles to meet the requirements of the standard commencing on September 1, 2008 and completing by September 1, 2011. All new light vehicles starting with the 2012 model year were equipped with ESC with exceptions for some vehicles manufactured in stages or by small volume manufacturers. The standard estabilished vehicle dynamic performance requirements that were engineered to require an ESC system and must be met for the vehicle to be compliant.

Figure 3 shows the insertion rate of ESC from model year 1998 through 2015. In model year 2009 vehicles began to be produced so as to meet the FMVSS 126 requirements. Prior to that and up until the 2012 MY, vehicle equipped with ESC met requirements set forth by the individual vehicle manufacturers to meet their own dynamic specifications.

The National Highway Traffic Safety Administration (NHTSA) was able to use crash data studies with vehicles equipped ESC technology prior to the regulation to support the NHTSA's

effectiveness in preventing single-vehicle-loss-of-control crashes.

Rollover Activated Curtains

In January 2011 FMVSS 226 – Ejection Mitigation, was established to address partial and complete ejection of vehicle occupants through vehicle side windows in crashes, particularly rollover crashes [16]. The agency anticipated that enhanced side curtain airbag technology would be inserted in vehicles to meet the requirements of the standard. The standard prescribes a specific evaluation method and acceptance requirements. Phase-in of the regulation began September 1, 2013 with 2014 MY vehicles and will continue through until September 1, 2017 when all 2018 new model vehicles (with some exceptions) will be required to meet the standard.

Enhanced curtain airbags that provide ejection mitigation began to be inserted into the stream of commerce starting in model year 2002, *Figure 4*. Although the technology inserted prior to the release of the safety standard would not have been engineered to satisfy the prescribed performance test and acceptance requirements of the yet to be established FMVSS rule, evaluation of those early emerging systems enabled NHTSA research projects in developing a test procedures and acceptance criteria eventually adopted in the Final Rule.

Back-up Cameras

To reduce the risk of back over crashes involving vulnerable populations (including young children) NHTSA issued a final rule revising FMVSS 111 – Rear Visibility, to expand the required field of view for all passenger cars, trucks, multipurpose passenger vehicles, buses, and low-speed vehicles with a gross vehicle weight of less than 10,000 lbs. [17]. The ruling specifies an area behind the vehicle which must be visible to the driver when the vehicle is placed into reverse as well as other related performance requirements. The technology anticipated to fulfill the standard is a combination of rearview video camera systems with in-vehicle visual display monitors. In accordance with the phase-in required by the standard, vehicle manufactured beginning May 1, 2016 will begin to comply with the rule with all new vehicles manufactured complying by May 1, 2018.

Rear back-up cameras began being inserted into vehicle models beginning in model year 2003 and have continued through 2015, *Figure 5*. The majority of vehicles were optionally equipped with the technology as opposed to a standard feature.

CRASH AVOIDANCE TECHNOLOGY INSERTION

Forward collision warning, forward collision autobrake, lane departure warning, lane departure prevention, adaptive headlights and blind spot detection are fairly new technologies being introduced on new model vehicles. There insertion rates on new model vehicles are show in Figure 6 through Figure 10 with the exception of Adaptive Headlamps which is shown Figure 2.

CONCLUSIONS

ESC had a high market penetration, almost 90% of 2009 MY vehicles, at the time FMVSS 126 phase-in required installation of ESC whereas enhanced curtain airbags with roll sensing had about 50% market penetration on 2014 model year vehicles at the time FMVSS 226 began phase-in. Back-up camera technology did not require phase-in until 2016 model year vehicles and as of 2015 model year, the new car fleet provided back-up camera technology on about 80% of those models. Manufacturers and safety component suppliers are continuously researching and developing new safety technologies well in advance of regulation.

Crash avoidance technologies are being introduced into the market as optional and standard equipment in the same manner as other injury mitigation technologies.

As reported in 2011, emerging safety technologies are applied into the new vehicle fleet in small numbers of models initially, offerings are commonly provided as both optional and as standard equipment, successful technologies increase application proportions over time, and often as emerging technologies can be assessed for safety benefit, the early systems can serve as a basis for effectiveness measures that can be considered in rulemaking to mandate the technology through new FMVSS requirements.

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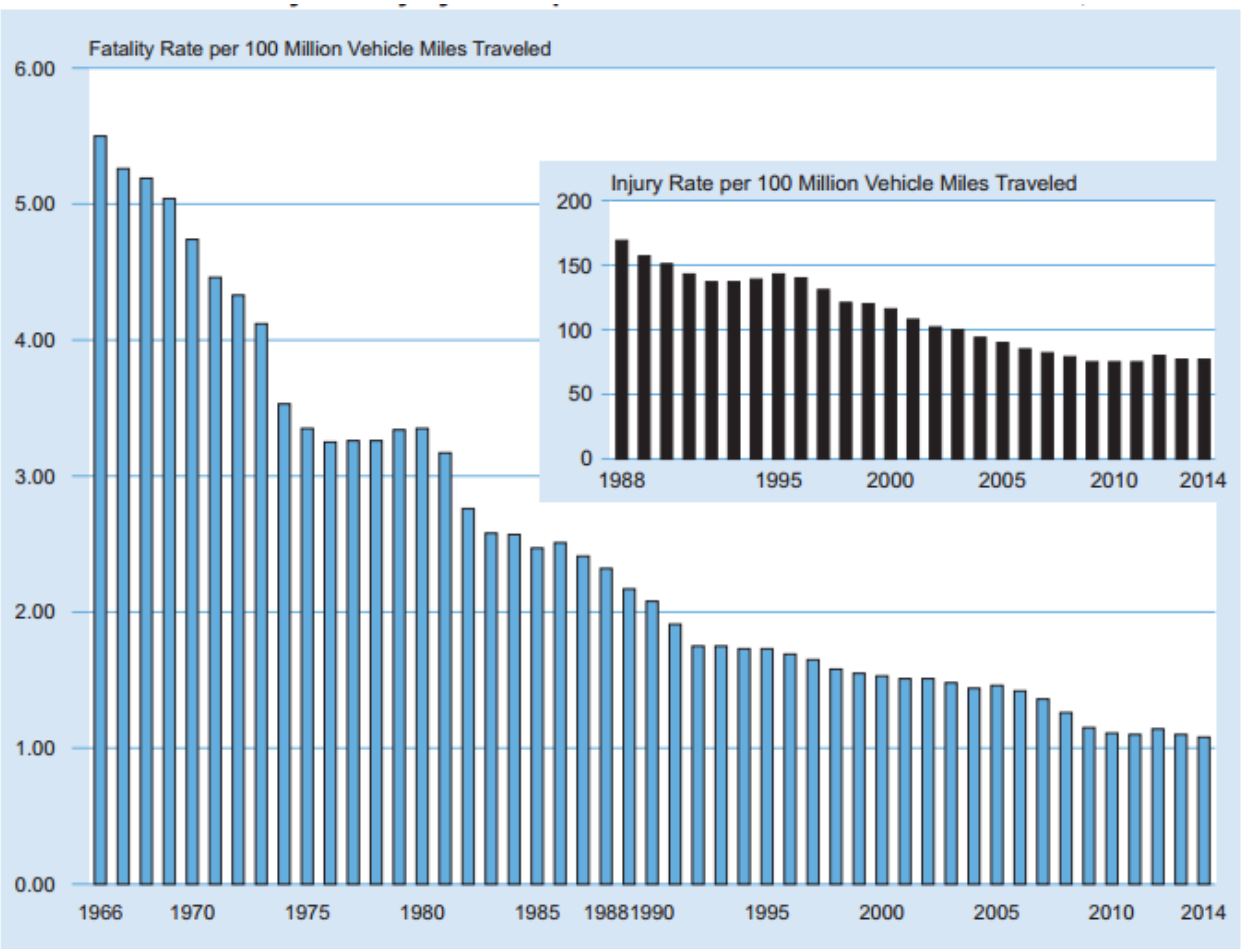

Figure 1. Fatality rate per 100 million vehicle miles traveled

Table 1. Model Availability Table

Model Year 2015

Safety Technology: Adaptive Headlights

									Camaro								
									Spark								
					Transit Connect				Corvette								
					C-Max				Cruze								
					Fiesta				Impala								
					Focus				Malibu								
					Fusion				Sonic		Elantra						
					Mustang				Volt		Sonata						
					Taurus				Avalanche		Santa Fe	Cadenza					
	Avenger				Econoline				Captiva		Accent	K900					
	Challenger				Edge			ATS	Equinox	Acadia	Azera	Optima					
	Charger				Escape			CTS	Express	Savana	Elantra	Sorento					
	Dart				Expedition	MKS	Encore	XTS	Silverado	Sierra	Equus	Forte	LR2		V60		
	Viper	Compass	Promaster		Explorer	MKZ	LaCrosse	Escalade	Silverado HD	Sierra HD	Genesis	Optima	LR4	F-Type	S60		
200 Series	Caravan	Grand Cherokee	Ram Pickup 1500		Flex	MKT	Regal	Escalade ESV	Suburban	Terrain	Veloster	Rio	Range Rover	XF Series	S80		
300 Series	Durango	Patriot	Ram Pickup 2500		F-150	MKX	Verano	Escalade EXT	Tahoe	Yukon	Santa Fe	Soul	nge Rover Evo	XJ Series	XC60		
Town & Country	Journey	Wrangler	Ram Pickup 3500	500	F-Super Duty	Navigator	Enclave	SRX	Traverse	Yukon XL	Tucson	Sportage	nge Rover Sp	XK Series	XC70		
Chrysler	**Dodge**	**Jeep**	**Ram**	**Fiat**	**Ford**	**Lincoln**	**Buick**	**Cadillac**	**Chevrolet**	**GMC**	**Hyundai**	**Kia**	**Land Rover**	**Jaguar**	**Volvo**		
Fiat S.p.A.					**Ford**		**GM**				**Hyundai**		**Tata Motors**				
Italy					**US**						**South Korea**		**India**				
									Avalon								
									Camry								
				Altima					Corolla								
				Leaf					Matrix								
				Maxima					Highlander								
				Sentra					RAV4								
				Versa					RAV4 Electric								
				Armada					Sequoia								
				Frontier					Sienna					GLA-Class			
				NV/NVP					Tacoma			i8		GL-Class			
				NV200					Tundra			i3		M-Class			
				Pathfinder					Venza			X3		C-Class			A3
Accord				Titan					Camry			X5		CL-Class			A4
Civic				Xterra	Q40		Legacy		Corolla	RX		X6		CLS-Class		Beetle	A5
Crosstour		Mazda2		370Z	Q50		Outback		Prius	CT		1-Series		E-Class		Jetta	A6
CR-V	ILX	Mazda3		Cube	Q60		Tribeca		Yaris	ES		3-Series		S-Class	Cayman	Passat	A7
Fit	TL	Mazda6		GT-R	Q70		BRZ	FR-S	4Runner	GS		5-Series		SL-Class	Macan	CC	A8
Insight	MDX	MX-5 Miata		Juke	QX60		Impreza	iQ	FJ Cruiser	IS		6-Series		SLK-Class	911	Eos	TT
Odyssey	RDX	CX-5	Outlander Sport	Murano	QX50		WRX	tC	Highlander	LS	Cooper	7-Series		SLS	Boxster	Golf/GTI	Allroad
Pilot	ZDX	CX-9	Lancer	Quest	QX70		Forester	xB	Land Cruiser	GX	Countryman	Z4		G-Class	Panamera	Tiguan	Q5
Ridgeline	TSX	Mazda5	Outlander	Rogue	QX80		XV Crosstrek	xD	RAV4	LX	Paceman	X1	Fortwo	GLK-Class	Cayenne	Touareg	Q7
Honda	**Acura**	**Mazda**	**Mitsubishi**	**Nissan**	**Infiniti**	**Suzuki**	**Subaru**	**Scion**	**Toyota**	**Lexus**	**Mini**	**BMW**	**SMART**	**Mercedes-Benz**	**Porsche**	**Volkswagen**	**Audi**
Honda		**Mazda**	**Mitsubishi**	**Nissan**		**Suzuki**	**Subaru**		**Toyota**		**BMW**		**Daimler AG**		**Volkswagen AG**		
Japan											**Germany**						

Green=standard Yellow=optional

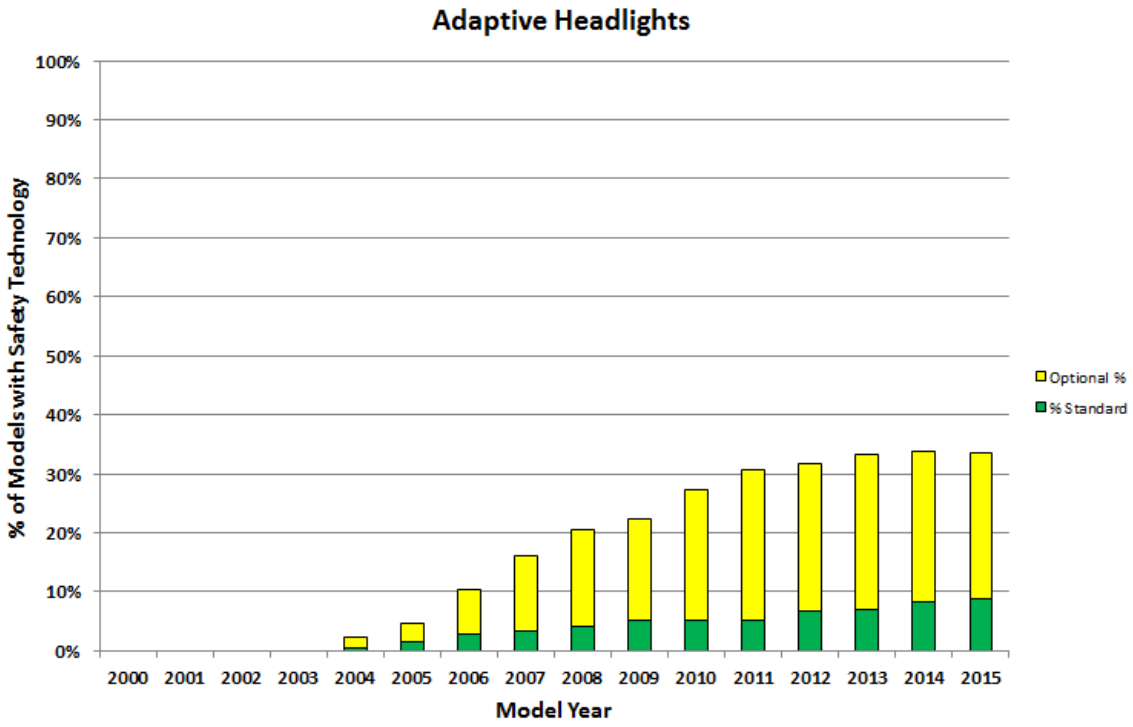

Figure 2. Insertion Bar Chart

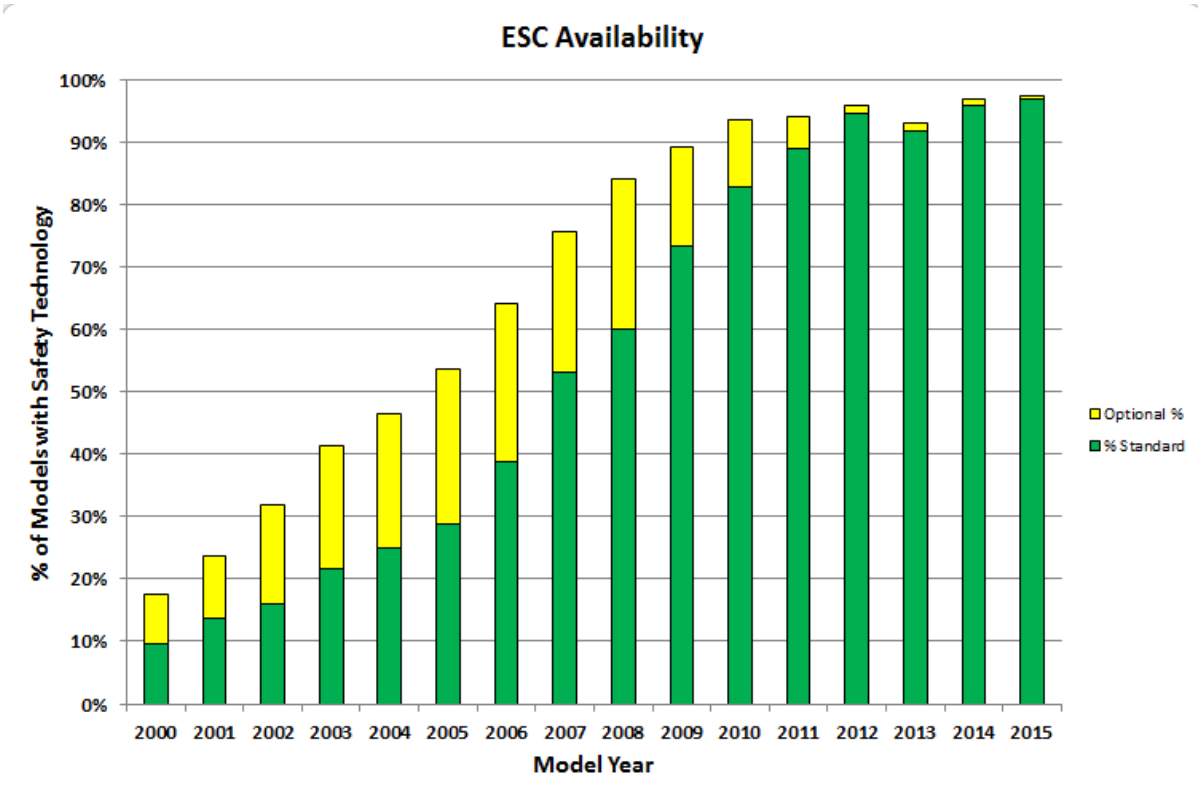

Figure 3. Electronic Stability Control (ESC) Insertion by Model Year

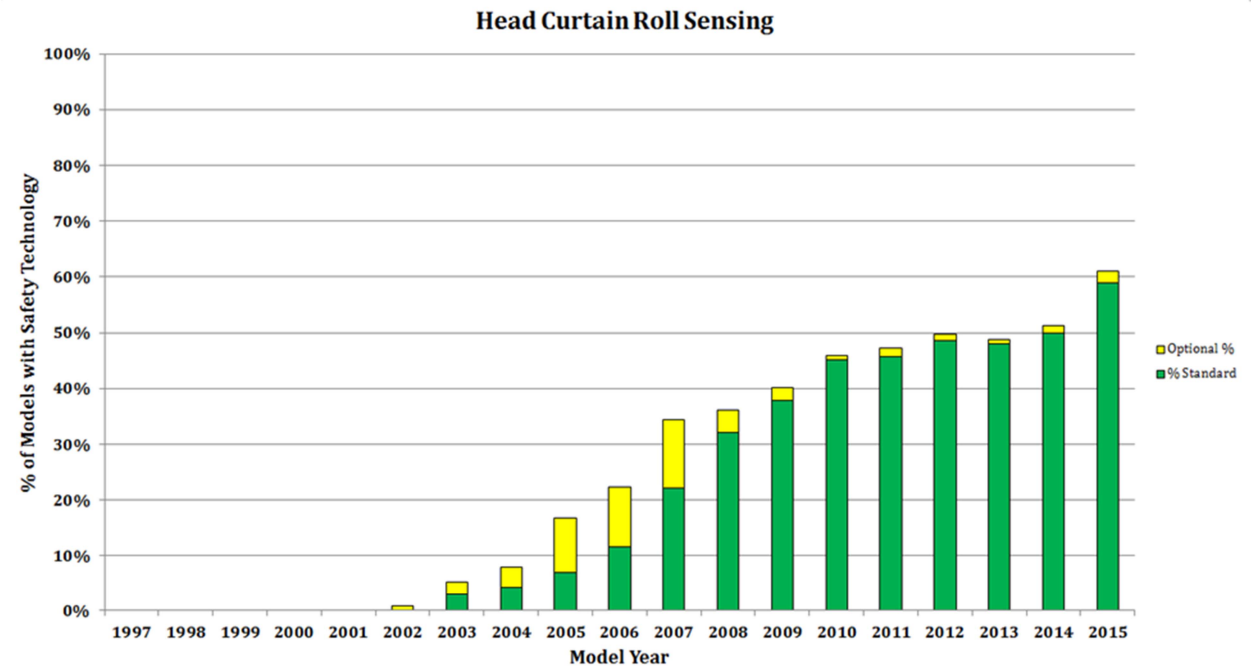

Figure 4. Enhanced Curtain Airbag with Roll Sensing Insertion by Model Year

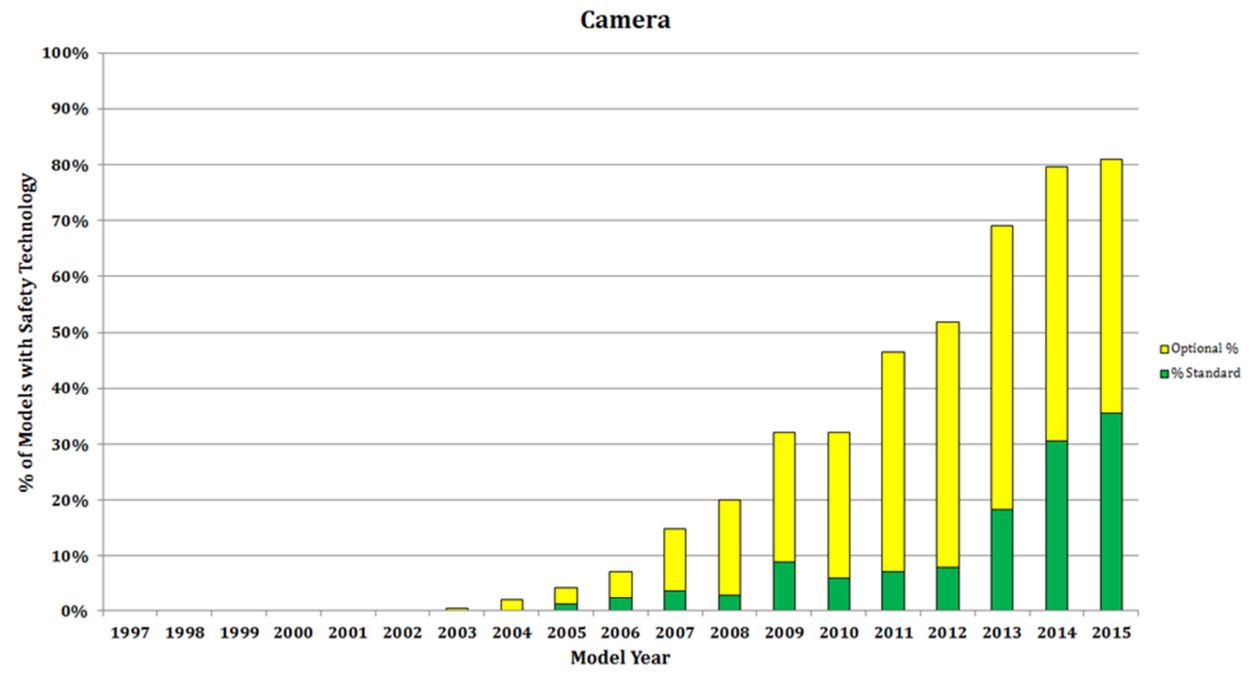

Figure 5. Back-up Camera Technology Insertion by Model Year

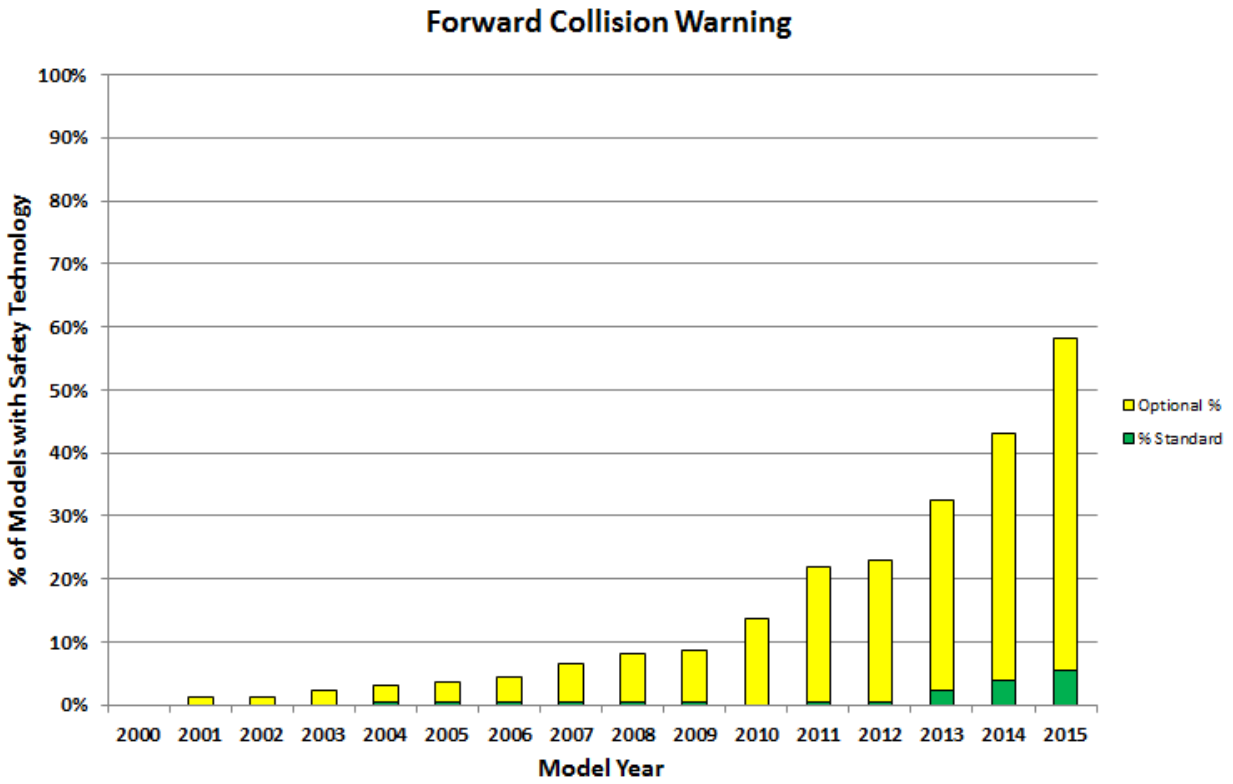

Figure 6. Forward Collision Warning insertion by Model Year

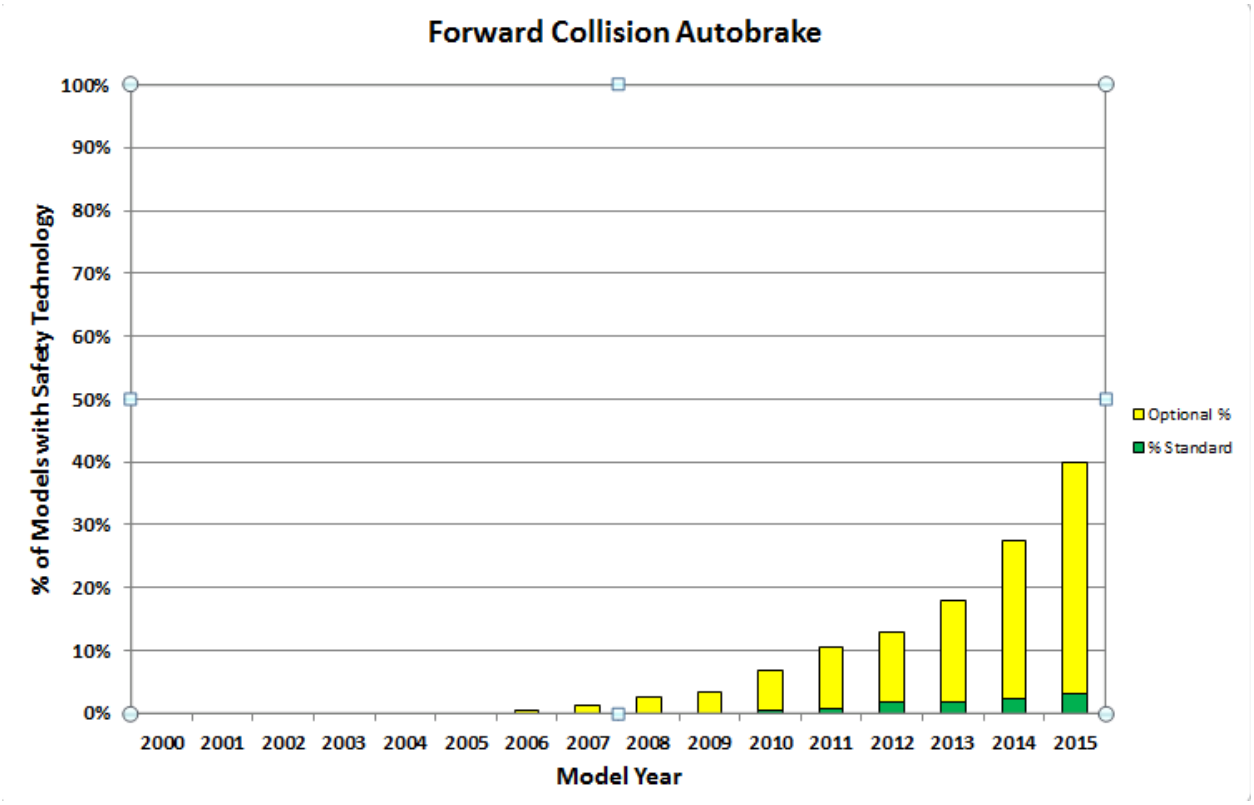

Figure 7. Forward Collision Autobrake insertion by Model Year

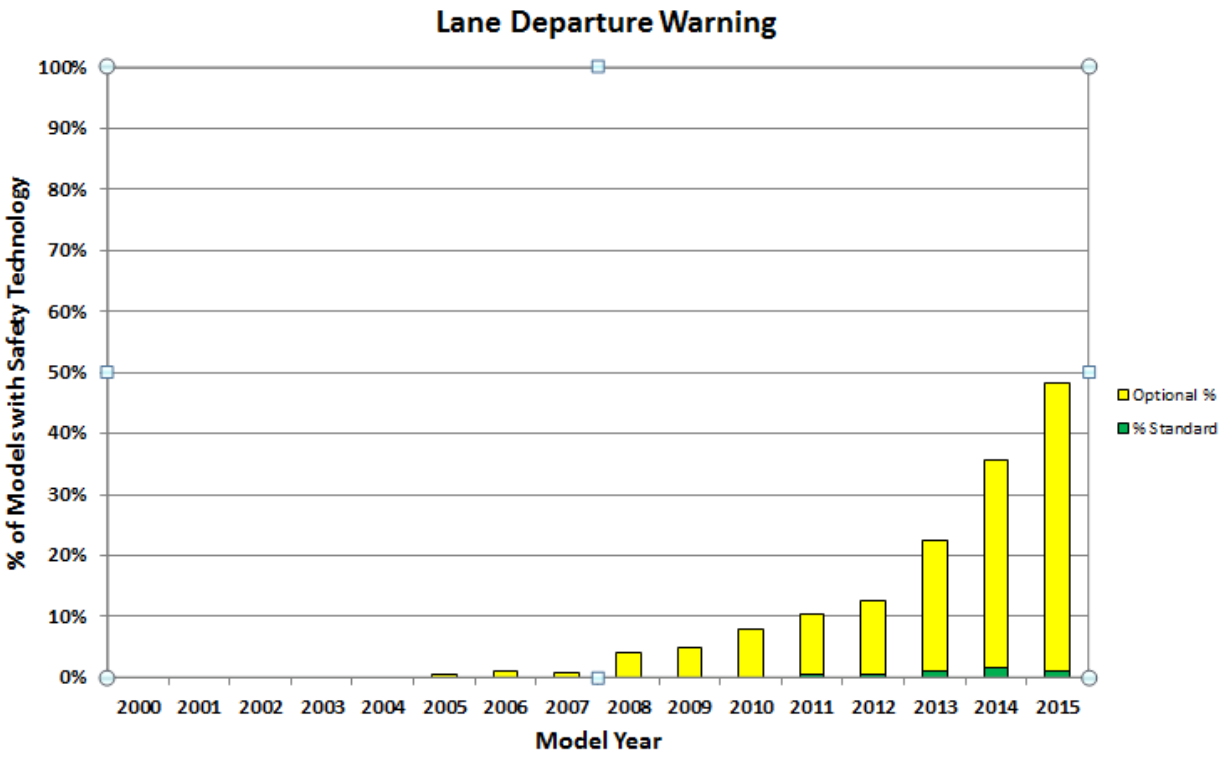

Figure 8. Lane Departure Warning insertion by Model Year

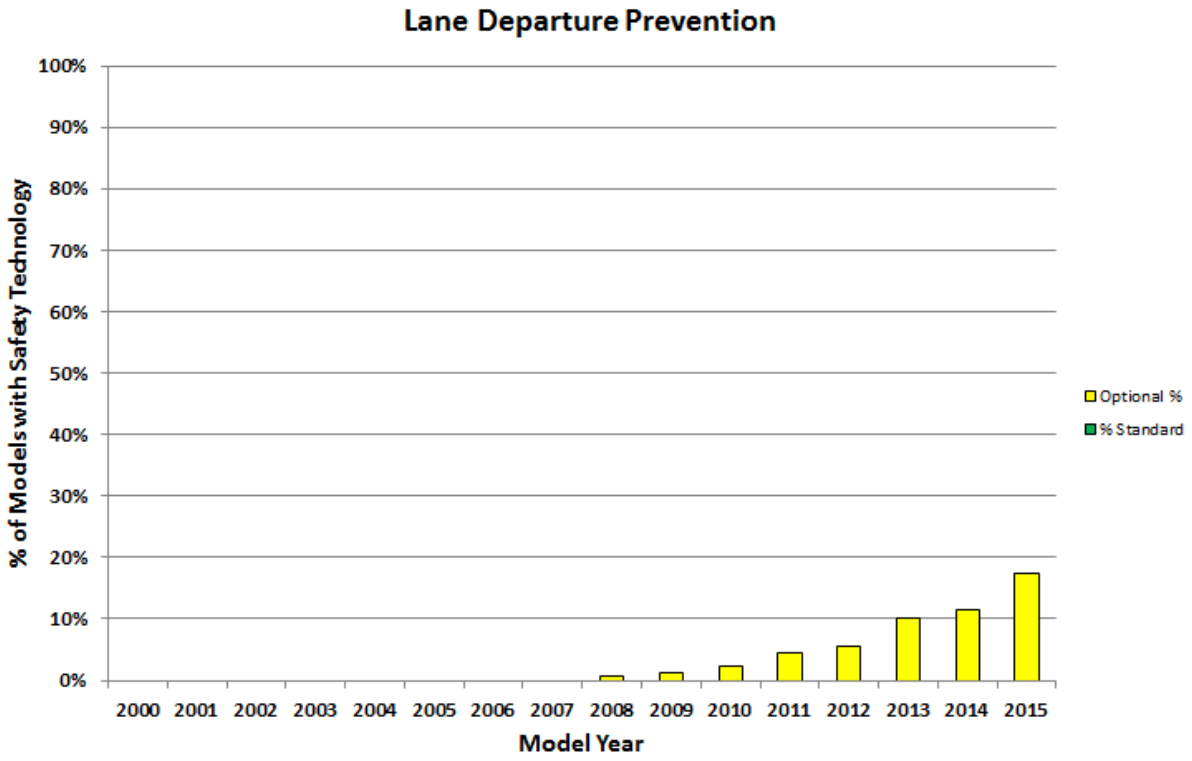

Figure 9. Lane Departure Prevention insertion by Model Year

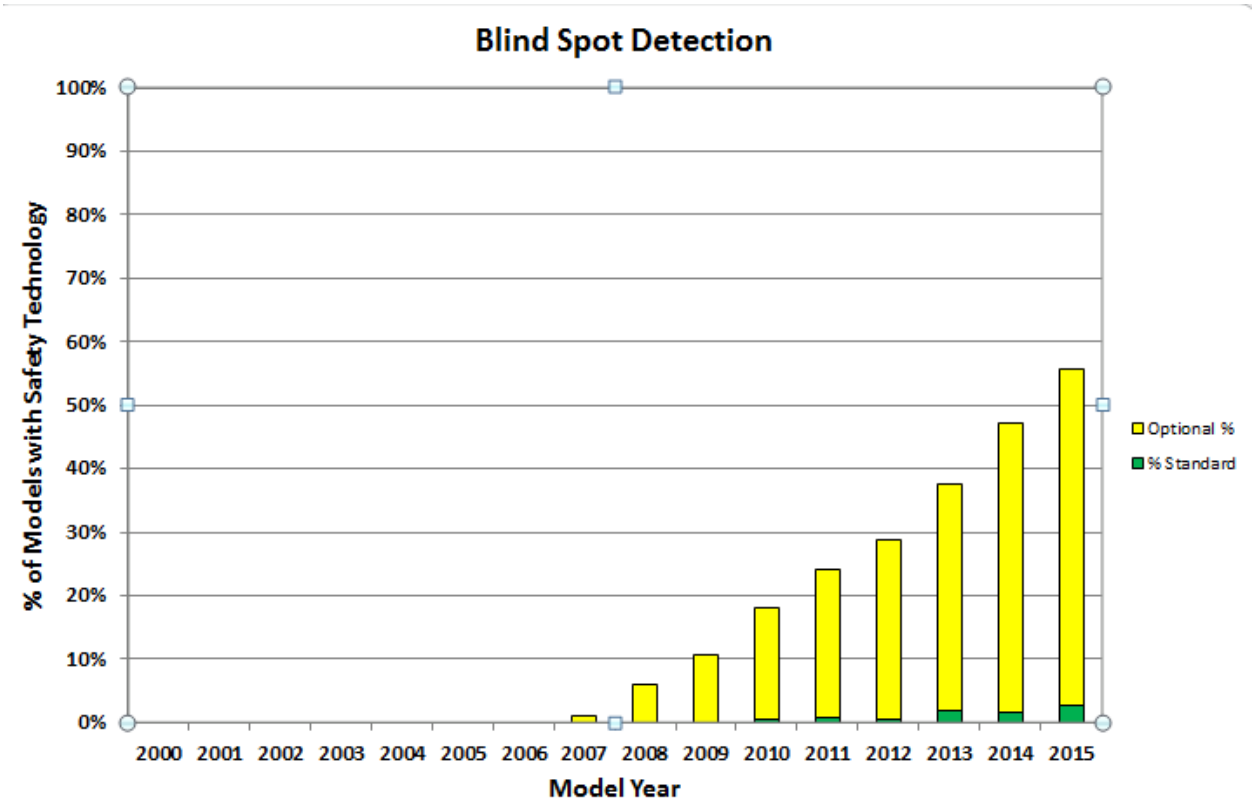

Figure 10. Blind Spot Detection insertion by Model Year