INSTALLATION PATTERNS FOR EMERGING INJURY MITIGATION TECHNOLOGIES, 1998 THROUGH 2010

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Paper Number 11-0088

ABSTRACT

The period 1998 through 2010 has been one of great flux in the development and application of motor vehicle injury mitigation (safety) technologies. Over this period, vehicle manufacturers have implemented: depowered air bags, advanced technology air bags, side impact air bags, automatic occupant classification and air bag suppression, electronic stability control, daytime running lamps, advanced belt restraints, various driver warning and assist devices, automatic collision notification, etc. Most of these technologies have been led by manufacturers' voluntary development and application of emerging technologies. Some technologies have been driven by new rules, and some were permitted by rule changes.

The introduction and application of 28 safety technologies have been compiled in a database created by combining data from NHTSA and Ward's Automotive. A census of technology presence has been tabulated by: technology, model year, manufacturer, make, model, body style, and technology not available or technology presence as standard or optional equipment. The research includes information for specific identifiable technologies but does not include safety technology advances that manufacturers may have applied at an architectural or structure level in vehicle integration over this time period. Data is tabulated for each technology/model year pairing, analyzed as the proportion of vehicle models equipped with the technology, and tracked over time. Thus, researchers can determine which specific models are offered for sale with an emerging technology and the proportion of new models in each model year that are offered with the equipment.

Examination of the resultant data shows: 1) each new safety technology begins with small model penetration proportions, 2) the proportion of new vehicle models offered with an emerging technology grows over time, 3) commonly in about 5 years after first introduction the penetration proportions are substantial, and 4) nearly all newly emerging safety technologies are offered both as optional and standard equipment during the introduction period.

This may be the first study of safety technology insertion patterns; the raw data and tabulated results should prove to be useful to regulators and manufacturers in planning for future safety technologies and scheduling rule driven lead time and phase in periods. The study is limited to models offered for sale in the United States market only. Rollover roof rail air bags are an exception in that throughout most of the introduction period, most applications were as standard equipment only.

MOTOR VEHICLE SAFETY AND PUBLIC HEALTH

The National Traffic and Motor Vehicle Safety Act was adopted in 1966. The law established the National Highway Traffic Safety Bureau, now the National Highway Traffic Safety Administration (NHTSA) to address the need for vehicle safety and required the NHTSA to promulgate motor vehicle rules to protect the public against "unreasonable risk of death or injury" in traffic collisions [1]. Following its Congressional mandate, the NHTSA has implemented a rules based structure that establishes specific requirements for safety performance at a vehicle, system, or component level. Vehicle manufacturers must certify that all products offered for sale satisfy those requirements. In doing so, manufacturers meet the safety need established by the NHTSA.

In many dimensions of safety performance and technology implementation, manufacturers have exceeded the specifications set in applicable rules and have implemented safety improvements not mandated by rule. By allowing motor vehicle manufacturers the flexibility to exceed rule based performance standards and to apply new safety equipment and technologies for which there are no regulations, the NHTSA promotes the advance of motor vehicle safety and progress in the science and application of motor vehicle collision injury control. Most regulatory requirements and safety improvements voluntarily implemented by motor vehicle manufacturers have been developed through the application of a public health model for injury reduction involving the following steps:

1. Collection and analysis of collision injury data to identify opportunities for improvement and prioritize safety needs.
2. Selection of priority safety improvement targets and application of research efforts to invent possible countermeasures.
3. Establishment of a staged research plan encompassing five elements: concept definition, requirements and specifications definition, technology development, feasibility and marketability assessments, and final validation for vehicle integration. Research is used in part to: size the safety improvement opportunity that might be offered by a technology concept and to define the operational parameters that characterize a safety need. In characterizing the operational parameters of a safety need, regulators and researchers can establish test conditions, evaluation criteria, and performance specifications for the technologies that are intended to address that particular safety opportunity.
4. Initiation of rule making, if started in advance of technology implementation schedules, and eventual finalization of rule making.
5. Development of technologies that satisfy established performance requirements and can be balanced with vehicle level imperatives (vehicle mass, package constraints, vehicle level performance metrics, direct material costs, etc.)
6. Creation of the supply chain necessary for materials, components, and systems that can be inserted into the Vehicle Development Process (VDP) and eventually support production applications.
7. Planning and execution of vehicle programs structured to integrate the newly developed safety technologies into the VDP and to provide a balanced vehicle with the new technology into the stream of commerce.
8. Once sufficient time has passed from implementation to collect a significant sample size, the countermeasure can be evaluated by collection and assessment of collision injury data and the process can begin again in identifying the next candidate opportunities and priorities.

It is not possible to establish test conditions, evaluation criteria, and performance specifications for every condition that might occur in real world traffic collisions. Therefore, regulators and safety researchers use collision data to characterize a particular safety need and then select specific test conditions, criteria, and performance specifications to control vehicle responses to that particular safety challenge. Test conditions, criteria, and performance specifications are set at the outer bounds of real world collision types to ensure that the applied technological solutions will be robust to many different real world collision conditions that are not specifically tested and evaluated in laboratory settings and comprehended in manufacturers' VDP for validation or certification. In this way, tests and acceptance criteria are established that apply to a broad range of collisions and affect a safety improvement for many more collision types than are replicated in the particular test itself.

This public health improvement process has been successfully applied in the U.S. over several decades. We can measure and judge the success of this injury reduction model by review of fatal injury rates over time. Figure 1 shows that the motor vehicle collision fatality rate has declined about 80 % over the period 1966 to 2009 [2].

Safety improvements have been realized due in part to improvements in: driver and occupant behaviors (seat belt use, child restraint use, and reduced drunk driving); roadway designs (highway design, roadway signage, traffic controls, roundabouts, overhead lighting, etc.); legislative and law enforcement initiatives (restraint laws, anti-drunk driving laws); public education efforts (National Safety Council, Safe Kids, the Airbag and Seat Belt Safety Campaign (ABSBSC), "Click it or Ticket," NHTSA and State programs); post collision treatment and care (emergency response times, comprehensive treatment at Level 1 trauma centers, automatic collision notification); and broad implementation of motor vehicle safety technologies (seat belts, structural collision performance criteria, fuel system integrity, supplemental restraints, electronic stability control, etc.). This paper reviews and compiles data regarding the patterns of safety technology insertion over the period 1998 through 2009.

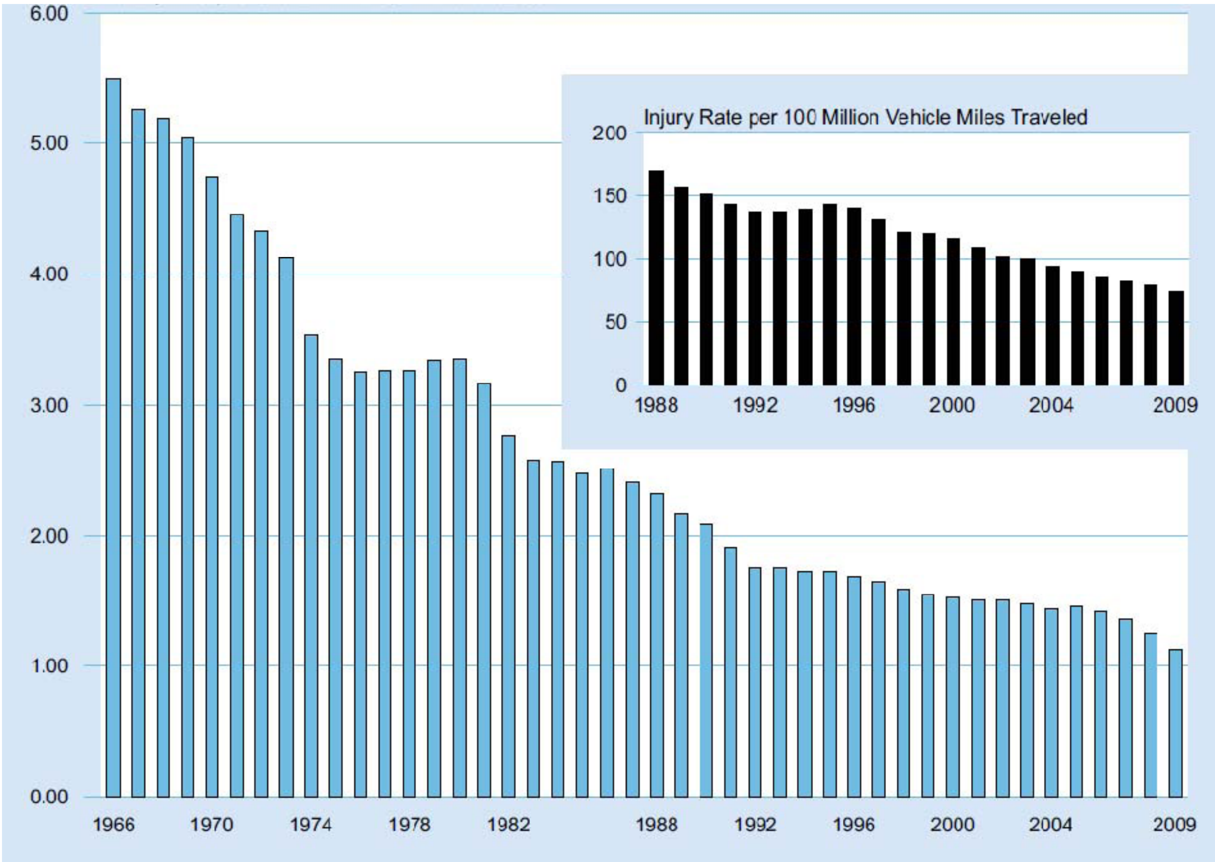

Figure 1. Fatality rate per 100 million vehicle miles traveled [2].

METHODOLOGY & DATA FORMAT

The goal in data collection was to compile a comprehensive and detailed list of safety technologies for all vehicles sold in the U.S. market. NHTSA's New Car Assessment Program (NCAP) database was identified as the best foundation on which to build. The NCAP database compiles data on about 28 different safety features for the vehicles tested each year in the program. Important information, though, is missing from this database. Since only a portion of all available models and body styles are tested, there was not a comprehensive list of all models and body styles available. There was no information on pricing, fuel economy, dimensions, weights, powertrains, or trim levels. Information was purchased from Ward's Automotive to supply this additional information. A time consuming, manual process was then undertaken to make the nomenclature for model and body style common between the two sets of data. The two sets of data were then combined in an Access database in a format capable of complex manipulation and future data update. The resulting database contains about 1.7 million cells of data.

One application of the database is to create a model year table of technology availability as shown in the table of side air bag availability shown in Table 1. All models offered in each model year in the survey are shown in the table and organized by brand and manufacturer. The model cells are filled in white if the technology was not available. They are filled in yellow if the technology is optional on any trim level. They are filled in green if the technology is standard equipment on all trim levels. For this table one specific body style was chosen for each model due to the limitation on the size of graphics. But data has been collected down one more level to body style as there are often important differences in technology applications between different body styles of the same model. One example is the technology of all belts to seats (ABTS). While sedans often do not employ this technology since belts can be anchored more efficiently to the B-pillar, coupes to some degree and convertibles in almost all cases do not have a B-pillar and are thus more likely to employ ABTS. Thus resolution down to body style is important.

Table 1.
2000 side air bag availability model table

Model Year 2000

Safety Technology: SAB Availability

									Camaro								
									Cavalier								
									Corvette								
									Impala								
Contour									Lumina								
Crown Victoria									Malibu								
Escort									Metro								
Escort ZX2									Monte								
Focus									Prizm								
Mustang									Astro								
Taurus									Express	Envoy							
Econoline									Blazer	Jimmy							
Excursion									S10	Safari							
Expedition	626	Cougar							Silverado	Savana		Bonneville					
Explorer	Miata	Mystique						Catera	C/K	Sierra		Firebird					
F-Series	Millenia	Grand	Continental	C70			Century	DeVille	Suburba	Sierra Classic	Alero	Grand Am		LS/LW		Accent	
F-Super-Duty	Protégé	Sable	LS	S70/V70		XJ-	LeSabre	Eldorado	Tahoe	Sonoma	Bravada	Grand Prix		SL/SW	Lanos	Elantra	Sephia
Ranger	B-Series	Mountaineer	Navigator	S80	Discovery	XK-	Park	Escalade	Tracker	Yukon	Intrigue	Montana	9-3	SC	Leganza	Sonata	Spectra
Windstar	MPV	Villager	Town Car	S40/V40	Range Rover	S-Type	Regal	Seville	Venture	Yukon XL	Silhouette	Sunfire	9-5	EV1	Nubira	Tiburon	Sportag
Ford	**Mazda**	**Mercury**	**Lincoln**	**Volvo**	**Land Rover**	**Jaguar**	**Buick**	**Cadillac**	**Chevrolet**	**GMC**	**Oldsmobile**	**Pontiac**	**Saab**	**Saturn**	**Daewoo**	**Hyundai**	**Kia**
Ford							GM								Daewoo	Hyundai	
US															South Korea		

							Avalon											
							Camry											
							Camry					Avenger						
							Celica					Intrepid						
Accord							Corolla					Neon			C-Class			
Civic			Altima				Echo					Stratus			CLK			
CR-V			Frontier				4Runner	ES300		Cirrus		Viper		Diamante	CL		Beetle	
Insight		Amigo	Maxima				Land	GS	3-Series	Concorde		Caravan		Eclipse	E-Class		Cabrio	
Odyssey	Integra	Hombre	Pathfinder	G20	Esteem	Forester	RAV4	SC	5-Series	300M	Breeze	Dakota		Galant	S-Class		EuroVan	A4
Passport	NSX	Rodeo	Quest	I30	Grand Vitara	Impreza	Sienna	LS400	7-Series	LHS	Neon	Durango	Cheroke	Mirage	SL		Golf/Gti	A6
Prelude	3.5RL	Trooper	Sentra	QX4	Swift	Legacy	Tacoma	RX300	X5	Sebring	Prowler	Ram Pickup	Grand	Montero	SLK	911	Jetta	A8
S2000	3.2TL	VehiCross	Xterra	Q45	Vitara	Outback	Tundra	LX470	Z3	Town & Country	Voyager	Ram Van &	Wrangler	Montero	M-Class	Boxster	Passat	TT
Honda	**Acura**	**Isuzu**	**Nissan**	**Infiniti**	**Suzuki**	**Subaru**	**Toyota**	**Lexus**	**BMW**	**Chrysler**	**Plymouth**	**Dodge**	**Jeep**	**Mitsubishi**	**Mercedes**	**Porsche**	**VW**	**Audi**
Honda		Isuzu	Nissan		Suzuki	Subaru	Toyota		BMW	Daimler AG						Porsche	VW	
Japan									Germany									

Green=Standard	Yellow=Optional

Another application of the database is to create a bar chart showing the insertion of the technology into the vehicle fleet over time. Figure 2 shows the insertion history for head curtain air bags. For each model year the optional and standard percentages of unique vehicle model body styles employing the technology are displayed.

The data collected is deep in detail. For example, side protection air bags are not simply listed as unavailable, optional, or standard. The detail specifying the availability, type of bag (torso, combo, or head curtain), seating position coverage, and source of deployment (seat, door or roof rail) add up to 110 unique identifying codes.

TECHNOLOGIES SURVEYED

The 28 technologies for which the database collected information are shown in Table 2.

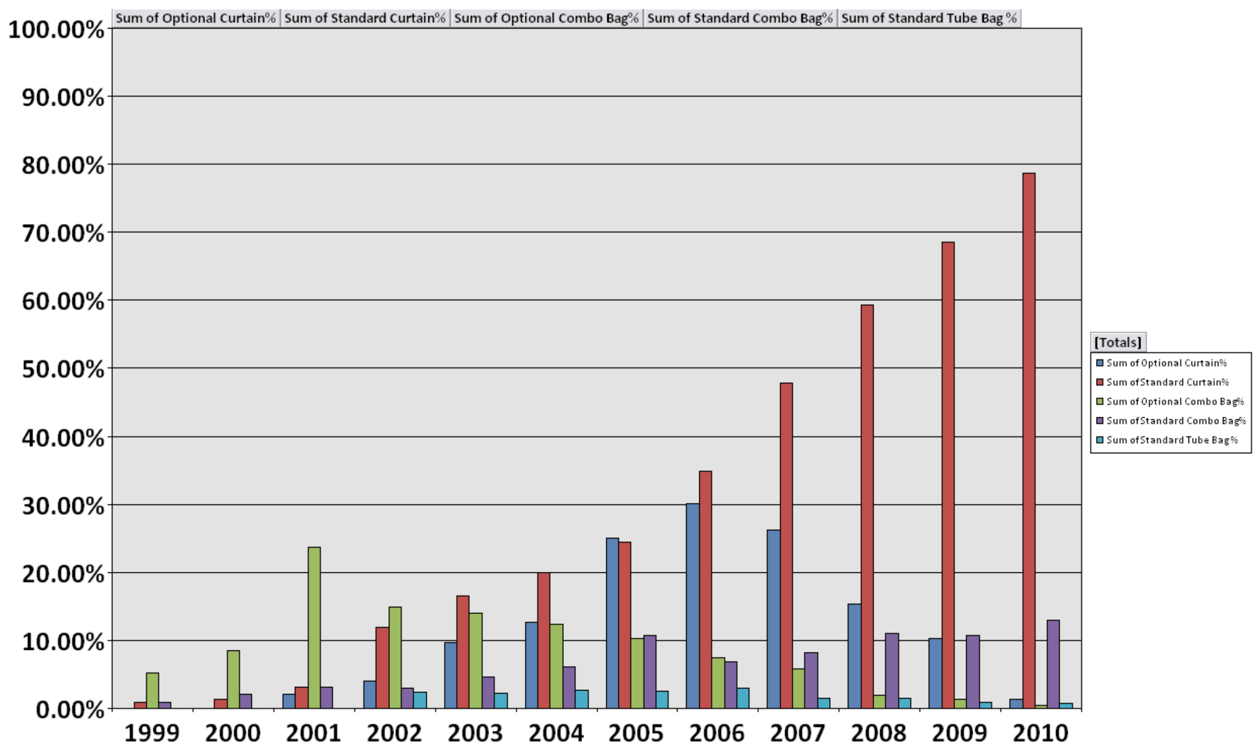

Figure 2. Head curtain, combo, and tube air bag availability.

Table 2.
Safety technologies compiled in database

ABS – 4 wheel	Collision warning frontal	Safety power windows
ABS – rear wheels	Collision warning rear	Seat belt energy management
Airbag – advanced features	Crash data recorder	Seat belt pretensioners
Airbag on/off switch	Daytime running lights	Side air bag
Auto crash notification	Dynamic head restraints	Stability control
Auto dim mirrors	Head curtain air bag	Tire pressure monitoring
Automatic door locks	Head curtain air bag rollover detection	Traction control
Brake assist	Lane departure warning	Trunk release
Built in child seat	Rear center lap-shoulder belt	
Camera	Rear seat head restraints	

INSERTION PATTERNS

In general, new safety technologies developed for insertion into the new vehicle fleet during the period 1998 through 2009 were phased in over lengthy periods of time, often extending throughout the entire decade. None of the new emerging safety technologies surveyed were adopted and inserted ubiquitously throughout the fleet in a single model year. Insertion patterns reflect a deliberate pace dictated by the constraint conditions identified above. Safety technologies of unknown efficacy and unknown potential adverse effects can be feathered into the vehicle fleet with limited early applications; thereby giving manufacturers opportunities to assess safety efficacy and to resolve questions over unanticipated adverse effects.

The insertion of new safety technologies is not unconstrained. The research and development processes must advance the state of knowledge regarding injury control science sufficiently to justify resource expenditures in research and development. Research must establish test procedures reasonably reflective of real world collision conditions and acceptance criteria related to safety improvements and achievable with engineered solutions that can be manufactured and integrated into production vehicles. Technology countermeasures must be engineered to be compatible with vehicle architectures and technologies or those incompatible architectures must be modified to accommodate new safety technologies. Technology and vehicle development processes must be configured to comprehend human, capital, and test capacity resource limitations. Unknowns regarding the effectiveness of new technologies often limit manufacturers' ability to adopt the technologies as benefits are difficult to define and promote. The pace of new safety technology insertion is dependent upon consumer acceptance and affordability, concerns regarding unanticipated consequences of the new technology and successful experiences in early applications to resolve those concerns. Regulatory activity can influence or inhibit the pace of technology insertion contingent upon the uncertainties regarding test requirements, acceptance criteria, reliability and repeatability of test procedures, and technology readiness to perform at a regulated level.

Consumer reactions and acceptance of new safety technologies cannot be accurately assessed until some models are introduced with new technologies; thereby motor vehicle manufacturers and the supply base can appropriately ramp up production capacities and capabilities to accommodate the additional demands imposed by new technology requirements. Phased in introduction facilitates movement downward on the cost curve with successive iterations of manufacturing and design efficiencies; instantaneous uniform introduction of a new technology would impose and institutionalize initial high cost levels upon the entire new vehicle fleet and supply base; efficiencies would be delayed for second and third round resource allocations rather than can be realized with successive generations of improved designs and efficiencies generated by rapid application of cyclic learnings.
For these and other reasons, many manufacturers and models adopt new safety technologies on an optional basis initially, and contingent upon market acceptance and competitive considerations, the optional technologies may migrate to standard equipment.

Figures 3 through 10 show the insertion patterns for eight of the safety technologies. Some technologies are collision avoidance technologies: Antilock Braking System (ABS), Electronic Stability Control (ESC), Tire Pressure Monitor Systems (TPMS), Daytime Running Lights (DRLs), and backup cameras that help prevent low speed collisions with near objects in reverse. Others are crashworthiness technologies: side air bags, head curtain air bags (Figure 2), and seat belt pretensioners. Finally, automatic collision notification improves emergency medical service response to a collision.

CONCLUSIONS AND OBSERVATIONS

Some injury mitigation technologies started in application prior to the first year of registration in the database we have constructed, for example ABS.

Injury mitigation technologies of the same character may vary substantially in specific execution; see for example the type variations for side impact air bags.

Installation of injury mitigation technologies often is initiated by individual manufacturers in advance of rule making. Successful safety technologies grow in application over time.

Injury mitigation technologies are often introduced into the stream of commerce as optional equipment and as standard equipment. The only observed exception registered in this survey is the installation pattern for front seat safety belt pretensioners.

REFERENCES

[1] Laws of the 89th Congress 2nd Session. "National Traffic and Motor Vehicle Safety Act of 1966. 1966.

[2] NHTSA. "Traffic Safety Facts 2009. 2009.

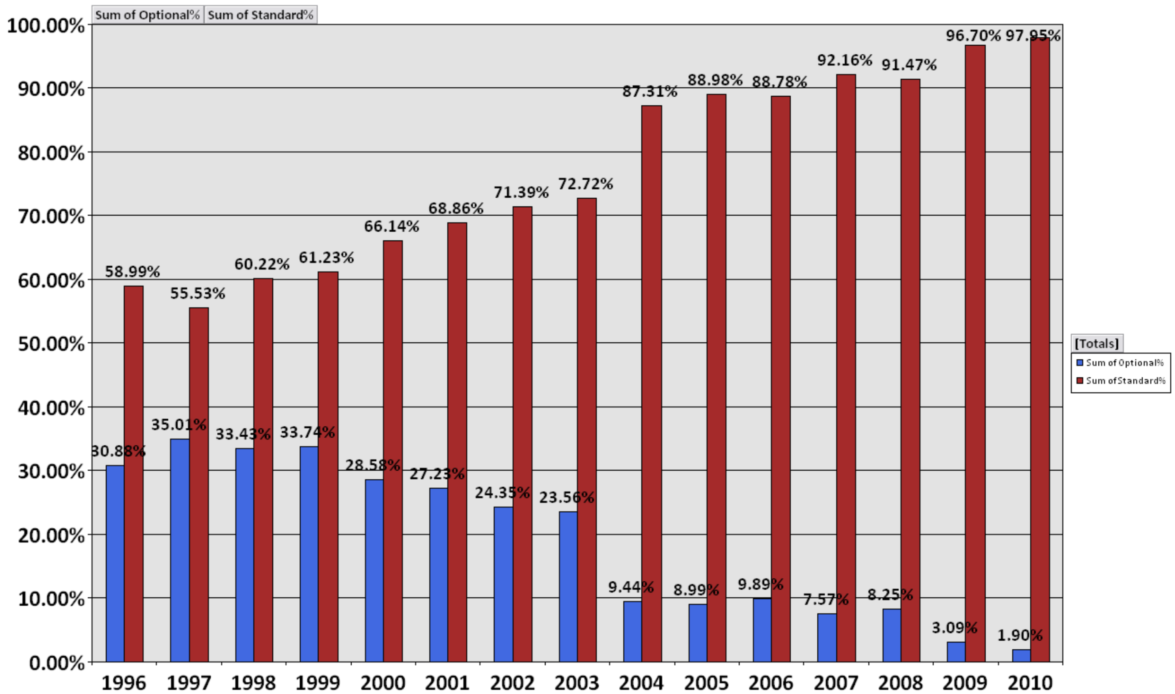

Figure 3. ABS technology insertion by model year.

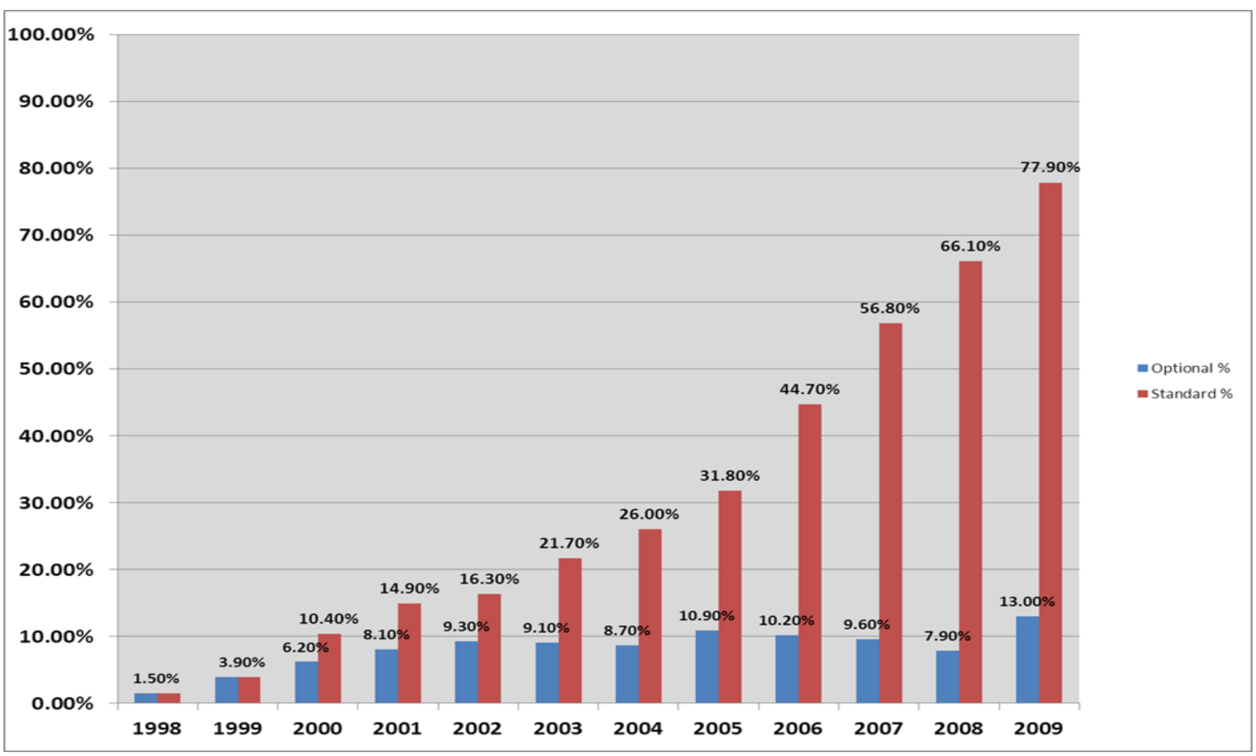

Figure 4. Electronic stability control technology insertion by model year.

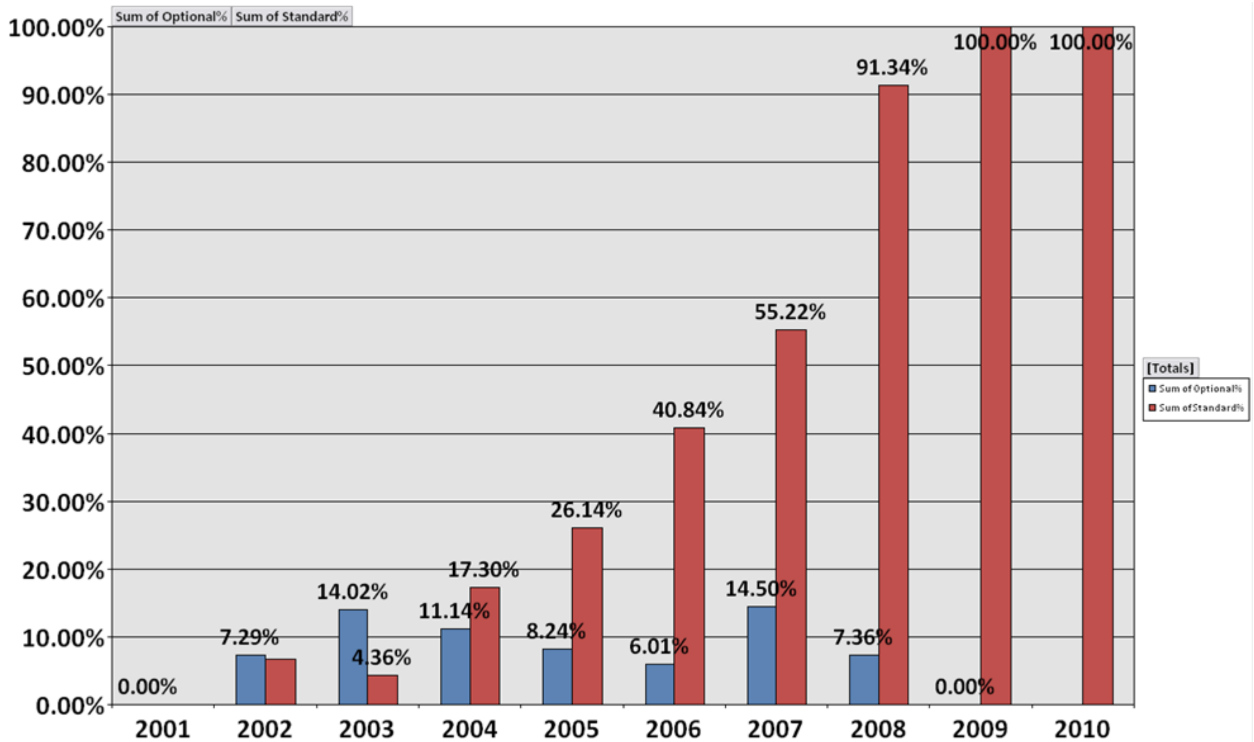

Figure 5. Tire pressure monitoring technology insertion by model year.

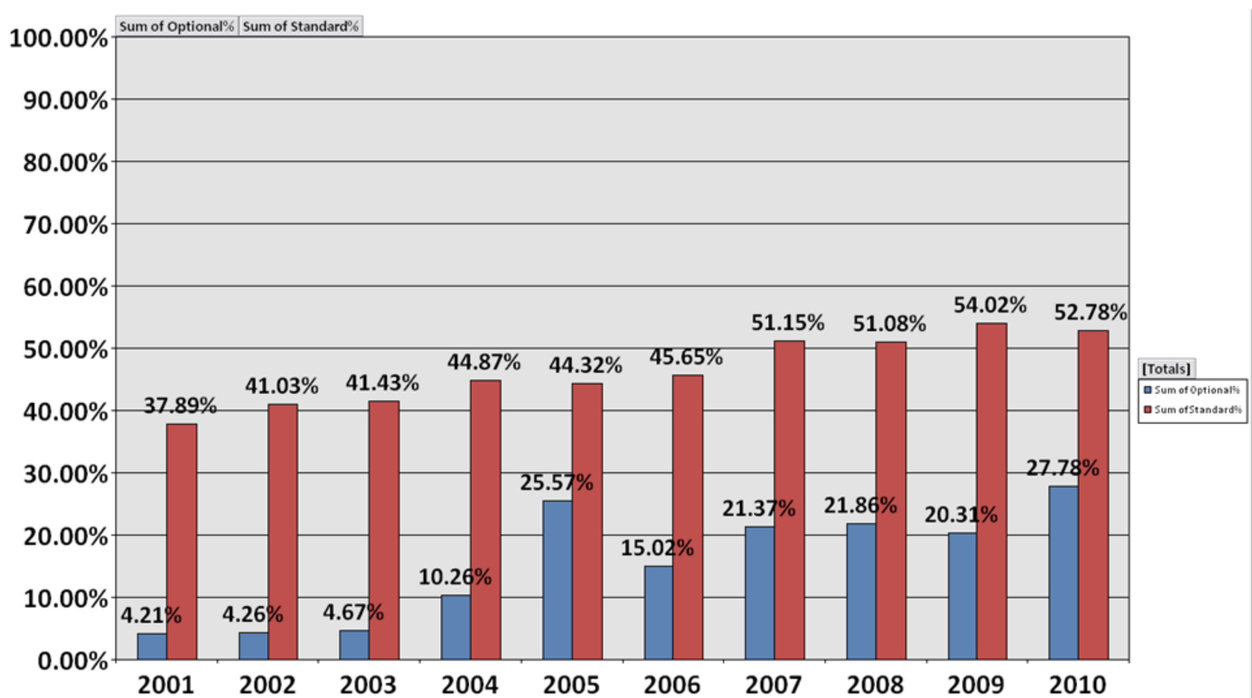

Figure 6. Daytime running lights technology insertion by model year.

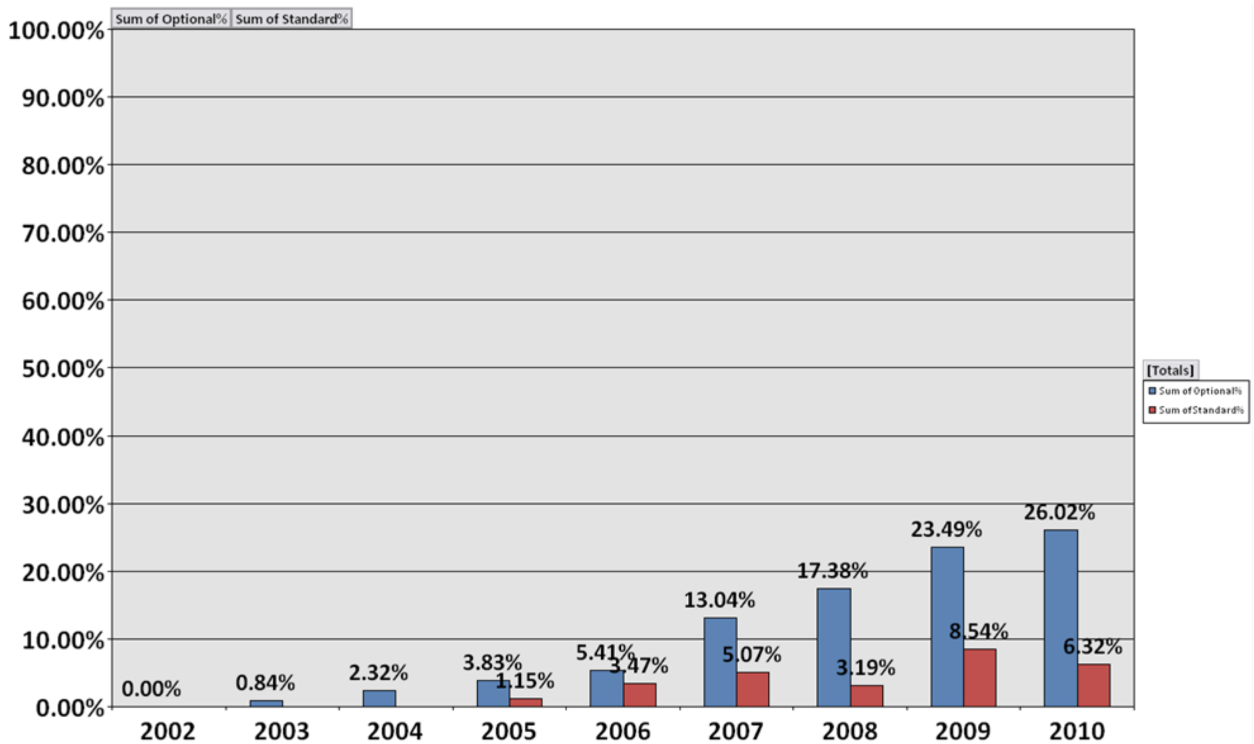

Figure 7. Backup camera technology insertion by model year.

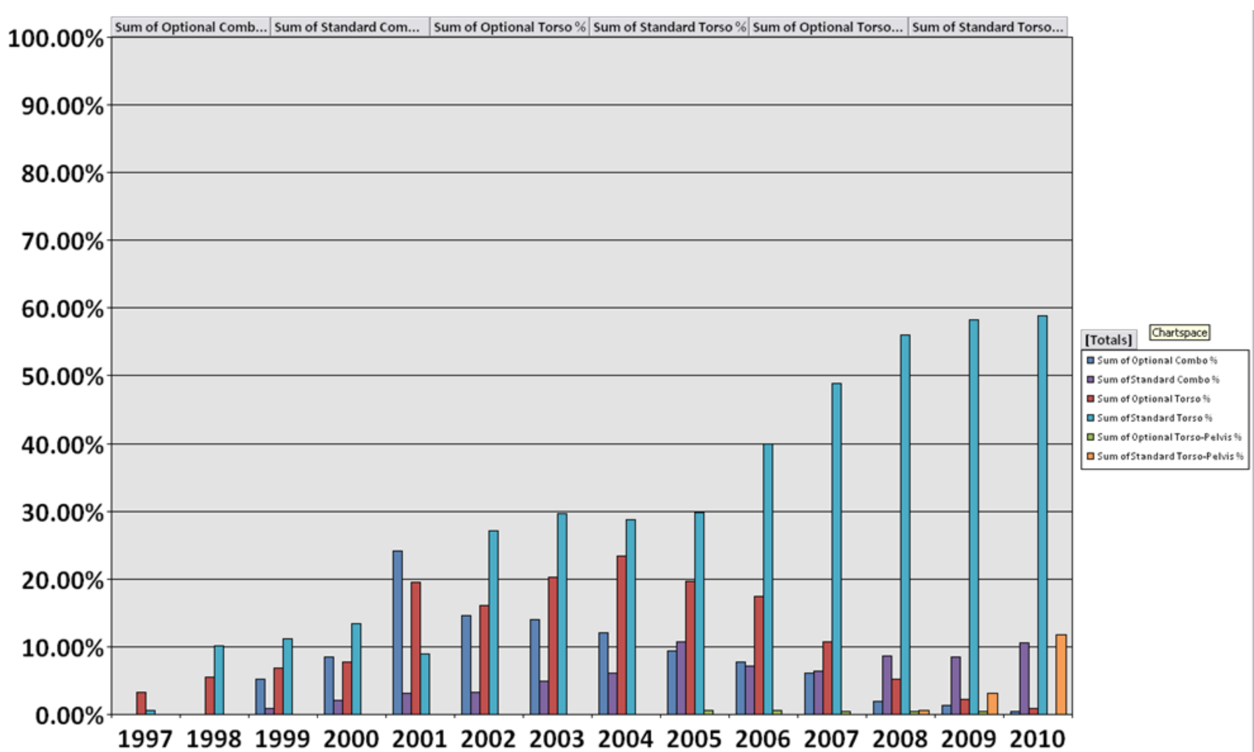

Figure 8. Side air bag technology insertion by model year.

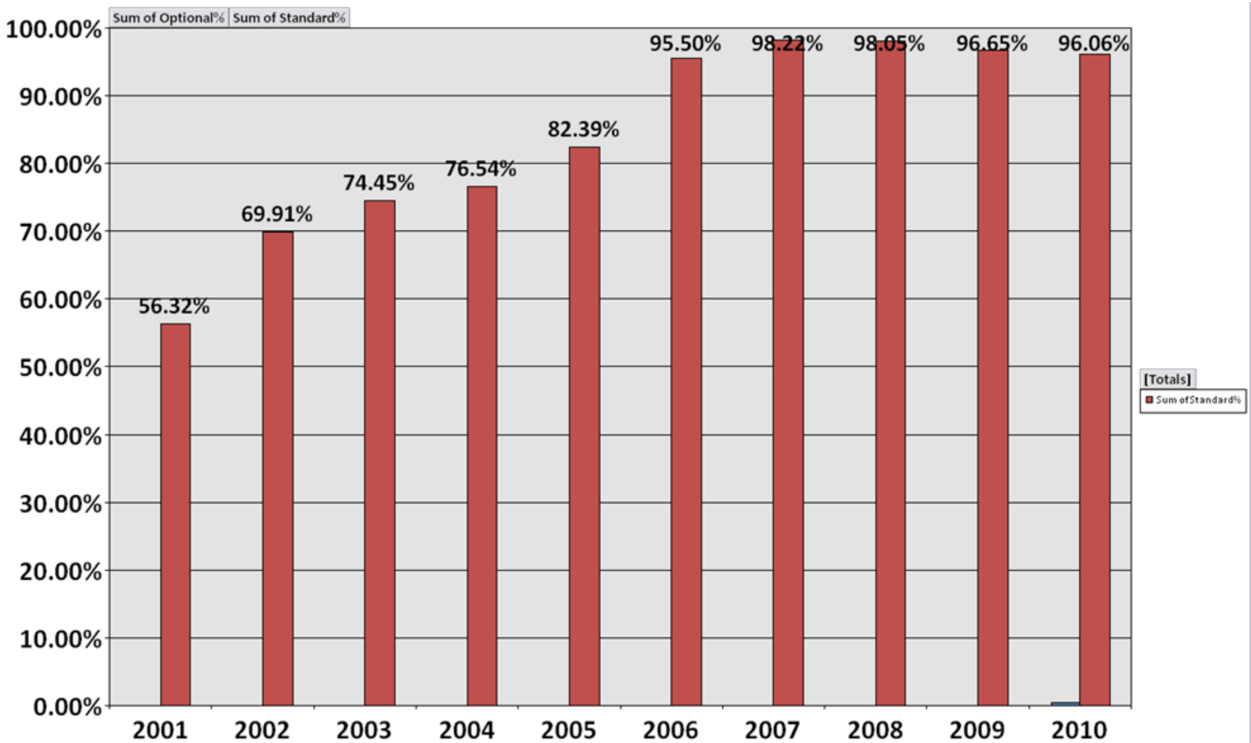

Figure 9. Seat belt pretentioner technology insertion by model year.

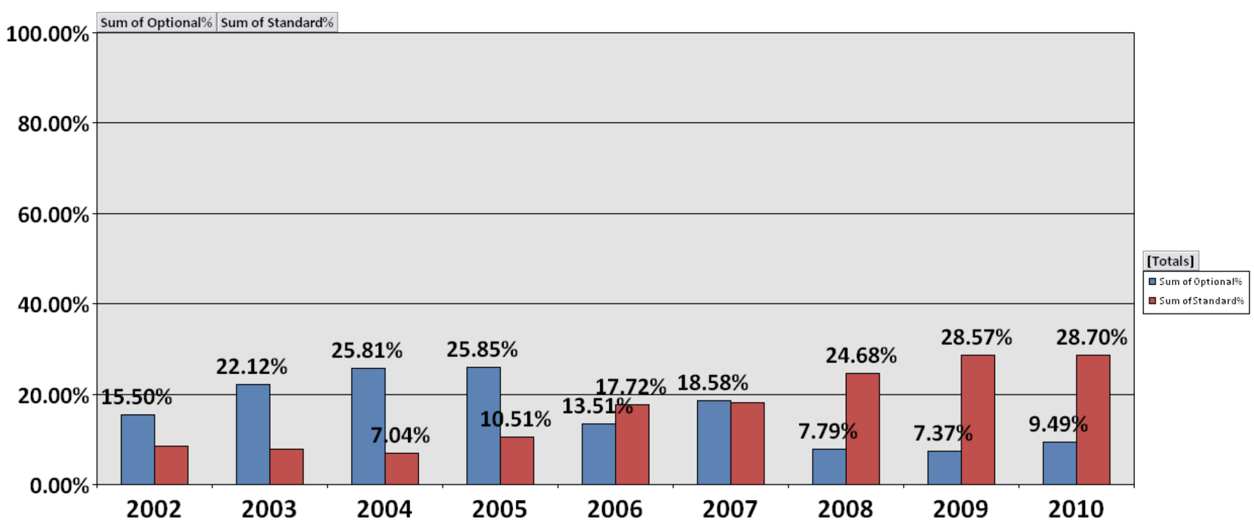

Figure 10. Auto crash notification technology insertion by model year.