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Fatalities in Frontal Crashes Despite Seat Belts and Air Bags

Review of All CDS Cases
Model and Calendar Years 2000-2007
122 Fatalities

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16. Abstract

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LIST OF ABBREVIATIONS

ATD	Anthropomorphic test device (dummy)
BES	Barrier-equivalent speed
BAC	Blood alcohol concentration, measured in grams per deciliter (g/dL)
BMI	Body-mass index
BMW	Bayerische Motoren Werke
CAC	Certified advanced compliant air bag
CDC	Collision Deformation Classification
CDS	Crashworthiness Data System, a part of NASS, a probability sample of police-reported crashes in the United States since 1979, investigated in detail
CFR	Code of Federal Regulations
DOT	United States Department of Transportation
EDR	Event data recorder, devices that record the belt use, ΔV and status of air bags of vehicles involved in crashes
ER	Emergency room
FARS	Fatality Analysis Reporting System, a census of fatal crashes in the United States since 1975
FMVSS	Federal Motor Vehicle Safety Standard
GAD1	Primary general area of damage
IIHS	Insurance Institute for Highway Safety
IP	Instrument panel
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
km/h	Kilometers per hour
LATCH	Lower anchors and tethers for children
LTV	Light trucks and vans, includes pickup trucks, SUVs, minivans, and full-size vans
mph	Miles per hour

MY	Model year
NASS	National Automotive Sampling System, consists of two NHTSA databases, CDS and the General Estimates System
NCAP	New Car Assessment Program, consumer information supplied by NHTSA on the safety of new cars and LTVs, based on test results, since 1979
NHTSA	National Highway Traffic Safety Administration
PDOF	Principal direction of force
RF	Right-front (passenger)
SAS	Statistical and database management software produced by SAS Institute, Inc.
SCI	Special Crash Investigations (by NHTSA)
SUV	Sport utility vehicle
VIN	Vehicle Identification Number
VMT	Vehicle miles of travel
VW	Volkswagen
WinSMASH	Windows Simulation of Motor Accident Speeds on the Highway

EXECUTIVE SUMMARY

Why are people still dying in frontal crashes despite seat belt use, air bags, and the crashworthy structures of late-model vehicles? Statistical analyses show the combination of seat belt use and air bags is highly effective, reducing fatality risk by 61 percent compared to an unbelted occupant of a vehicle not equipped with air bags – but 61 percent is not 100 percent. To address the question, an interdisciplinary NHTSA team reviewed every case of a frontal fatality to a belted driver or right-front passenger in a model year 2000 or newer vehicle in the Crashworthiness Data System of the National Automotive Sampling System through calendar year 2007. Aside from a substantial proportion of these 122 crashes that are just exceedingly severe, the main reason people are still dying is because so many crashes involve poor structural engagement between the vehicle and its collision partner: corner impacts, oblique crashes, impacts with narrow objects, and underrides. By contrast, few if any of these 122 fatal crashes were full-frontal or offset-frontal impacts with good structural engagement, unless the crashes were of extreme severity or the occupants exceptionally vulnerable.

The approach taken was to have one team member summarize a case, adhering to a uniform format, and then discuss it with the rest of the team until consensus was reached regarding the nature of the fatality. The team reviewed the coded variables in CDS and examined the photographs, case summaries, injury patterns, contact points, vehicle structural performance including intrusion measurements, and overall outcome of the crash. The team used any available data to reconstruct the events and kinematics of the crash, from the moments just prior to impact until the time of the occupant's death. Information from the electronic data recorder (EDR) was reviewed when available. In addition to field data, the analysis considered how the vehicle model had performed in full-frontal and offset-frontal crash tests.

The initial goal was to find the crashworthiness or survivability <u>factor</u> or list of factors that made the impact fatal. A menu of possible factors evolved during the course of the reviews. They included attributes of the crash configuration, such as hitting a tall, narrow object; descriptions of restraint-system performance, such as air bags not deploying; assessments of structural performance, such as roof intrusion; and human factors, such as elevated occupant age. The team also tried to discriminate between <u>primary</u> factors that seemed a first or an indispensable link in the chain of events leading to a fatality – and <u>secondary</u> factors that merely increased risk or were a direct consequence of earlier events. For example, a severe underride into the rear of a semi-trailer (primary factor) almost certainly resulted in windshield-header intrusion (secondary factor) and fatal head injuries to the occupant.

The final goal was to assign each crash to a single, or at most two high-level <u>crash-classification bins</u> – groupings that best characterize the most important feature of the crash and may form a basis for further study of crashworthiness issues. The team could define as many bins as needed. However, it was found that five bins were sufficient to house 114 of the 122 cases, and the remaining eight were aggregated into an "all others" bin. When a case seemed to belong in two bins – a condition applicable to twelve cases – it was usually evident which of the two bins was primary and which was secondary. Whereas the team's uniform approach to the cases was designed to minimize subjectivity and inconsistency, it must be stressed that the final

conclusions on the factors and bins for each case are this team's judgments and not the product of a mechanistic algorithm.

Based on the cases' only or primary bin, the crashes categorize as follows:

Exceedingly severe crash and/or anomaly: 49 fatalities
This bin includes three types of crashes: (1) Full-frontal or offset-frontal impacts with good structural engagement, but the deceleration was too severe (due to a high closing velocity) and the intrusion of the instrument panel (IP) or buckling of the floor pan was too great to allow adequate time and space for the occupant to safely "ride down" the crash; in short, the restraint system was overwhelmed; (2) Impacts with poor structural engagement, but so severe they would likely have been fatal even if there had been good engagement; And (3) Anomalies: unusual crash configurations that are difficult to address through vehicle improvements, such as being hit in the front of the upper occupant compartment by an airborne vehicle.

Corner and/or oblique impact: 29 fatalities
The primary factors in this bin are limited horizontal structural engagement at the corners and/or a direction of force sufficiently far away from longitudinal to affect occupant trajectories – often both. Twelve of the cases were corner impacts, 13 were oblique crashes, and 4 were oblique corner impacts. In a corner impact, the case vehicle's longitudinal structural members may be missed entirely, resulting in insufficient structural interaction with the front structure to absorb the energy of the impact. The struck object or other vehicle often peels away the front fender of the case vehicle and then contacts the firewall area, producing large instrument-panel or side-structure intrusions. In an oblique crash, the primary longitudinal structures may not experience a compressive, accordion-type of collapse to absorb the energy. The longitudinal frame rails bend out of the way instead of crushing as they typically would in a collinear crash. The occupant in corner-type crashes is exposed to intrusion from the IP, A-pillar and possibly even the door. In an oblique impact, the occupant moves in the direction of the impact, which could sometimes be a trajectory toward the A-pillar or the center of the IP where the occupant is not afforded proper protection from the deploying air bag. Although Federal Motor Vehicle Safety Standard No. 208, "Occupant Crash Protection" includes oblique tests with unbelted dummies into flat barriers at angles up to 30 degrees, these tests do not necessarily reveal a vehicle's response to impacts with quite limited structural engagement and/or strongly oblique force.

Tall, narrow object, centered impact: 4 fatalities
In addition to the risks associated with the narrow object's limited horizontal engagement, the height of the object, typically a tree or pole tends to push components in front of it, such as the instrument panel and steering assembly, upwards and into the occupant compartment. The vehicle's crush and restraint performance are also sensitive to the location of the impact. For example, air bag timing could be adversely affected if the primary longitudinal structure is not hit as would be the case in some vehicles with a centered impact into a pole or tree. Flat-barrier tests cannot be expected to reveal the distinctive characteristics of a vehicle's response when the object struck is a tree or a pole.

Underrode rear/side of heavy vehicle: 17 fatalities
There were 14 impacts with the rear and three into the sides of heavy vehicles, in which the striking car or LTV experienced severe underride with intrusion extending into the greenhouse

area of its occupant compartment, leading to fatal head injuries. Most semi-trailers currently on the road are equipped with a rear-impact guard, although only trailers built after January 1998 are required to have guards fully meeting FMVSS Nos. 223, "Rear Impact Guards," and 224, "Rear Impact Protection." CDS is not well suited for detailed analysis of these crashes, because it collects little information on the trailers (which are typically not accessible to the CDS researcher). For the cases reviewed in this study, the type of rear-impact guards present on the trailers was unknown, and there was likewise no measure of their performance in the crash. The substantial number of these cases is, by itself, enough to suggest a need for additional study. As in the two preceding bins, the key is poor structural interaction with the crash partner.

Vulnerable occupant: 15 fatalities

For occupants with a physical vulnerability, moderately severe and even low-speed impacts can be fatal. Thirteen of the fatalities were elderly (typically age 75 or older), who have a high risk of rib, pelvis and leg fractures, leading to internal thoracic and abdominal injuries. Moreover, three of these elderly occupants were also obese, placing added demand on the restraints. The other two occupants had pre-crash medical conditions such as advanced cancer. In an oblique impact, for example, where occupant interaction with the restraint system is already less than optimal, there may still be a margin of safety for a young occupant, but not for an older one.

Other: 8 fatalities

The remaining cases involved phenomena that did not occur frequently enough to merit separate bins, but the impacts themselves were not exceedingly severe or so unusual as to seem "anomalies." They were all placed in the "Other" bin. A seat belt that tore loose from its anchorage, an air bag that did not deploy, and a multiple-event crash in which an out-of-position occupant was injured by a deploying air bag: these are examples of cases in the "Other" bin. A belted driver endangered by an unrestrained passenger sitting behind the driver (acting as a "back-seat bullet") also joined the "Other" bin.

As stated above, there were no cases of restrained fatalities in current vehicles in full-frontal and offset-frontal impacts with good structural engagement unless the crashes were quite severe or the occupants exceptionally vulnerable. The implicit good news is that seat belts plus air bags plus the energy-absorbing frontal structures of late-model vehicles are accomplishing their goal of protecting occupants from fatal injury in frontal crashes resembling the crash tests currently used for regulations and consumer information. There were no cases in which an air bag was not replaced after a previous crash or where misuse of seat belts was considered a risk-increasing factor; there was only one case of an air bag that did not deploy in an impact where deployment would typically be expected and likely to benefit the occupant, and only one case where a seat belt tore loose from the anchorage.

CHAPTER 1

BACKGROUND AND OBJECTIVES

1.1 Trends in frontal fatalities to drivers and right-front passengers

Fatalities in frontal crashes to belted occupants at seats equipped with frontal air bags are now commonplace for the simple reason that most people buckle up and most of the vehicles on the road are equipped with air bags. Fatality Analysis Reporting System data suggests there were 4,835 such fatalities in 2007.

Table 1-1 shows trends of occupant fatalities in frontal impacts to drivers and right-front passengers of cars and LTVs during 1979-2007, the years when FARS enabled a uniform definition of "frontal" impact based on the variables IMPACT2 (principal impact point), IMPACT1 (initial impact point), ROLLOVER, HARM_EV (first harmful event) and M_HARM (most harmful event). For this analysis we will define "frontal" impacts to include any whose IMPACT2 (or IMPACT1 if IMPACT2 is unknown) is 11, 12, or 1 o'clock, even including some cases with subsequent rollover – but excluding any vehicles whose <u>first</u> harmful event was a rollover, fire or immersion and/or whose <u>most</u> harmful event was a rollover. Estimates have been adjusted to account for the small percentages of missing data on these variables.

The good news is that, even in absolute numbers, frontal fatalities decreased from 15,582 in 1979 to 11,659 in 2007. But a caveat is that most of the decrease was in the earliest years and the latest years. From 1982 to 2003, the fatalities were usually in the 12,800-13,800 range.

The next two columns of Table 1-1 show the count of all fatalities to these occupants and the percentage of all fatalities that were frontal. Overall fatalities decreased from 30,336 to 25,663 – i.e., by a lesser proportion than frontal fatalities. As a consequence, the proportion of fatalities that are frontal decreased from 51.4 percent to 45.4 percent. While this is in the right direction, it is difficult to draw conclusions from the trend line. There have been safety improvements addressing side impacts (dynamic test, side air bags) and rollovers (belt use) as well as frontals, so there is no particular reason that frontal fatalities should change as a proportion of all fatalities. Furthermore, factors other than intentional safety improvement can influence the trend. For example, older drivers and smaller cars tend to increase side-impact fatalities, and fortuitously reduce the proportion of fatalities that are frontal. The shift from cars to SUVs tends to increase rollovers, and again reduce the proportion of fatalities that are frontal.

TABLE 1-1: TRENDS IN DRIVER AND RF PASSENGER FATALITIES IN FRONTAL CRASHES, CARS AND LTVs

CY	Frontal Fatalities	All Driver & RF Fatalities	Percent That Are Frontal	Car & LTV VMT (10^6 miles)	Frontal Fatalities Per 10^9 miles	Belted Frontal Fatalities at Seats With Air Bags		Observed On-Road Belt Use (%)	Percent of On-Road Fleet With Air Bags
						N	%		
1979	15,582	30,336	51.4	1,405,545	11.09	0	0.0	11	0.0
1980	15,215	30,368	50.1	1,402,531	10.85	0	0.0	no survey	0.0
1981	15,045	29,686	50.7	1,429,675	10.52	0	0.0	11	0.0
1982	12,922	26,103	49.5	1,467,854	8.80	0	0.0	11	0.0
1983	12,355	25,398	48.6	1,522,697	8.11	0	0.0	14	0.0
1984	12,670	26,438	47.9	1,585,049	7.99	0	0.0	14	0.0
1985	12,946	26,336	49.2	1,637,759	7.90	0	0.0	21	0.0
1986	13,542	28,451	47.6	1,694,082	7.99	0	0.0	37	0.0
1987	13,958	29,358	47.5	1,772,852	7.87	0	0.0	42	0.1
1988	14,288	30,328	47.1	1,872,478	7.63	1	0.0	46	0.1
1989	14,219	29,758	47.8	1,937,696	7.34	8	0.1	46	0.3
1990	13,765	28,979	47.5	1,982,837	6.94	40	0.3	49	1.2
1991	12,838	27,210	47.2	2,007,579	6.39	106	0.8	51	2.7
1992	12,461	26,076	47.8	2,078,432	6.00	140	1.1	no survey	4.6
1993	12,954	26,595	48.7	2,120,459	6.11	280	2.2	no survey	7.3
1994	13,183	27,235	48.4	2,170,723	6.07	486	3.7	58	11.3
1995	13,447	28,277	47.6	2,228,323	6.03	745	5.5	no survey	17.2
1996	13,501	28,649	47.1	2,286,394	5.90	1,147	8.5	61	24.2
1997	13,637	28,530	47.8	2,353,295	5.79	1,456	10.7	no survey	30.0
1998	13,264	28,170	47.1	2,417,852	5.49	1,772	13.4	69	36.2
1999	12,861	28,439	45.2	2,470,122	5.21	2,060	16.0	no survey	42.6
2000	13,062	28,440	45.9	2,523,346	5.18	2,474	18.9	71	48.9
2001	12,976	28,297	45.9	2,571,539	5.05	3,009	23.2	73	54.6
2002	13,160	29,049	45.3	2,624,508	5.01	3,236	24.6	75	59.8
2003	12,894	28,557	45.2	2,656,173	4.85	3,775	29.3	79	64.2
2004	12,521	28,136	44.5	2,727,054	4.59	4,083	32.6	80	67.9
2005	12,300	27,873	44.1	2,749,555	4.47	4,443	36.1	82	71.4
2006	12,163	27,218	44.7	2,771,684	4.39	4,630	38.1	81	74.7
2007	11,659	25,663	45.4	2,755,131	4.23	4,835	41.5	82	77.6

The frontal fatality rate per billion vehicle miles of travel (VMT) is a much more positive indicator of progress. VMT of cars and LTVs increased from 1,405,545,000,000 in 1979 to 2,755,131,000,000 in 2007. Thus, the fatality rate decreased from 11.09 in 1979 to 4.23 in 2007. On a per-mile basis, safety in frontal crashes has improved enormously. But even here, we must be cautious in attributing the improvement to seat belts and air bags. Rates dropped sharply during the recessions circa 1982-1983 and 1990-1992 and then did not deteriorate when the recessions ended. The reasons are not clearly understood. The steady decrease in drunk drivers and young drivers before the mid-1990s must have contributed, too. Nevertheless, the steady reduction in the fatality rate from 1995 to 2006 – years when vehicles equipped with air bags gradually superseded the older on-road fleet and belt use increased, while demographic trends flattened out and there was little turbulence in the economy – is a most positive sign.

The next two columns of Table 1-1 specifically address fatalities to belted occupants at seats equipped with frontal air bags. The fatality count includes occupants who were belted or in child safety seats according to FARS (REST_USE 1, 2, 3, 4, 8, 13 or 14) and whose VIN and model year indicate that the seat position was equipped with an air bag when the vehicle was new.[1] Estimates have been adjusted to account for non-reported belt use and/or missing VINs.

The first belted fatality at a seat equipped with an air bag was reported in 1988. The annual count first exceeded 100 in 1991 and 1,000 in 1996. There were an estimated 4,835 fatalities with belts and air bags in 2007. That was 41.5 percent of all the frontal fatalities to drivers and RF passengers of cars and LTVs. The last two columns of Table 1-1 explain why these numbers and proportions have increased so greatly. Belt use observed in the general driving population was 11 percent in 1979 and 82 percent in 2007. The largest increase took place when belt laws initially went into effect in most of the States in 1985-1987. But buckle-up campaigns and the move to primary belt laws have contributed to steady, sustained gains after that. Air bags began to appear on new cars in substantial numbers in 1989. Although by the mid-1990s most new vehicles were equipped with air bags, it was not until 2001 that this accumulation of newer vehicles had become the majority of vehicles on the road. In 2007, 77.6 percent of the on-road fleet was equipped with frontal air bags.

Given 82 percent belt use and 77.6 percent of cars on the road equipped with air bags, the binomial law suggests 63.6 percent of the frontal fatalities could be belted occupants at seats with air bags. The fact that only 41.5 percent of the actual frontal fatalities were such occupants is clear preliminary evidence that buckling up <u>and</u> having an air bag available is much safer than a belt alone, an air bag alone, or neither. But even more obviously, it shows the effectiveness of buckling up and having an air bag is nowhere near 100 percent, because thousands of fatalities are still occurring. FARS data provide limited insight why individual crashes are fatal. This report will explore more detailed data from the Crashworthiness Data System of the National Automotive Sampling System and quantify how often various phenomena are occurring to make frontal crashes fatal despite belts and air bags.

[1] Pre-1985 test-fleet vehicles are not included.

1.2 Fatality reduction in frontal impacts by seat belt use and air bags

Although FARS has limited information on individual crashes, it can be statistically analyzed to estimate the fatality reduction by seat belt use and air bags in all frontal crashes, and in certain subgroups of frontals. Seat belt use and air bags are each quite effective in reducing fatality risk in frontal impacts; the combination of seat belt use and air bags, even more. NHTSA estimates that when drivers and right-front passengers buckle up with 3-point belts, they reduce their fatality risk in frontal impacts by 40 to 64 percent, as follows.[2]

Estimated Fatality Reduction (%)
By Seat Belt Use in Frontal Impacts

In passenger cars	
Impacts with fixed objects	60
Impacts with another vehicle	42
In LTVs	
Impacts with fixed objects	64
Impacts with another vehicle	40

"Frontal" impacts in these statistics are vehicles where the principal impact point is 11, 12, or 1 o'clock in FARS, including vehicles that rolled over after the frontal impact (but excludes first-harmful-event rollovers, fires and immersions).

Statistical analyses of FARS also demonstrate that frontal air bags reduce fatality risk in frontal crashes, but substantially more so when the principal impact point is 12 o'clock (front-center or front-distributed) than when it is 11 or 1 o'clock (front-corner). Air bags are also slightly more effective for adult passengers than for drivers, and for unbelted than for belted occupants, but the effectiveness is about the same in cars and LTVs, and in single-vehicle and multivehicle crashes.[3]

[2] Kahane, C. J. (2000). *Fatality Reduction by Safety Belts for Front-Seat Occupants of Cars and Light Trucks*, NHTSA Technical Report No. DOT HS 809 199, p. 30. Washington, DC: National Highway Traffic Safety Administration.
[3] Kahane, C. J. (2004). *Lives Saved by the Federal Motor Vehicle Safety Standards and Other Vehicle Safety Technologies, 1960-2002*, NHTSA Technical Report. DOT HS 809 833, pp. 108-113 and 311-312. Washington, DC: National Highway Traffic Safety Administration.

Estimated Fatality Reduction (%) By Air Bags in Frontals

	Belted Occupants	Unbelted Occupants
In 12 o'clock impacts		
Drivers	25	33
RF passengers age 13+	28	36
In 11 and 1 o'clock impacts		
Drivers	13	17
RF passengers age 13+	15	19

The combined effect of seat belt use and air bags is quite large. Relative to an unrestrained occupant in a seat position not equipped with air bags, the estimated combined fatality reduction for seat belts and air bags is at least 48 percent, for LTV drivers in 11 and 1 o'clock impacts with other vehicles,[4] and ranges as high as 74 percent for LTV passengers in single-vehicle 12 o'clock impacts.[5]

Overall, the average fatality reduction by seat belt use in all frontal crashes – given the CY 2005 mix of cars and LTVs, and single- and multivehicle crashes – is 50 percent, relative to an unrestrained occupant. This average effectiveness can change slightly from year to year as, for example, the proportion of vehicles on the road that are LTVs (where belts are more effective) increases. Fatality reduction by air bags averaged 25 percent in all frontal crashes – given the calendar year 2005 mix of belted and unbelted occupants, drivers and passengers, and 11, 12, and 1 o'clock impacts. This average, too, changes slightly from year to year, for example, as belt use increases (because the average effectiveness of air bags is slightly lower for a belted occupant, 22%, than for an unbelted occupant, 28%). Overall, the average combined fatality reduction for seat belt use and air bags in all frontal crashes – given the calendar year 2005 mix of occupants, vehicles and crashes – is 61 percent, relative to an unrestrained occupant without an air bag.[6] In other words, for every 100 frontal fatalities that would have occurred to unbelted occupants in vehicles without air bags, 39 would still be expected to happen even if these occupants had buckled up and the vehicles had been equipped with air bags.

Incidentally, the statistical estimate that air bags are only about half as effective in what FARS calls 11 and 1 o'clock impacts as in 12 o'clock impacts presages two important findings of this study, namely, that many of the fatalities still occurring are corner impacts and/or oblique impacts. The FARS IMPACT2 variable is based on damage location rather than direction of force, and it does not involve precise, uniform measurement criteria. It is fair to say, though, that corner impacts are most likely to be classified 11 or 1 o'clock, and not 12 o'clock. (However, there are many other 11 and 1 o'clock impacts on FARS that CDS would not call "corner" impacts but just offset impacts.) Even though IMPACT2 is not strictly a direction of force, many

[4] 40% fatality reduction for belts + 13% fatality reduction by air bags for belted drivers = 1 – (1 - .4)(1 - .13) = 48%.
[5] 64% fatality reduction for belts + 28% fatality reduction by air bags for belted RF = 1 – (1 - .64)(1 - .28) = 74%.
[6] Fatality reduction for belt use: 50%. Fatality reduction by air bags for a belted occupant: 22%. Combined effect: 1 – [(1-.50)(1-.22)] = 61%.

oblique impacts are also likely to be classified 11 or 1 o'clock because damage is often concentrated on one side in an oblique impact.

1.3 Objectives of the CDS case review

Thousands of people a year are dying in frontal crashes despite seat belts and air bags, and despite the fact that seat belts and air bags are the two most effective injury-mitigation measures we have. We looked one-by-one at a nationally representative subset of these thousands of fatalities to find out – in quantitative terms – why people are still dying. What were the main factors, conditions or events that made the crashes fatal and how frequent was each factor?

Then we tried to find the bigger picture in this mass of individual case studies. What are the principal categories of crashes where things go wrong for the occupants? How big is each category? What particular mechanisms are leading to fatal injuries in each category of crash? The purpose is to identify areas for further study that have high potential for payoff, because they are where the fatalities are.

Conversely, we also tried to enumerate crash types with few or no fatality cases when more had perhaps been expected. In what kinds of crashes do late-model vehicles do an excellent job preventing fatalities to belted occupants at seat positions equipped with air bags?

1.4 Safety advances 2000-2007

The implementation of vehicles with the first generation of air bags and energy-absorbing structures began over 20 years ago. On July 17, 1984, NHTSA amended Federal Motor Vehicle Safety Standard No. 208, "Occupant Crash Protection," to phase in automatic protection, such as air bags or automatic belts, into the front-outboard seats of passenger cars between September 1, 1986, and September 1, 1989. To encourage the development of air bags, NHTSA exempted the right-front seat from the automatic protection requirement until August 31, 1993, in cars equipped with driver air bags. During the implementation of automatic protection, automatic belts initially dominated, then driver air bags with manual 3-point belts, and, after September 1, 1993, driver and front-passenger air bags with manual 3-point belts.[7] Also during these years, NHTSA, the manufacturers and the safety community dedicated themselves to a successful effort to encourage buckle-up laws in the States.

The Intermodal Surface Transportation Efficiency Act, passed by Congress in 1991, required all passenger cars manufactured after September 1, 1997, and light trucks manufactured after September 1, 1998, to have driver and passenger air bags, plus manual lap-shoulder belts. Also in 1991, NHTSA extended the automatic occupant protection requirements to light trucks and vans on a phased-in basis for model years 1995, 1996, 1997, and 1998.

To meet the automatic protection requirements of FMVSS No. 208, vehicles were required to meet a 48 km/h (30 mph) rigid barrier crash test with unbelted and belted anthropomorphic test devices (ATD) in the driver and right front passenger positions. The barrier could be set

[7] *Federal Register* 46 (January 8, 1981): 2064, 49 (July 17, 1984): 28962, 50 (August 23, 1985): 34152; *Code of Federal Regulations,* Title 49, Parts 571.208 S4.1.3, 4.1.4 and S7.4

perpendicular to the line of travel of the vehicle or it could be set at any angle up to 30 degrees in either direction to simulate an oblique crash. The performance criteria specified limits for injury criteria for the head, chest, and femurs measured with 50^{th} percentile male adult ATDs.

On May 12, 2000, the agency amended FMVSS No. 208 to phase in "advanced" air bags from September 1, 2003, to September 1, 2006. Advanced air bags do not deploy at all for children ("suppression"), deploy only at a low level of force ("low-risk deployment"), or track an occupant's motion and suppress the air bag if they are too close ("dynamic automatic suppression").[8] Furthermore the agency adopted an unbelted crash test requirement with a 50th percentile adult male ATD that includes an oblique impact with a fixed rigid barrier. The unbelted test may be conducted at any speed between 32 km/h (20 mph) and 40 km/h (25 mph) into a barrier that is perpendicular to the line of travel of the vehicle or at any angle up to 30 degrees in either direction to simulate an oblique crash. Also for the first time, the standard would require protection for small-stature adults represented by a belted 5th percentile female Hybrid III ATD in a 48 km/h (30 mph) perpendicular-barrier test – in addition to a test with a belted 50th percentile adult Hybrid III male ATD under the same conditions, that between September 1, 2007, and September 1, 2010, would phase in to a 56 km/h (35 mph) speed. On August 31, 2006, the agency further amended FMVSS No. 208 to increase the maximum test speed for the belted perpendicular-barrier test using the 5th percentile female Hybrid III ATD from 48 km/h (30 mph) to 56 km/h (35 mph). This amendment is to be phased in from September 1, 2009, to September 1, 2012.[9]

In addition to the implementation of new frontal safety requirements over the years, consumer information programs such as the agency's New Car Assessment Program (NCAP) and the vehicle crash test ratings from the Insurance Institute for Highway Safety (IIHS) have provided an added incentive for manufacturers to improve vehicle crashworthiness.

The purpose of NCAP is to provide consumers with a measure of the relative safety potential of vehicles in frontal crashes by comparing the frontal crashworthiness among new passenger vehicles, and it has been a major contributor to the crashworthiness improvements in newer vehicle designs. This program involves 56 km/h (35 mph) crash tests into a full-width rigid barrier with instrumented 50^{th} percentile male Hybrid III ATDs in the outboard front seat locations. Of the model year 2000 vehicles tested, 17 percent of the drivers and 26 percent of passengers earned a 5-star rating. By the 2007 model year, 68 percent of the drivers and 64 percent of the passengers earned 5-star ratings with just about all the rest earning 4 stars for both seat locations.

The full-width barrier test has driven significant advances in restraint technologies, including the installation of advanced dual-stage air bags, load-limiting retractors and seat belt pretensioners. These technologies aid in ensuring the occupant is in position and properly restrained during a crash and also help the occupant ride down the impact while minimizing injurious loads to their body.

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[8] *Federal Register* 65 (May 12, 2000): 30679; *Code of Federal Regulations*, Title 49, Part 571.208 S14.
[9] *Federal Register* 71 (August 31, 2006): 57168.

The Insurance Institute for Highway Safety initiated a frontal offset crash consumer information program in 1995. In the Institute's 64 km/h (40 mph) offset test, 40 percent of the total width of the front of the vehicle strikes a barrier on the driver side. The barrier's deformable face is made of aluminum honeycomb, which makes the forces in the test similar to those involved in a frontal offset crash between two vehicles of the same weight, each going just less than 40 mph. Injury metrics are obtained from a 50th percentile male Hybrid III ATD in the driver's seat.

According to the IIHS,[10] three main factors are evaluated in the frontal offset crash test: structural performance, injury measures, and restraints/dummy kinematics. The various measures are combined into each vehicle's overall frontal offset crashworthiness evaluation (Poor, Marginal, Acceptable, or Good).

The IIHS crashworthiness evaluation is a less aggressive test of the restraint system when compared to the agency's full-width rigid barrier test. However, the IIHS test drives a stronger occupant compartment, to reduce the amount of intrusion a vehicle may sustain in real-world crashes, as well as energy-absorbing longitudinal rails, generally located on either side of the engine to manage the energy in a crash event.

Vehicle results in the IIHS frontal test show a similar improvement over time as in the agency's NCAP program. About 25 percent of the 2000 model year vehicles tested by the IIHS earned the top "Good" rating. However, by model year 2007, that number increased to almost 90 percent.

To address vehicle incompatibility between cars and LTVs, especially the larger pickup trucks and SUVs, the Alliance of Automobile Manufacturers and the Association of International Automobile Manufacturers agreed in 2003 to enhance geometric alignment of the front energy-absorbing structures of the fleet. Given the leadtime necessary to redesign vehicles, the participants in the agreement will design 100 percent of their light truck fleet with primary or secondary front structures that align with the 49 CFR Part 581 bumper zone of passenger cars by September 1, 2009. The intent is to assure engagement of the energy-absorbing structure in frontal crashes between small cars and large LTVs to reduce override and share more evenly the crash forces.

As a result of enhancements to the regulatory requirements including testing with large and small ATDs and manufacturers designing vehicles to perform well in consumer-information programs, significant gains have been made in frontal occupant crashworthiness. Manufacturers are also taking a systems approach to both side and frontal crash protection. Because of an industry voluntary commitment, side-curtain head protection is widely available in the fleet. For instance, side-curtain head-protection air bags were standard equipment in 52 percent of model year 2007 vehicles and increased to 74 percent for 2008. Some manufacturers today will deploy the side-curtain air bags in a severe frontal crash as added head protection in case the occupant travels toward the side windows or A-pillar during the event.

Even with the safety advances made in today's fleet, this study has identified some crash characteristics where front-seat occupants are at risk of sustaining fatal injuries.

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[10] http://www.iihs.org/ratings/frontal_test_info.html

CHAPTER 2

METHOD

2.1 CDS case selection

We wanted to study a census of frontal fatalities despite seat belt use and air bags in late-model-year passenger vehicles in the Crashworthiness Data System of the National Automotive Sampling System. That involved compromising between two conflicting needs:

- Obtaining enough cases for statistically meaningful results on the relative frequency of the most important factors that made the crashes fatal, namely, a study of somewhat more than 100 cases; and
- Limiting to vehicles new enough to largely exclude safety issues that have been resolved and are no longer relevant to current vehicles.

There are 138 cases in CDS through 2007 of belted fatalities in frontal impacts at seats with air bags in vehicles of model year 2000 or later, and because that is close to the targeted number of cases, "MY 2000 and later" became the criterion for inclusion. One shortcoming of a strictly model-year criterion is that vehicles often carry over the design of a previous year, and although the VIN plate may say MY 2000+, the design could be, say, 1995 or in some cases even earlier. This problem will be reflected in the fair number of instances of "vehicle did not perform well in crash-safety rating programs" that show up in the study.

Now let us look at the detailed definitions in CDS. A "frontal" is a case vehicle whose "principal" damage location GAD1 is F. A problem occasionally arises in multiple impacts. CDS defines the "principal" impact as the one that created the most energy. However, the fatal injury is sometimes attributable to one of the less energetic impacts. If so, the team subsequently deleted that case from the initial 138 crashes. Section 2.2 has a more detailed discussion of the 17 cases deleted for this reason or other reasons.

CDS has to attribute the fatality to a motor vehicle crash (TREATMNT = 1). Fatalities explicitly attributed to a pre-crash heart attack or suicide would not be included in the 138, as they can hardly be "blamed" on the frontal impact. Here, too, though, there are some cases that the team subsequently deleted because they appeared to be illness or suicide despite TREATMNT = 1.

CDS attributes some fatalities to disease rather than the crash, or bows to official sources (such as medical examiners) if they attribute a fatality to disease (TREATMNT = 2). These cases were also reviewed to see if, notwithstanding the official classification, the fatalities in some might have been due to crash injury. There were 13 reported cases of this type for belted occupants (all of them drivers) in MY 2000+ vehicles with GAD1 = F. In 10 of the cases, it was fairly evident that the onset of the disease, typically a heart attack, began before the impact; that the driver was already dead or dying, lost control of the vehicle, and subsequently hit something; and that the impact itself resulted in at most minor injuries. In two cases, the team found evidence that the driver was, in fact, unbelted. That left one case where a belted driver's fatality should probably have been attributed to crash injury; it was added to the other 138, for a total of 139 crash cases.

"Fatal despite air bags," of course, limited the study to drivers and right-front passengers, because other seats are not equipped with frontal air bags. We included any vehicle that would have been equipped with air bags when it was new – and because all MY 2000+ passenger vehicles were so equipped, all were included. That would include cases where an air bag was present but did not deploy, or was switched off (intentionally or unintentionally), or was not replaced after a previous crash (known or unknown to the driver). The rationales for including them were (1) to find out how frequent non-deployment events are and to what extent, if any, they contribute to the number of fatalities still occurring, and (2) these crashes are included in the statistical analysis of effectiveness based on FARS (see Section 1.2). As it turns out, our 139 crashes did not include any cases of air bags not replaced after a previous collision.

By the same rationales, "seat belts" includes any occupant using a belt, whether properly or improperly (and in these MY 2000+ vehicles, the belt supplied at the driver and RF positions is always a manual 3-point belt), and including cases where the belt subsequently did not restrain the occupant for some reason. Children in safety seats or booster seats, secured by a belt or LATCH, were also to be included. MANUSE had to be 2, 3, 4, 5, 12, 13, 14 or 15. Actually, the 139 cases did not include any children in safety or booster seats (and only one person younger than 16, a belted 10-year-old). Also, there were no improperly belted adults, e.g., people who wore the shoulder harness behind their backs.

"Census" was the keyword for case selection. Including all frontals on CDS, and not limiting to crashes of a particular type or severity range makes it possible to estimate the actual frequency of the various factors that are making these crashes fatal across the United States.

2.2 Case analysis approach

The authors of this report were the review team, drawn from different offices within the agency, including crashworthiness and biomechanical engineers, crash investigators, and a statistician. Since the objective of the study required more detailed information than what could be extracted from CDS coded variables alone, the team developed a case analysis strategy that could be employed for each individual case review. As well as a review of coded variables, the strategy involved examination of photographs, case summaries, injury patterns, vehicle crash performance, and overall outcome of the crash. If the corresponding case was also one of NHTSA's special crash investigations (SCI), the SCI report was incorporated as well. In an attempt to minimize subjectivity, a case review template was developed and a number of factors and classifications were specified to capture the essence of the cases.

Each team member conducted the initial analysis on a subset of the cases and summarized them, guided by the template, including detailed information about the vehicle, object contacted, and fatal occupant, and highlighting the intrusions, injuries, reconstruction program results, and electronic data recorder information (when available) that were relevant to the outcome. Significant images and the results of the NCAP and IIHS crash tests were also included. The ΔV estimate coded on CDS, computed by the WinSMASH program as it existed before 2008, was in some cases supplemented by a second estimate computed by the WinSMASH 2008 program that incorporates make-model-specific stiffness parameters derived from NCAP tests. The template concluded with the reviewer's short assessment of the crash and assignment of primary and secondary factors, which will be discussed in section 2.3.

The entire group then discussed each individual case, using the initial reviewer's summary as a guide. Following subjective evaluation of the pre-crash period and thorough discussion of the vehicle dynamics and occupant kinematics, the team reached a consensus judgment on the various factors that led the crash being fatal for the occupant of interest. Once primary and secondary factors were identified the cases were then assigned to one of six bins for final grouping. Whereas a uniform review template and discussion structure minimized inconsistency between cases, it must be stressed that the final conclusions on the factors and group-assignment of each case are this team's judgments and interpretation of the full case; they are not the product of a mechanistic and repeatable algorithm operating only on the coded data elements.

During the case reviews, it became apparent that some of the cases did not fit the study criteria and were thus deleted from the study. Examples include cases in which it was determined, after careful review, that the fatality-inducing event was not a frontal impact. (Typically, these were multiple-event crashes, including frontal and non-frontal impacts. If the fatality-inducing event was a rollover that was a direct and instant consequence of a frontal impact, the case was not excluded, but if the rollover occurred before or some time after the frontal, the case was excluded.) The team dropped cases if they found evidence that the occupant was most likely not wearing the manual belt restraint. Cases in which the occupant died immediately prior to the crash due to illness or was apparently committing suicide were also deleted. Seventeen cases were deleted from the original set, **leaving 122 for analysis**.

2.3 Definitions of primary and secondary factors

A crashworthiness or survivability "factor" is an event or condition present at or after the time of the impact that probably and logically increased the likelihood that <u>this specific</u> impact would be fatal to the occupant. For example, the condition that the occupant is obese is likely to be a factor in many of the impacts where occupants bottomed out the air bag and had fatal thoracic injuries. It is unlikely to be a factor in crashes where an exterior object hit the occupant in the head. The list of factors did not include crash-avoidance technologies that could hypothetically have prevented the collision or reduced its severity.

The list of crashworthiness and survivability factors was open-ended. Each member of the group had permission to define new factors if they thought a case justified them. Later, when the group reviewed one another's cases, similar factors were sometimes merged – e.g., instrument-panel intrusion, toe-pan intrusion, and floor-pan buckling. We checked that factor selection was consistent across the team. For example, one team member originally listed the occupant's "short stature" as a separate factor on several cases. The team agreed it was a valid, separate factor. Subsequently, "short stature" was added as a factor on other case reviews that had specifically mentioned it.

The team explicitly distinguished between "primary" and "secondary" factors. That gave some structure to what was most important and what was less important as a cause of fatalities. It also encouraged the team to name as many relevant factors as needed per case – because by designating the lesser factors "secondary" they would not bury what happened in an avalanche of information.

The designation as primary or secondary was subjective, based on discussion and consensus of the team. Two guidelines influenced the choice:

- A primary factor more likely seems a necessary condition for a fatality. Take it away and the crash would probably not have been fatal. Secondary factors increase risk, and may even have been the last straw in a specific case, but not so evidently as a primary factor.
- A primary factor tends to be an original cause; secondary factors may be consequences of a primary factor. For example, if a car severely underrides a heavy trailer, upper-compartment intrusion resulting in fatal head injuries is an almost inevitable consequence. Underride is the primary factor; upper-compartment intrusion is the secondary factor.

The above are just guidelines – the team designated the primary factors based on what they believed best described what happened in a particular crash.

There can be two or more primary factors if both are necessary for the crash to be fatal. For example, consider a centered impact with a tree, resulting in late deployment and fatal injuries to an elderly driver. If this elderly driver would have likely survived a timely deployment, and a 30-year-old driver would have survived even this late deployment, then "impact with tall, narrow object" and "occupant's age" should both be primary factors (because if either of the two factors had not been present, the crash would likely not have been fatal). If the driver had been even older and would likely not have survived even a timely deployment, only "occupant's age" should be a primary factor (and "tall, narrow object" would have been secondary, because the impact would likely have been fatal for this driver even with a wide object). But if the crash had been more severe and even a 30-year-old driver would not have survived the late deployment, only "impact with tall, narrow object" should be a primary factor (and "occupant's age" would have been secondary, because the crash would likely have been fatal even for the younger driver). If the same crash had been yet even more severe, to the point where a 30-year-old driver would not likely survive a timely deployment, "exceedingly severe crash" might become the single primary factor (and "occupant's age" and "tall, narrow object" would have become secondary, because the crash would likely have been fatal without either of them). Of course, nobody knows for sure exactly what the last straw was in the actual crash, let alone in the hypothetical situations where one factor is removed, so all designations have to be based on the team's judgment and consensus.

2.4 The factors

<u>Factors describing the crash configuration or partners</u>

<u>Exceedingly severe crash</u>: the velocity change and acceleration are so great that it is not very likely the occupant could ride down and survive in the time and space available, even if structural engagement had been excellent, the vehicle had performed well in crash-safety rating programs, the occupant was young, and the restraint system functioned well. Fundamentally, if this had been a full-frontal impact, it would likely have been fatal to the driver and RF passenger; if it had been an offset with 50 percent overlap, it would likely have been fatal to the occupants of the impacted half. Typically, the time and space available for the restraint system, already

limited because of the high speed, is further reduced because the instrument panel intrudes and the floor pan buckles at these force levels, even in vehicles that perform well in crash-safety rating programs. In short, the restraint system is overwhelmed. "Exceedingly severe" is usually a primary factor, but the team called it a secondary factor if a crash was just below that severity level, and there were other risk-increasing factors.

Underride: the primary frontal longitudinal members of the case vehicle did not engage with the structure of the other vehicle due to a height mismatch. This results in excessive damage depth and compromise of the occupant compartment on the case vehicle. Underride becomes a primary factor if an impact at the same velocity with good structural engagement would have had a low fatality risk.

Trailer's guard did not prevent underride: The case vehicle hit the rear of a semi-trailer or single-unit truck equipped with an underride guard. Nevertheless, there was severe underride, presumably because the vehicle ran under the guard or pushed the guard out of the way, upward or sideways. This factor and the preceding one are not mutually exclusive; crashes where the trailer's guard did not prevent underride are also crashes with underride. But crashes with underride do not necessarily involve the trailer's guard – e.g., they could be collisions with a vehicle not equipped with guards, or into the side of a trailer where there is no guard.

Limited horizontal structural engagement: the primary frontal longitudinal members of the case vehicle did not engage with the structure of the other vehicle or object because the impact was (1) on the corner of the case vehicle, (2) strongly offset to the point where the direct damage on the case vehicle was outside the longitudinal member, and/or (3) with a narrow object that fits between the longitudinal members. Intrusion of various components may increase and occupant trajectory can be affected. Air bags may deploy late or not at all. It becomes a primary factor if an impact at the same velocity with good structural engagement would have had a low fatality risk.

Tall, narrow object: In addition to the risk-increasing factors associated with the narrow object's limited horizontal engagement, the height of the object, typically a tree or pole tends to push components in front of it such as the instrument panel and steering assembly upwards and into the compartment. The occupant's head may contact the tree or pole.

Oblique crash: The direction of impact is sufficiently far away from longitudinal so as to affect occupant trajectories (away from the air bag and not straight ahead into the seat belt). Components may be displaced laterally or intrude longitudinally.

Front-to-front incompatibility: When the case vehicle hits a car or LTV head-on, and that other vehicle is much stiffer and/or heavier, or has the frame rails located substantially higher, the case vehicle may experience a disproportionate share of the damage and experience compartment intrusion above and beyond what might be expected from the speed and degree of offset.

Anomaly: Unusual crash configuration or circumstances, such as being struck by an airborne or rolling vehicle; hitting an unusually shaped vehicle or object; or experiencing multiple frontal impacts, with the air bag deploying on the first severe impact, but the injuries attributable to a subsequent, possibly more severe impact.[11]

Multiple-event crash: Impact(s) prior to the main impact cause the air bag to deploy before it is most needed, or displace the occupant out of position, or cause the occupant to load the belt system and/or air bag from an angle other than straight-ahead.

Post-crash fire resulting in fatal burns: A frontal impact triggered the fire.

Out-of-position occupant: Includes people displaced out of position by small impacts or off-road excursion prior to the main impact and, less frequently, people who were already out of position before the crash (e.g., asleep). It can result in belted occupants coming too close to the air bag, or to static components such as the side structure or steering assembly.

Factors describing performance of the restraint systems in the case vehicle

Poor occupant air-bag interaction: The occupant's thorax does not hit the center of the air bag, and as a result enjoys at best a limited portion of the energy-absorbing capability of the air bag. This happens often as a direct consequence of oblique force or a vehicle rotation introduced by a corner impact or strongly offset impact; as a result this factor is often secondary (because a consequence) to "oblique crash" or "limited horizontal engagement." It may also result from delayed deployment, an occupant with unusual stature or out of position, and upward displacement of the steering assembly.

Belt system did not adequately restrain: Includes one case where the belt anchorage tore loose. Much more common are cases of excessive occupant excursion. The majority of them involve shoulder belts integrated with the seat, where a large occupant exerted enough force to bend the seatback and pull it forward. Excursion could also be increased by loosely worn belts without pretensioners, or by a series of impacts.[12]

Air bag bottomed out: This was quite common in this select group of often very severe crashes, but it was always a secondary factor. It was a consequence of the impact's severity and/or the occupant's weight. We did not see cases where the air bag bottomed out "for no particular reason." We also did not see cases where we were confident that a more capacious air bag would have prevented the fatality, because most of these crashes were quite severe.

Air bag injured out-of-position occupant: These are the characteristic injuries when occupants are too close to deploying air bag, such as atlanto-occipital cervical spine dislocation plus brain injury plus abrasions of the neck and face. They are rare in our study of belted occupants in vehicles with redesigned air bags (MY 1998+). But occupant excursion despite belt use (e.g.,

[11] Multiple frontal impacts, per se, would not be an anomaly, and would just get the factor, "multiple-event crash." But if the air bag deploys on the first impact and the injuries are attributable to a later impact, this would be assigned two factors, "multiple-event crash" and "anomaly."
[12] A load limiter that allowed excessive excursion would be included here; however, there were no instances of it as a severity-increasing factor among the 122 fatality cases.

belts without pretensioners worn loosely) or multiple impacts can allow occupants to approach the air bag before it deploys.

Air bag did not deploy: In a crash where a deployment would have typically been expected and would likely have benefited the occupant. In other words, where this was the primary factor (one case), the team believes a deployment would likely have prevented the fatality.

Belt-caused injury: Although CDS attributed injuries to the belt system in several cases, the team only considered it a factor if these injuries were fatal, and of higher severity than would be expected for this type of impact.

Factors describing performance of the structure or other components of the case vehicle

Roof, A-pillar or other upper-component intrusion: The roof, A-pillar, front header, roof side rail, and/or striking vehicle/object entered the space of the occupant compartment from the front, side, and/or top, resulting in fatal head injuries to the occupant. This is the single most frequent factor in our study. However, it is usually a secondary factor, because it is a direct consequence of what happened in the crash (underride; corner impact; tall, narrow object).

Excessive IP or toe-pan intrusion, or buckling of the floor pan: Instrument panel intrusion and floor-pan buckling both reduce the space available between the occupant and the front interior for ride-down by the restraint system. Severe IP intrusion can result in direct contact with the belted occupant, and fatal thoracic injuries. Severe toe-pan intrusion can cause multiple leg fractures; on rare occasions, these injuries can have life-threatening consequences.

Vehicle did not perform well in crash-safety rating programs: This usually refers to MY 2000+ vehicles that were likely carryovers from somewhat earlier designs, with poor or marginal performance on the IIHS offset test, especially structural performance. These vehicles tend to allow more IP, toe-pan or floor-pan intrusion and deformation than the latest designs. These vehicles may also have not incorporated safety technologies such as seat belt pretensioners that might have improved belt performance.

Seat did not adequately restrain: The seat tore loose from its track, or moved forward during the track during impact, or moved up or down in response to intrusion. That reduced the occupant space available for ride-down or caused the occupant to contact the front interior with a more vulnerable body region (neck or abdomen rather than thorax).

Steering assembly moved upward: The upward motion of the steering assembly, in response to the vehicle’s structural deformation, concentrated the impact of the steering wheel into the driver’s chest. The phenomenon was a consequence of exceedingly severe impacts or tree impacts, and not a primary, first-cause factor.

Factors describing intrinsic occupant vulnerability

Elevated occupant age: An impact resulted in fatal injuries to this occupant. The impact would probably not have been fatal to a 30-year-old occupant, either because they would have sustained a less severe type of injury than this occupant, or even if they had sustained the same injury, they would probably have survived it. There is no specific minimum age for this factor; typically these occupants are over 70, but in some of the more severe crashes, as young as 65 to 70 years old.

Obese occupant: The occupant had a body mass index (BMI) of 30 or more and that increased fatality risk because the occupant bottomed out the air bag, overtaxed the belt system or the seat, increased impact force on the ribcage, or reduced the space between the occupant's torso and the steering assembly or instrument panel.

Pre-existing medical condition: The occupant was more vulnerable to impact trauma than the average for his or her age due to an illness (which was not, itself, the cause of the fatality). The occupant could not exit the vehicle, when that was necessary for survival, because of an illness.

Post-crash injury complications: An injury or combination of injuries that is rarely fatal became fatal as a result of complications during the convalescence. Typically, the victim would be an older person.

Short-stature occupant: Because of short stature, the occupant contacts the air bag with a vulnerable body region (e.g., with the neck instead of the center of the chest). Because of short stature, a driver sits closer to the air bag and reduces the space available for ride-down by the restraint system or even becomes exposed to injury by the deploying air bag. There is no specific height limit; this factor is assigned if, in the team's judgment, it contributed to the severity of the injuries.

Tall or large occupant (not obese): Usually advantageous, but could increase risk if the occupant contacts upper-interior components despite being belted or overtaxes the seating system. The only occupant in our study with this factor stood 6'4" and weighed 233 pounds.

Factors describing actions by people that increased somebody's injury risk

Back-seat bullet: An back-seat occupant sat behind the victim and did not buckle up. During the frontal impact this "back-seat bullet" contacted the back of the front seat, increasing the load on the victim and/or reducing the space between the front seat and the instrument panel.

Air bag switched off: The case vehicle was factory-equipped with an on-off switch for the passenger air bag (most of these are pickup trucks), and somebody had turned the switch off – with or without the occupants being aware of it. (This could also apply to aftermarket switches for drivers or passengers, but there were none among our cases.)

2.5 Assigning cases to crash-characteristic bins

The team assessed the crash data and determined for each case the primary and secondary factors that explain why the occupant was killed in the event. Afterwards the primary factors were analyzed for frequency and patterns for additional insight into the fatal frontal crash problem. From this analysis, there emerged six high-level bins to which the 122 cases were then assigned.

These high-level bins characterize the crash event and may provide a basis for further study. The bins are as follows:

Exceedingly severe crash and/or anomaly

Corner and/or oblique impact

Underrode rear/side of heavy vehicle

Vulnerable occupant

Tall, narrow object

Other

Exceedingly severe crash and/or anomaly: Cases where the primary factor was determined to be either exceedingly severe and/or an anomaly were placed into this bin. The team believed, given the severity or randomness of the event, the occupant and safety systems were overwhelmed and it would not be reasonable to assume the crash was survivable or likely addressable with advanced crashworthiness technologies.

Corner and/or oblique impact: Offset crashes where the primary factor was determined to be limited horizontal structural engagement at the corners and/or the direction of the impact in the crash was sufficiently far away from longitudinal to affect occupant trajectories and alter the crush properties of the vehicle's structure. Generally in these crashes there was insufficient structural interaction at the corners of the vehicle in the event. Either the longitudinal structural member were missed entirely in the impact or in the case of an oblique crash, the structure did not experience a compressive, accordion type of collapse to absorb the energy but rather the member just bent out of the way.

Underrode rear/side of heavy vehicle: Because of their frequency, cases where the primary factors were determined to be excessive "Underride" and the "Trailer's guard did not prevent underride" are captured in this bin. Generally the subject vehicle also experienced "Roof, A-pillar or other upper-component intrusion" as a secondary factor from the impact with trailer leading to fatal head injuries.

Vulnerable occupant: Cases where the primary factor for the fatal event was attributed to the occupant's age, weight, size or medical condition making them vulnerable were placed into this category. The occupant's state, independent of the crash events, was considered to have made them at risk for severe injury in a moderate to severe crash.

Tall, narrow object: This primary factor occurred with enough frequency to warrant a crash-classification bin**.** In addition to the risk-increasing factors associated with the narrow object's limited horizontal engagement, the height of the object, typically a tree or pole tended to push components in front of it such as the instrument panel and steering assembly upwards and into the compartment. The vehicle crush and restraint performance was also sensitive to the locations of the impact. For example air-bag timing could be adversely affected if the primary longitudinal structure is not impacted, e.g., if the impact is between the frame rails. This could also increase the amount of IP intrusion. The height of the object also tended to increase the severity of the crush, particularly when the impact was at the corners.

Other: The remaining cases involved crash events that did not occur frequently enough to merit separate bins (but were not exceedingly severe crashes nor so unusual as to seem "anomalous"). They were all placed in the "Other" bin. An out-of-position occupant injured by a deploying air bag would be an example of a case in the "Other" bin.

It should be noted that cases may be assigned to more than one bin. For example, the fatal occupant in a case reviewed could have been elderly. The injuries to the occupant could have been aggravated by an oblique impact with another vehicle resulting in poor restraint performance. This particular case using our methodology would have been placed in the "Vulnerable occupant" and the "Corner/oblique impact" categories if the occupant's age and the crash configuration both seemed essential to making the crash fatal.

To further illustrate the methodology, if a vehicle hit a tree or pole with its corner, the case might be placed in both the "Corner/oblique impact" and "Tall, narrow object" bins. These two bins, in particular, were not considered mutually exclusive and in many cases had similar crush patterns, intrusion, and occupant dynamics.

Twelve of the 122 cases were assigned to two bins, while the other 110 each fit into single bins. However, on each of the 12 two-bin cases, the team judged that one of the bins was "primary," in the sense that it captured the most salient feature of the crash, whereas the other bin was "secondary" – a necessary condition for the crash to have been fatal, perhaps, but somehow not the most characteristic feature of that crash.

There is no predetermined relationship between the bins and the factors in a particular case. There is usually a primary factor closely corresponding to the bin to which the case is assigned. For example, a case in the corner/oblique impact bin usually has the primary factor "limited horizontal structural engagement" or "oblique crash" (or both). Cases assigned to two bins typically have at least two primary factors, one corresponding to each bin. For example, a corner impact with a tall, narrow object may have "corner impact" as the primary bin (if that is the most salient characteristic of the crash) and "tall/narrow object" as the secondary bin, but "limited horizontal structural engagement" and "tall/narrow object" might both be primary factors if both seem necessary to make the crash fatal. However, there are exceptions to these patterns, because in each case the assignment of bins and factors is based on judgment, not a deterministic algorithm.

Appendix A summarizes the individual cases, including a description of the crash, the crash-classification bin(s), and the primary and secondary factor(s); it also specifies the age, gender, height, and weight of the victim; the collision deformation classification (CDC) of the vehicle; and its ΔV (when an estimate is available).

Appendix B lists the case numbers belonging to each bin, specifying whether as the sole/primary bin or as a secondary bin, and also specifying details of the bin membership – e.g., if the crash is in the corner/oblique bin, it specifies whether the crash is a corner impact, an oblique impact, or both. Appendix C lists the case numbers exhibiting each of the factors, specifying whether as a primary or as a secondary factor. Appendices B and C are indexes, allowing the reader to find the available examples of any particular bin or factor.

CHAPTER 3

PRINCIPAL FINDINGS

3.1 Number of cases in each bin

49	**Exceedingly severe crash and/or anomaly** (single bin)	49	
	Exceedingly severe crash		*34*
	Anomaly		*13*
	Exceedingly severe crash and anomaly		*2*
29	**Corner and/or oblique impact** (single bin)	21	
	Corner impact		*5*
	Oblique impact		*12*
	Oblique corner impact		*4*
	Corner/oblique primary bin, **Tall, narrow object** secondary bin	5	
	Corner/oblique primary bin, **Vulnerable occupant** (age) secondary bin	1	
	Corner/oblique primary bin, **Other** secondary bin	2	
	Corner plus incompatibility		*1*
	Oblique plus underrode front of heavy truck		*1*
17	**Underrode rear/side of heavy vehicle** (single bin)	16	
	Underrode rear		*14*
	Underrode side		*2*
	Underrode rear/side primary bin, **Corner/oblique** secondary bin	1	
15	**Vulnerable occupant** (single bin)	12	
	Age		*7*
	Age and weight		*3*
	Pre-existing medical condition		*2*
	Vulnerable occupant (age) primary bin, **Corner** (2)**/oblique** (1) secondary	3	
4	**Tall, narrow object** (single bin; centered impact)	4	
8	**Other** (single bin)	8	
	Did not perform well in crash-safety rating programs		*2*
	Air bag did not deploy		*1*
	Air bag injured out-of-position occupant		*1*
	Back-seat bullet		*1*
	Belt anchor and seat track tore loose		*1*
	Post-crash injury complications		*1*
	Underrode front of heavy truck		*1*
122			

Above are the bin assignments for the 122 cases in the study; 110 cases belong to a single bin. Twelve cases belong to two bins, but one bin is considered primary and the other secondary, as explained in Section 2.5 (the primary bin describes the most salient feature of that crash). In the preceding table, the cases are subdivided according to their primary bin.

The largest bin consists of the exceedingly severe crashes and anomalies, 49 cases, accounting for 40 percent of the 122 unweighted CDS cases (and 44% of the weighted cases). However, the second largest bin comprises the corner and/or oblique impacts (29 cases where it is the primary bin). The primary bin in 33 cases (27% of the unweighted cases, 23% of the weighted cases) is a corner/oblique impact and/or an impact with a tall, narrow object. If we accept the FARS-based statistic that there were an estimated 4,835 fatalities with belts and air bags in 2007, we could infer that about 1,100 of them were primarily corner/oblique and/or tall-narrow-object impacts, without being exceedingly severe. Underride of the rear or side of a heavy vehicle was the primary bin 17 times (14% of unweighted cases, 10% of weighted cases). A vulnerable occupant was the principal issue 15 times (12% of unweighted cases, 16% of weighted cases). Only 8 of the 122 cases do not fit in those four bins, and constitute the "other" bin (7% of unweighted cases, 7% of weighted cases).

Here are counts for the number of cases in each bin, if the cases in two bins are double-counted – e.g., if "corner impact" is the primary bin and "tall, narrow object" is the secondary bin for a particular case, that case is counted twice in the next table, once with the corner impacts, once with the tall, narrow objects:

Exceedingly severe crash and/or anomaly	**49**	
Exceedingly severe crash		*34*
Anomaly		*13*
Exceedingly severe crash and anomaly		*2*
Corner and/or oblique impact	**33**	
Corner impact		*15*
Oblique impact		*14*
Oblique corner impact		*4*
Underrode rear/side of heavy vehicle	**17**	
Underrode rear		*14*
Underrode side		*3*
Vulnerable occupant	**16**	
Age		*11*
Age and weight		*3*
Pre-existing medical condition		*2*
Tall, narrow object	**9**	
Corner impact		*5*
Centered impact		*4*
Other	**10**	

Now let us review the bins one-by-one, identify the typical crash configurations (with examples) and injury mechanisms, and try to explain why occupants with belts and air bags are still experiencing fatalities in late-model vehicles. We will hold the discussion of the "exceedingly severe" bin – where it is pretty obvious why crashes are fatal and there are few opportunities to improve crashworthiness – and start with the next largest, the corner/oblique-impact bin. Next, we will review the tall/narrow-object bin, because it resembles and substantially overlaps with the corner/oblique bin. The two other large bins, underrides and vulnerable occupants, follow.

3.2 The corner/oblique-impact bin

The team identified 33 offset crashes where the primary factor was determined to be limited horizontal structural engagement at the corners and/or the direction of the impact in the crash was sufficiently far away from longitudinal to affect occupant trajectories: 15 corner impacts, 14 oblique impacts, and 4 oblique corner impacts. Generally in these crashes there was insufficient structural interaction at the corners of the vehicle to absorb the energy in the event, resulting in severe occupant compartment intrusion. In these crashes either the longitudinal structural members were missed entirely or, in the case of an oblique crash, the structure did not experience a compressive, accordion type of collapse to absorb the energy. In the oblique crashes the longitudinal frame rails bent out of the way instead of crushing. The occupant in corner-type crashes was exposed to intrusion from the IP, A-pillar and possibly even the door. In an oblique impact, the occupant moved in the direction of the impact, which was toward the A-pillar or the center of the IP and was not afforded the proper protection from the deploying air bag.

Limited horizontal structural engagement was coded when the front of the vehicle was loaded in a way that failed to engage one of the two primary longitudinal frame rails in an effective manner. Limited engagement shifts part of the energy-absorption responsibility to the occupant compartment, and typically results in large intrusions that shrink the occupant ride-down space.

Limited horizontal engagement cases did not demonstrate good energy management with the longitudinal frame rails of the vehicle and the result is usually severe occupant compartment deformation. The struck object often peels away the front fender and then contacts the firewall area resulting in large instrument-panel intrusions. Crashes with limited horizontal engagement can be identified frequently as having Collision Deformation Classification (CDC)[13] designations of FLEE or FREE. The "E" in the fourth position denotes 16 inches or less of direct damage, located at a corner of the vehicle. It should also be mentioned, the WinSMASH ΔV estimated for many of these crashes appears to be unreliable and underestimate the ΔV. This is consistent with a study[14] that investigated the accuracy of WinSMASH as a function of crash mode, vehicle type, and vehicle stiffness. The authors concluded WinSMASH underestimated longitudinal ΔV by 29 percent for frontal overlap lower than 50 percent. The corner impacts identified in this crash classification bin are well under that overlap. The median effective overlap (as defined in Section 3.9) in the cases of this bin that had limited horizontal engagement as a primary or secondary factor was 18 percent.

[13] Collision Deformation Classification, *2009 SAE Handbook*, Recommended Practice No. J224. (2009). Warrendale, PA: Society of Automotive Engineers.
[14] Niehoff, P., & Gabler, H. (2006). *The Accuracy of WinSMASH Delta-V Estimates: The Influence of Vehicle Type, Stiffness, and Impact Mode*. Paper No. 06B-306. Warrendale, PA: Society of Automotive Engineers.

Obliqueness in the direction of the impact force was also a factor in many crashes with a small overlap as the principal direction of force was at enough of an angle from twelve o'clock to affect occupant trajectories and the subsequent restraint interaction. It was found that occupants sometimes did not receive the full protection of the air bag as they moved forward and laterally in response to the impact. Depending on the seating position and the direction of the obliquity, the occupant would move towards the A-pillar or center instrument panel. Large A-pillar intrusions were common in oblique cases because of the less-than-optimal structural engagement, and this would exacerbate the severity for the occupant by even further reducing ride-down space.

The findings in this section are also consistent with recent studies identifying the severity and frequency of vehicle crashes involving limited engagement of the vehicle's structure. In an analysis of fatal frontal crashes in Sweden, Lindquist et al.[15] found 34 percent of the belted fatalities occurred in crashes where there was no involvement of the longitudinal frame rails because of limited overlap. Based upon a review of NASS-CDS, Sherwood et al.[16] also found small-overlap crashes increase the injury risk to frontal occupants because of occupant compartment intrusion. The study identified that small-overlap crashes involved events with narrow fixed objects and vehicle-to-vehicle crashes including oblique impacts. The study concluded that, despite structural improvements, occupants are at risk to intrusion when a vehicle is loaded outboard of the longitudinal members.

Here are some case histories of corner and oblique impacts. At this point, let it be reiterated (see Section 2.2) that the conclusions on the sequence of events and causes of injury in each case are the authors' judgments and interpretation of the available evidence in the full case. In some of the cases, there is much evidence, and the team sifted through it to find the best explanation, in their judgment; in other cases, key evidence is unavailable, and the team had to infer what most likely happened.

Also, in the photographs accompanying the case histories, some of the visible damage may be due to post-crash efforts to extricate and save the occupant rather than impact forces. For example, doors and roofs may be removed and steering assemblies twisted out of the way to allow emergency medical technicians to extricate an occupant. The crash investigators on the review team were able to identify damage that likely occurred during extrication efforts.

Case No. 2005-2-54 is a corner impact example between two similar vehicles, a 2004 Dodge Neon (curb weight 2,584 lbs[17]), shown in Figure 3-1, and a 1997 Ford Escort (2,524 lbs), shown in Figure 3-2. The CDC code was a 12FLEE6, the estimated ΔV was 15 mph (based on the pre-2008 WinSMASH algorithm) and the posted speed was 55 mph. (The ΔV estimates for the cases discussed in the text of this report are the ones coded on CDS, computed by the WinSMASH program as it existed before 2008, unless the text explicitly specifies they were computed by the WinSMASH 2008 program that incorporates make-model-specific stiffness parameters derived

[15] Lindquist, M., Hall, A., & Bjornstig, U. (2004). Car Structural Characteristics of Fatal Frontal Crashes in Sweden, *International Journal of Crashworthiness*, Vol. 9, pp. 587-597.
[16] Sherwood, C., Nolan, J., & Zuby, D. (2009). Characteristics of Small Overlap Crash, *Proceedings of the Twenty-First International Technical Conference on the Enhanced Safety of Vehicles*, Paper No. 09-0423. Washington, DC: National Highway Traffic Safety Administration.
[17] Vehicle weights in this report are the curb weights specified in the CDS data.

from NCAP tests or they were extracted from an EDR.) In this crash, for both vehicles, there was no engagement of the longitudinal structural elements. Both vehicles overrode the front left wheel, and intrusion in the driver's occupant compartment included A-pillar deformation.

The air bags in the Neon did deploy; however, the driver of the Neon (age 60, weight 300 lbs) sustained fatal chest injuries from the steering wheel, which intruded 13 inches. The Neon driver also sustained chest injuries attributed to the door panel. Another characteristic of many corner crashes is door damage sustained as the striking vehicle pivots into the side of the struck vehicle. According to the information in the case, the 29-year-old male driver of the Escort survived the event with incapacitating lower leg injuries.

Neither vehicle performed well in the IIHS offset test. However, those are not primary factors, because the damage patterns are consistent with other corner impacts with limited horizontal engagement, even in the most recent vehicle designs.

Figure 3-1

Case No. 2005-2-54
Dodge Neon
(Note the narrow overlap and lack of engagement of longitudinal structural member)

Figure 3-2

Case No. 2005-2-54
Ford Escort
(Note the narrow overlap and lack of engagement of longitudinal structural member)

Case 2004-50-32 involved a 2001 Subaru Forester in which the right front passenger was killed as a result of an extreme right offset pole impact. The air bags deployed in the event. The pole contacted the right front of the vehicle, outboard of the longitudinal member, and caused the instrument panel, toe pan, and windshield header to intrude into the occupant's seating position. Instrument panel intrusion was measured as 2 feet 8 inches for the right front seating position.

The CDC was 12 FRAE9 with an unknown ΔV. The right front passenger received multiple abdominal lacerations as well as multiple chest, hip, and leg fractures including a crushed pelvis from the door trim. It should be noted that in many corner impacts, the striking object pockets itself into the door, resulting in injuries normally associated with a side impact.

Figure 3-3

Case 2004-50-32
Subaru Forester
Corner Impact With a Pole

Case No. 2006-75-23 involved a 2005 Mitsubishi Lancer (2,771 lbs) into a 1998 Chevrolet Suburban (5,399 lbs) in which the air bags deployed in both vehicles. The CDC code was 12FLEE7, the estimated ΔV was 35 mph, and the posted speed limit was 40 mph. The 22-year-old male driver of the Lancer sustained fatal blunt trauma to the head attributed to contact with the A-pillar, which had intruded deeply. The driver of the Suburban sustained minor injuries to the lower legs from the intruding toe pan.

Figure 3-5 shows that the corner impact resulted in a minimal engagement of the primary longitudinal structural frame rails. There was also a mass discrepancy between the vehicles that was almost 2-to-1 and a ride-height discrepancy. In this case, the large physical height of the Suburban induced crush in the Lancer consistent with a corner impact with a pole or tree (See Case 2004-50-32, above; note similarity of damage in Figure 3-3 and Figure 3-4).

Figure 3-4

Case No. 2006-75-23
Mitsubishi Lancer
Corner Impact

Figure 3-5

Case No. 2006-75-23
Mitsubishi Lancer (left side, toward front)
(Note limited structural engagement)

Figure 3-6

Case No. 2006-75-23
Chevrolet Suburban
(Note A-pillar intrusion)

Compared to Case No. 2005-2-54 (Neon versus Escort), the intrusion into the subject vehicle was aggravated by the mass and height of the Suburban. Because of the physical height of the vehicle, the Lancer experienced a substantial amount of occupant compartment intrusion. It should also be noted that because of the lack of horizontal structural engagement between the vehicles, the Suburban also experienced A-pillar intrusion and IP intrusion. However, the amount of intrusion was not recorded because the researcher investigating the case was only given quite limited access to the vehicle.

Case No. 2004-49-168, which involved a 2004 Mercedes S430, is an example of a crash with an oblique impact as the primary factor. This vehicle was struck by a 1999 Toyota Camry at a 40 degree PDOF, a CDC of 11FREW2 (i.e., somewhat wider than a FREE), and a total WinSMASH-estimated ΔV of 19 mph (30 km/h). In this crash the frontal structure did not absorb the energy by collapsing but bent in the direction of the impact. A 56-year-old female died from head injuries associated with the crash.

The team reviewed all the available information for this case and believes the right front passenger most likely moved forward and to the right in response to the impact. Thus, the occupant's head did not fully engage the deployed frontal air bag, striking the A-pillar instead and causing serious head injuries. Because of the oblique intrusion and the occupant's trajectory, she did not benefit from the frontal air bag or the side curtain air bag that also deployed in this crash. The team's assessment is that the head injuries were caused by a direct contact with the A-pillar and the chest injuries were associated with loading the seat belt.

Intrusion measurements were not taken for this case. From photos such as Figure 3-8, it is apparent that there was a severe amount of occupant compartment intrusion on the right side. The intrusion likely altered the trajectory of the deployed passenger air bag during the event. Large intrusions of the roof, A-pillar, windshield header, and instrument panel were frequently identified in this study for oblique impacts at the corners. In most cases, these large intrusions were the result of poor structural engagement or extreme crash severity. In these types of crashes it was determined the intrusions may have caused the injuries; however, it was secondary to the lack of structural engagement.

Figure 3-7

Case No. 2004-49-168
Mercedes Benz S430
Oblique Corner Impact

Figure 3-8

Case No. 2004-49-168
Mercedes Benz S430
Right-Side IP and A-Pillar Intrusion

An example of an oblique corner impact is Case No 2007-47-61, involving a 2005 Honda CRV and a 2001 Chevrolet Silverado. The Silverado's frontal plane contacted the front of the CRV and then rotated counter-clockwise. The CRV rolled over after the initial frontal impact. This vehicle was struck with a 350-degree PDOF, the CDC code for the first event was 12FYAW9, the posted speed limit was 55 mph, and a ΔV could not be estimated.

The male driver of the CRV died from head injuries attributed to direct contact injury with the hood of the Silverado. It appears the driver of the CRV moved toward the A-pillar because of the oblique nature of the crash and then hit the top of the Silverado's hood when it hit the door.

It appears the side impact was not of a sufficient force to deploy the curtain bags during this stage of the event. According to photos, the curtain bags did deploy. The CRV was equipped with a rollover sensor and the side curtain air bags likely deployed during the rollover. The side curtain air bags when deployed cover almost the entire window except for a small area at the lower A-pillar. If the side air bags had deployed prior to the rollover, the driver's head would have likely not hit the hood of the Silverado.

The CRV's A-pillar intruded into the occupant compartment 10 inches (see Figure 3-10). The primary longitudinal structure of the CRV was not engaged and the upper longitudinal structural element over the front wheel, connecting to the lower A-pillar (appears to protect against A-pillar intrusion under axial loading) was bent toward the centerline of the vehicle, exposing the occupant compartment.

Figure 3-9

Case No 2007-47-61
Honda CRV
Oblique Corner Impact

Figure 3-10

Case No 2007-47-61
Honda CRV
A-Pillar Intrusion

Table 3-1 tallies the primary and secondary factors in the 33 crashes of the corner/oblique bin. The factors were defined in Section 2.4. As explained in Section 2.3, each case must have at least one primary factor and many have more than one. A case need not have any secondary factors but most of them have more than one. The 33 crashes in this bin involve a total of 53 primary factors and 86 secondary factors. The predominant factors are limited horizontal engagement; oblique force; tall, narrow objects; upper-compartment intrusion; and poor occupant-air bag interaction. Excessive IP intrusion is common as a secondary factor.

Table 3-1: Primary and Secondary Factors Contributing to Corner/Oblique Impact Fatalities

Primary	Secondary	FACTOR
17	5	Limited horizontal structural engagement
16	2	Oblique crashes
5	1	Tall, narrow object
4	14	Roof, A-pillar, or other upper-compartment intrusion
3	10	Poor occupant-air bag interaction
3	6	Elevated occupant age
2	4	Underride, limited vertical structural engagement
1	10	Excessive IP or toe pan intrusion, or buckling of floor pan
1	5	Front-to-front incompatibility between two passenger vehicles
1	4	Exceedingly severe crash
0	7	Vehicle did not perform well in crash-safety rating programs
0	6	Obese occupant (BMI $\geq$ 30)
0	4	Air bag bottomed out
0	2	Belt system did not adequately restrain
0	2	Short-stature occupant
0	2	Seat did not adequately restrain
0	1	Out-of-position occupant
0	1	"Back-seat bullet"

3.3 The tall/narrow-object bin

The team identified nine cases involving a crash with a tall or narrow object such as a tree or pole: five corner impacts and four centered impacts. Hitting a tall/narrow object can lead to excessive intrusion and diminished restraint performance even in vehicles that perform well in crash-safety rating programs. The location of the impact on the vehicle and the size of the object are also important to how a vehicle performs. For example, if a vehicle hits the tall/narrow object at its corner or at the centerline of the vehicle, there is little structure to absorb the energy of the crash and that will result in excessive intrusion into the occupant compartment. The height of the object is also important, because in some cases the object would intrude at the roof header. In many ways, this crash-characteristic bin could be a subset of the corner/oblique bin when the point of impact is at the corners of the vehicle.

For example, in Case No. 2002-2-114, the driver of a 2000 Ford Ranger fell asleep, ran off the road, and hit three large diameter trees on the driver's side of the frontal plane. The posted speed limit was 55 mph, while the estimated WinSMASH ΔV was 11 mph and the CDC code was 12FLEE2. This vehicle had earned an acceptable rating in the IIHS frontal offset test.

The 68-year-old male driver sustained fatal head injuries, attributed to contact with the A-pillar or left side IP. The driver also received thoracic injuries from the steering wheel. The air bag deployed during the event and the IP intruded nine inches rearward.

The crush deformation to the Ranger is similar to the 2005 Mitsubishi Lancer that hit a taller 1998 Chevrolet Suburban in Case No. 2006-75-23, discussed in the Corner/oblique section of this report. Because of the similarities in intrusion and occupant kinematics, this case was also included in the corner/oblique crash-characteristic bin.

Figure 3-11

Case No. 2002-2-114
Ford Ranger
Corner Impact with a Tall/Narrow Object

Figure 3-12

Case No. 2002-2-114
2000 Ford Ranger
Side-Door Damage

Case No. 2002-49-100 is an example of an impact with a tall/narrow object that is slightly closer toward the center of the vehicle and appears to have at least partial engagement of a frame rail. In this case, a 2000 Chrysler Town & Country left the roadway and hit a medium-size tree. The CDC code was 12FYEW6. The posted speed limit was 35 mph and the WinSMASH-estimated ΔV was 49 mph. As in other crashes of this type, the ΔV estimate does not appear to be reliable, because of lack of crush of the longitudinal frame rails and the localized nature of the impact.

From photos such as Figure 3-13, it appears there was partial engagement of the primary longitudinal structure. Because of the reduced amount of energy absorbed by the front structure, the tree reached the firewall and displaced the IP two feet into the occupant compartment, also displacing the steering assembly, as shown in Figure 3-14. The 66-year-old female driver died from thoracic injuries including rib fractures and a lacerated aorta from contact with the steering wheel.

Figure 3-13

Case No. 2002-49-100
Chrysler Town & Country
Offset Impact with a Tree

Figure 3-14

Case No. 2002-49-100
Chrysler Town & Country
IP Intrusion

Case No. 2006-41-64 is an example of an impact directly between the frame rails. In this case the driver of a 2005 Lexus ES330 veered off a suburban residential road into a tree. The posted speed limit was 30 mph, and WinSMASH estimated a ΔV of 42 mph. However, because the primary structures did not absorb much of the energy, the estimated ΔV may not accurately reflect the true ΔV, as in Case No. 2002-49-100.

Exterior damage is extensive because it occurred in a relatively soft area between the frame rails. The only major component in this section of the vehicle is the power train. From Figure 3-15, it appears the frame rails bent toward the centerline and did not absorb the energy by crushing longitudinally as intended. That must have resulted in a soft initial crash pulse. The team infers that the soft pulse, in turn, likely delayed the deployment of the air bag to some extent. That probably diminished its protective effect: the driver hit and deformed the steering assembly, sustaining fatal thoracic injuries. The occupant's age (78) and, to a lesser extent, obesity contributed to the severity of the thoracic injuries.

Unlike Case No. 2002-49-100, the occupant compartment structure performed well (see Figure 3-16). The IP intruded into the passenger compartment only one inch.

Figure 3-15

Case No. 2006-41-64
Lexus ES330
Center Impact With a Tree
(Note Frame Rail Not Compressed)

Figure 3-16

Case No. 2006-41-64
Lexus ES330
Minor IP, Toe Pan, and Steering Wheel Intrusion

Case No. 2006-75-22 is a more severe crash than the preceding ones, but it, too, is a good illustration of what can happen when a vehicle impacts a narrow object with no engagement of the longitudinal frame rails to absorb the energy. In this example, a 2006 Mitsubishi Eclipse departed the roadway, impacting a tree directly between the frame rails. The CDC code was 12FZAW6. At the location of the crash, the posted speed limit was 30 mph and the estimated WinSMASH-2008 ΔV (with make-model-specific stiffness parameters) was 53 mph. Because the frame rails were not hit, it is not known how well WinSMASH estimated the ΔV.

As is evident from the photos, the tree hit the soft engine compartment and did not engage the front longitudinal frame rails. As a result, the tree penetrated the engine compartment up to the firewall, pushing the IP 25 inches toward the occupant. That is substantially more intrusion than would typically occur at a similar ΔV in a full frontal or an offset frontal with good structural engagement. It likely altered the trajectory of the deployed air bag and reduced the ride-down space for the passenger. The right-front, 27-year-old male passenger died due to a lacerated heart attributed to direct contact with the IP.

Figure 3-17

Case No. 2006-75-022
Mitsubishi Eclipse
Center Impact with a Tree
(Note Crush up to Firewall)

Figure 3-18

Case No. 2006-75-022
Mitsubishi Eclipse
(Note No Engagement of Longitudinal Frame Rails Though they Appear to Be Bent in Towards the Center of the Car)

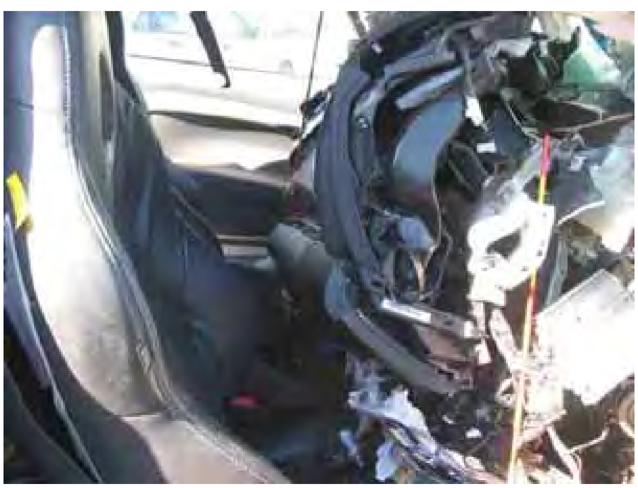


Figure 3-19

Case No. 2006-75-022
Mitsubishi Eclipse
25 Inches of Intrusion on Right-Side IP

Table 3-2 tallies the primary and secondary factors in the 9 crashes of the tall/narrow-object bin. As explained in Section 2.3, crashes may have multiple primary and secondary factors. The 9 crashes in this bin involve a total of 19 primary factors and 24 secondary factors. Understandably, “tall, narrow object” and limited horizontal engagement are the most important factors.

Table 3-2: Primary and Secondary Factors in Fatalities in Impacts with Tall/Narrow Objects

Primary	Secondary	FACTOR
9	0	Tall, narrow object
6	0	Limited horizontal structural engagement
2	4	Elevated occupant age
1	5	Excessive IP or toe pan intrusion, or buckling of floor pan
1	2	Roof, A-pillar, or other upper-compartment intrusion
0	3	Vehicle did not perform well in crash-safety rating programs
0	2	Obese occupant (BMI $\geq$ 30)
0	2	Air bag bottomed out
0	1	Exceedingly severe crash
0	1	Poor occupant-air bag interaction
0	1	Belt system did not adequately restrain
0	1	Out-of-position occupant
0	1	Seat did not adequately restrain
0	1	Steering assembly moved upward

3.4 The heavy-vehicle-underride bin

The team identified 17 cases that involved the subject vehicle impacting the rear, side or corner of a large truck, trailer or bus. Fourteen of those cases involved rear-end impacts with a large, heavy vehicle such as a semi-trailer or truck; the other three were side impacts. Because of their frequency, cases where the primary factors were determined to be excessive "Underride" and the "Trailer's guard did not prevent underride" are captured in this crash-characteristic category. Generally the subject vehicle also experienced "Roof, A-pillar or other upper-component intrusion" as a secondary factor from the impact with the truck/trailer, leading to fatal head injuries. The following examples provide insight into the severity of the case vehicle's damage and assess causes of the fatal injuries.

What could not be assessed in the majority of these cases was the heavy vehicle that was hit. Heavy vehicles are not CDS case vehicles; inspections and photos are not available. To reconstruct what happened in the event, reliance was placed on the photos of the subject vehicle. The difficulty was trying to determine if an underride guard was present on the struck vehicle and, if so, how did the guard and vehicle interact. What characterizes this crash bin is the severity of the upper-body intrusion. It would appear that in these crashes, if an underride guard was present, it could not withstand the force of the crash, leading to the rear of the heavy vehicle interacting with the A-pillar and upper compartment of the striking vehicle. Generally, these impacts lead to severe head and chest injuries from direct contact caused by intrusion of the steering wheel and/or roof components. Furthermore, the outcome of the crash can be similar for both small and large passenger vehicles.

For example, Case No. 2003-42-61 is a typical midsized passenger car impacting the rear end of a stopped truck. A 2002 Volkswagen Jetta was traveling on a six-lane divided highway hit the rear of a stopped 2000 Mitsubishi Fuso heavy truck that was parked in a travel lane, blocking traffic. At the location of the crash the posted speed limit was 55 mph. The CDC code was 32FDEW2. ΔV could not be estimated for this case; in general, ΔV can usually not be estimated with WinSMASH in collisions between passenger vehicles and heavy vehicles. The principle direction of force for the Jetta was at 10 degrees. The Jetta's dual frontal air bags deployed as a result of the impact.

The driver of the vehicle survived the event with minor injuries. The 47 year-old right front passenger in the Jetta, who was 5 feet 5 inches tall and weighed 205 pounds, sustained fatal chest injuries.

From photos such as Figure 3-20, it is apparent there was no structural engagement of the Jetta's primary longitudinal frame rails with the rear end of the parked truck. As a result the Jetta underrode the rear end of the truck causing severe deformation of the A-pillar/windshield on the right side of the vehicle (Figure 3-21). The greater damage to the passenger side of the vehicle likely explains why the driver survived. The passenger's head injuries are sourced to the roof header and the chest injuries sourced to the instrument panel on the right side.

The Mitsubishi truck was a non-CDS vehicle and there were no photos available for post-crash assessment of that vehicle. Therefore, it is unknown what sort of interaction there was between the rear-underride guard, if present, and the Jetta.

Figure 3-20

Case No. 2003-42-61
2002 VW Jetta
Front Right Corner View

Figure 3-21

Case No. 2003-42-61
2002 VW Jetta
Passenger Side Interior

Another example, Case No. 2004-73-165 involves an SUV, a taller vehicle than the Jetta in the preceding case. A 2002 Ford Explorer hit the rear end of a stopped trailer, the second of two trailers pulled by a 2005 Mack heavy truck. The crash occurred on a two-lane one-way divided expressway with a posted speed limit of 60 mph. The CDC code was 12FDAA6 and the ΔV could not be estimated.

As a result of the impact, the dual front airbags in the Explorer deployed. The driver of the Explorer was 52 years old, 6 feet 1 inch tall, and weighed 300 pounds. He sustained catastrophic head and neck injuries from the intruding windshield and steering wheel.

From Figure 3-22, it is evident the front longitudinal frame rails of the Explorer were barely damaged in the event. The primary impact was higher on the subject vehicle, and the rear end of the trailer hit the firewall, pushing the instrument panel and A-pillars into the occupant compartment. According to the case data, the steering-wheel assembly moved rearward toward the driver six inches (see Figure 3-23). The fatal internal chest injuries are sourced to the steering wheel.

The trailer was a non-CDS vehicle and there were no photos available for post-crash assessment of that vehicle. Therefore, it is unknown what sort of interaction there was between the rear-underride guard, if present, and the Explorer.

Figure 3-22

Case No. 2004-73-165
2002 Ford Explorer
Front

Figure 3-23

Case No. 2004-73-165
2002 Ford Explorer
IP Intrusion

Case No. 2005-9-189 involves a crossover SUV impacting the rear of a school bus, which is not required to have a rear underride guard. A 2005 Ford Escape was traveling on a four-lane divided roadway with a posted speed of 55 mph. The vehicle proceeded to impact the rear end of a stopped 1997 International school bus. The CDC code was 12FDAW9 and the ΔV could not be estimated.

The 43-year-old, 6 feet 2 inch, and 262-pound driver sustained fatal head injuries sourced to the roof header and chest injuries sourced to the steering wheel.

From Figure 3-24, it is evident the front longitudinal frame rails of the Escape were barely damaged in the event. The primary impact was higher, where it appears the Escape drove under the bus causing the windshield header to intrude 6 feet into the occupant compartment, as may be seen in Figure 3-25. Some of the injury sources may be direct contact with the rear end of the bus as opposed to case vehicle components, particularly the head and chest injuries.

As in the other cases discussed there are no photos available of the bus, because it is a non-CDS vehicle.

Figure 3-24

Case No. 2005-9-189
2005 Ford Escape
Front

Figure 3-25

Case No. 2005-9-189
2005 Ford Escape
IP Intrusion

The majority of the cases involved a rear-end impact with a heavy vehicle. However Case No. 2006-78-62 was one of three where the impact was to the side or corner of a trailer. A 2000 Dodge Ram 1500 Quad Cab was traveling eastbound on a two-lane roadway approaching an intersection with a posted speed of 55 mph. A 2005 Kenworth tractor/trailer was traveling southbound approaching the intersection. The left side of the Ram struck the right-rear trailer wheel/tires and then went under the trailer. The Ram experienced an engine fire and the vehicle was completely destroyed by fire. The CDC code was 69FDAW6 and the ΔV could not be estimated.

The driver and front passenger of the pickup truck extricated themselves and were found by the emergency crew on the ground, some distance away from the burning vehicle. The 50-year-old female driver died a few hours after the event. The driver died of neck and chest injuries. CDS sourced the fatal injuries to the steering wheel and left interior surface. The restrained passenger was hospitalized with a sternum fracture.

Consistent with the other underride cases discussed, from photos such as Figure 3-26 it is evident the front longitudinal frame rails of the Ram were barely damaged in the crash. The photos indicate this led to significant intrusion into the upper occupant compartment; however, intrusion measurements were not coded. Even though the impact was to the side of the trailer, the intrusion patterns and occupant injuries were consistent with those found in the impacts to the rear of a trailer, because of the extensive override.

Photographs were not available of the struck non-CDS vehicle. However, given the impact was on the trailer's side, it is unlikely there was an underride guard.

Figure 3-26

Case No. 2006-78-68
2000 Dodge Ram 1500 Pickup
Front

Figure 3-27

Case No. 2006-78-68
2000 Dodge Ram 1500 Pickup
Driver's Side Interior

Table 3-3 tallies the primary and secondary factors in the 17 crashes of the heavy-vehicle-underride bin. Crashes may have multiple primary and secondary factors. The 17 crashes in this bin involve a total of 32 primary factors and 21 secondary factors. Of course, underride and the trailer's guard are the two major primary factors. As explained in Section 2.4, these two factors are not mutually exclusive; an impact where the guard failed to prevent underride will also be an impact where there was underride. On the other hand, an impact into the side of a trailer can be a case of underride, but performance of the guard is not a factor, because there is no guard.[18] Upper-compartment intrusion is a common secondary factor; it is usually secondary because it is an inevitable consequence of the underride.

Table 3-3: Primary and Secondary Factors in Underrides of Rear/Side of Heavy Vehicles

Primary	Secondary	FACTOR
15	1	Underride, limited vertical structural engagement
13	0	Trailer's guard did not prevent underride
2	10	Roof, A-pillar, or other upper-compartment intrusion
2	0	Limited horizontal structural engagement
0	2	Exceedingly severe crash
0	2	Excessive IP or toe pan intrusion, or buckling of floor pan
0	2	Vehicle did not perform well in crash-safety rating programs
0	1	Belt system did not adequately restrain
0	1	"Back-seat bullet" – rear-seat occupant increased the load on the front seat and contributed to seat failure
0	1	Air bag bottomed out
0	1	Tall or large occupant (not obese)

3.5 The vulnerable-occupant bin

Sixteen cases were identified as fatalities due to some kind of occupant vulnerability that increased the risk of sustaining fatal injuries in what was not considered an overly severe crash: in 11 cases, the occupant's age was the primary factor, in 3 cases age and weight, and in 2 cases a pre-existing medical condition. It is known that injury tolerance tends to decrease as a person ages, but there is no specific age threshold at which injury risk markedly increases, as it depends on a number of factors and is unique to each individual. In addition to being more susceptible to any number of specific injuries, an elderly crash victim's body may have a poor response to multi-system trauma – meaning that their body's ability to cope with multiple crash injuries is diminished, leading to an overall increase in fatality risk. Certain medical conditions also decrease injury tolerance and the ability for an occupant to respond to multi-system trauma. In some cases, information pertaining to pre-existing medical conditions helped the team determine whether such conditions were relevant to the fatality.

Other occupant-related vulnerabilities were related to occupant size – both obesity and short stature can act to increase injury risk. Occupants with significantly higher body mass or girth tend to challenge restraint systems and require a larger volume of space for ride-down. When an occupant's height is much less than that of an average-size male, the occupant may have to sit very close to the steering wheel or the occupant's body may otherwise not interact with the

[18] Table 3-3 indicates one case among the 17 where underride was not a factor. A pickup truck drove into the side of a semi-trailer, but immediately hit the rear axles of the trailer, with fatal consequences, rather than further entering the space beneath the trailer. This case was included in the "side underride" bin because it closely resembled the other side-underride cases, except for the point of impact.

restraints and interior structures in an optimal manner. Weight or height was a primary or secondary factor in a number of these cases.

As an example of a case in which the occupant's age was deemed critical, see Case No. 2004-50-147, in which the 80-year-old driver sustained a number of thoracic injuries leading to her demise. CDS did not report any pre-existing medical conditions. The crash was not very severe with a coded ΔV of 22 mph (25 mph by make-model-specific WinSMASH-2008), and it did not result in any intrusions into the occupant's space. The team did not see signs of contact with the steering wheel and concluded that her numerous thoracic injuries were caused by loading from the shoulder belt. She suffered a number of fractured ribs and a heart laceration; the thoracic cage typically shows a greater tendency to sustain fracture with elevated age. Given that the chest injuries were responsible for her demise, and that this crash was not severe, the team felt that her age was a critical element leading to her death.

Figure 3-28

Case No. 2004-50-147
Honda Civic
Vulnerable Occupant (Age)

Case No. 2002-75-53 is an example of a fatality that was likely due to the occupant's pre-existing medical condition. The minor frontal crash, with a ΔV of 14 mph, of the Toyota 4Runner led to the death of the right-front passenger, who suffered from advanced lung cancer that had metastasized to the liver.

Figure 3-29

Case No. 2002-75-53
Toyota 4Runner
Occupant with Medical Condition

Her injuries included a heart laceration, a subdural hematoma and a cervical spine fracture. Although an older occupant (71 years old) who was of smaller stature (4'11"), she was in the right front passenger seat, making it unlikely that she was sitting close to the IP (as may be the case for a driver of her stature). In fact, the seat was noted to be in the mid-to-rear track position, so interaction with a deploying bag was unlikely and there would be little reason for her type of injuries to occur in a typical adult. Due to her advanced cancer, the team concluded that her body's condition was weakened, making her exceptionally fragile and more susceptible to injury in this minor crash. The two other occupants in this vehicle were either not injured or only suffered minor contusions – suggesting that the pulse of this crash should not be injurious to a normal belted occupant.

The final example of occupant vulnerability is in Case No. 2004-79-244, where a Cadillac DeVille Touring Sedan struck a Ford Escape in a right-offset manner. The impact was not very severe, as evidenced by a ΔV of 23 mph, and the right front passenger of the Cadillac survived with a femur fracture and some other minor injuries. The driver, a 70-year-old male weighing 300 pounds, suffered serious thoracic injuries from the impact. He likely, due to his weight, challenged the belt and the air bag. The occupant's loading also caused the seat to deform. His age was also likely to have contributed to the severity of his injuries.

Figure 3-30

Case No. 2004-79-244
Cadillac DeVille Touring Sedan
Vulnerable Occupant (Obesity and Age)

Table 3-4 tallies the primary and secondary factors in the 16 crashes of the vulnerable-occupant bin. As explained in Section 2.3, crashes may have multiple primary and secondary factors. The 16 crashes in this bin involve a total of 20 primary factors and 29 secondary factors. The occupant's age is by far the dominant primary factor (13 times); then obesity and pre-existing medical conditions. Short stature is never a primary factor, but it is a secondary factor in four cases. Poor occupant-air bag interaction and oblique force are also common as secondary factors.

Table 3-4: Primary and Secondary Factors in Fatalities to Vulnerable Occupants

Primary	Secondary	FACTOR
13	2	Elevated occupant age
3	1	Obese occupant (BMI ≥ 30)
2	0	Pre-existing medical condition
1	2	Limited horizontal structural engagement
1	0	Post-crash injury complications
0	4	Short-stature occupant
0	4	Poor occupant-air bag interaction
0	3	Oblique crashes
0	2	Vehicle did not perform well in crash-safety rating programs
0	2	Out-of-position occupant
0	2	Air bag injured out-of-position occupant (e.g., SCI case)
0	2	Air bag bottomed out
0	1	Front-to-front incompatibility between two passenger vehicles (cars or LTVs)
0	1	Multiple event crash
0	1	Belt system did not adequately restrain
0	1	Air bag switched off
0	1	Belt-caused injury

3.6 Exceedingly severe and/or anomaly cases

Exceedingly severe and/or anomaly cases made up the largest of the six bins in the study, with 49 cases. Of these, 34 were considered exceedingly severe, 13 were anomalies, and 2 fatalities were exceedingly severe with an additional anomaly.

Thirty-four of the fatalities were attributed primarily to the crash being exceedingly severe. While there were no quantitative criteria (ΔV, crush, etc.) used to determine whether a crash was exceedingly severe, this factor was typically selected when it was apparent that the amount of crash-energy absorbed was much higher than that at typical crash-test speeds. In these cases, it was understood that the vehicle structure and restraint systems were taxed beyond their reasonable design capabilities. Previous review of crash data, such as one by Viano and Ridella in 1996, also noted a high share of exceedingly severe crashes among belted fatalities.[19]

"Exceedingly severe" was applied as a primary factor more than any other factor, and it was frequently the only primary factor coded. In an exceedingly severe crash, it is expected that secondary effects may include large occupant-compartment intrusions and air bags that bottom out when loaded by the occupant. There were some cases in which "exceedingly severe" was considered a secondary factor. In these cases, the high level of crash energy was felt to play a role in the occupant's demise, but other factors such as structural engagement or crash direction were deemed more directly responsible.

[19] Viano, D. C., & Ridella, S. (1996). Crash Causation: a Case Study of Fatal Accident Circumstances and Configurations, *1996 SAE Transactions*, Paper No. 960458. Warrendale, PA: Society of Automotive Engineers.

One example of a case considered exceedingly severe was Case No. 2007-74-107, in which a 2000 Ford Taurus hit a 2000 Buick Park Avenue in a full-frontal configuration, resulting in fatality to the three front-seat occupants of the two cars. This crash of two similarly-sized passenger vehicles occurred on a highway where one vehicle was traveling in the wrong direction, so both vehicles were traveling at a high rate of speed immediately prior to the impact. The distributed impact resulted in a ΔV of 59 mph for the Taurus, which had received a 5-Star NCAP rating and a Good IIHS frontal offset rating. The high level of crash energy led to instrument-panel intrusion. The driver bottomed out the air bag, as evidenced by deformation of the steering wheel rim.

While not irrelevant to the study of the fatal frontal crash problem, the exceedingly severe crashes can be separated from the rest of the fatalities based on the difficulty associated with addressing crashes of such severity. Building vehicles to withstand high-energy crashes would require trade-offs, so designing structures and restraints for good performance in these rare crashes may not be feasible. The team felt that the exceedingly severe crashes would be more appropriate to look at from a crash-avoidance or crash-severity-mitigation perspective, and thus segregated them from the other cases when discussing potential research areas.

Figure 3-31

Case No. 2007-74-107
2000 Ford Taurus
Exceedingly Severe Impact

Figure 3-32

Case No. 2007-74-107
2000 Ford Taurus
Exceedingly Severe Impact

Thirteen anomalies were included in this bin, encompassing a wide variety of crash scenarios.

4	Struck by rolling or airborne vehicle
3	Hit unusual vehicle structure, or object
2	Died due to burns, not crash injuries
1	Went airborne and struck another vehicle
1	Hit object while rolling
1	Multiple event crash
1	Air bag deployed prior to highest ΔV

An example of an anomaly is Case No. 2003-8-23, a 2000 Ford E-150 cargo van that sustained a moderate impact with a pole, rolled one-quarter turn, and then burned. The driver's impairment and his possible medical condition hindered his exit from the vehicle. Another anomaly example was Case No. 2003-11-18, a 2001 Subaru Forester struck by an airborne snowmobile. Although these cases met the criteria for inclusion in the study they are outside the scope of potential crashworthiness research areas.

Figure 3-33

Case No. 2003-8-23
2000 Ford E-150 Cargo Van
Hit Pole, Rolled ¼ Turn, and Burned

Figure 3-34

Case No. 2003-11-18
2001 Subaru Forester
Struck by Airborne Snowmobile

Table 3-5 tallies the primary and secondary factors in the 49 crashes of the exceedingly severe/anomaly bin. Crashes may have multiple primary and secondary factors. The 49 crashes in this bin involve a total of 63 primary factors and 117 secondary factors. All of them have "exceedingly severe" and/or "anomaly" as a primary factor. Underride is not unusual as a primary or a secondary factor. Common as secondary factors, because they are consequences of the crash being so severe, include upper-compartment intrusion, bottoming out of the air bag, IP intrusion, or belts not adequately restraining. There were also numerous cases where the occupant's age or obesity, or the relatively poor structural performance of the less up-to-date vehicles was a factor, but secondary to the overall crash severity.

Table 3-5: Primary and Secondary Factors in Exceedingly Severe Crashes/Anomalies

Primary	Secondary	FACTOR
36	1	Exceedingly severe crash
16	0	Anomaly (unusual crash circumstance)
5	8	Underride, limited vertical structural engagement
2	0	Post-crash fire resulting in fatal burns
1	19	Roof, A-pillar, or other upper-compartment intrusion
1	6	Oblique crashes
1	4	Front-to-front incompatibility between two passenger vehicles (cars or LTVs)
1	0	Multiple event crash
0	16	Air bag bottomed out
0	13	Excessive IP or toe pan intrusion, or buckling of floor pan
0	13	Obese occupant (BMI $\geq$ 30)
0	12	Vehicle did not perform well in crash-safety rating programs
0	6	Elevated occupant age
0	5	Belt system did not adequately restrain
0	4	Poor occupant-air bag interaction
0	3	Limited horizontal structural engagement
0	2	Trailer's guard did not prevent underride
0	2	Steering assembly moved upward
0	1	Seat did not adequately restrain
0	1	Pre-existing medical condition
0	1	Short-stature occupant

3.7 The all-other-crashes bin

The final, "All Others" bin involved crash events that didn't occur frequently enough to justify their own category or fit into one of the other five bins. There was no predominant factor; the 10 cases in this bin had 16 different primary factors and 10 different secondary factors listed.

Some of the cases in the "All Other" bin contain areas for potential future research, but appear to be much less common than the crashes in the four large bins. Some example scenarios are air bags injuring out-of-position occupants and underride in a not-too-severe head-on crash with a heavy vehicle.

For example, Case No. 2004-43-291 involved a 2003 Dodge Caravan struck by an oncoming heavy truck that crossed a median and entered the Caravan's lane. This crash was not exceedingly severe; however, the underride caused 22 inches of header intrusion and 13 inches of IP intrusion, producing fatal chest injuries. The 33-year-old female driver was wearing the three-point belt equipped with a pretensioner and a force limiter. The advanced frontal air bag deployed during the impact. The primary factors coded to this crash were underride and limited horizontal structural engagement. Supporting the "not exceedingly severe" designation, two children seated in child restraints in the second row escaped virtually unharmed. Head-on crashes with heavy vehicles were not included in the "underrode rear/side of heavy vehicle" bin because (1) performance of existing rear-impact guards or potentially available side-impact guards is not an issue; and (2) most fatal head-on crashes with heavy vehicles are exceedingly severe, whereas most of our rear and side impacts are not that severe, aside from the underride.

Figure 3-35

Case No. 2004-43-291
2003 Dodge Caravan
(Note limited bumper engagement)

The remaining cases in this bin are less germane to future crashworthiness research. Some involved relatively old vehicle designs, carryovers from pre-2000 models. The structural performance of these models has already been improved in the intervening years. Another case involved an unrestrained back-seat occupant who hit the front seatback.

An example of relatively older vehicle design as a critical issue is Case No. 2007-12-180, which was a 2000 Dodge Dakota Quad Cab involved in an angled full-frontal collision with a Ford F-250, causing critical chest injuries to the 56-year-old female driver. As discussed in Section 2.4, the primary factor, "vehicles did not perform well in crash-safety rating programs" usually refers to vehicles that were carryovers from earlier designs with poor or marginal performance in the IIHS offset test. The 2000 Dakota is fundamentally a carryover from the 1997 redesign; the Dakota was again redesigned in 2005. The 1997-to-2004 2-door Dakota received a Poor IIHS offset rating (frontal structural performance would probably be similar for the Quad Cab). The other primary factor in the crash was excessive IP and toe-pan intrusion. WinSMASH-2008 calculated a ΔV of 38mph and barrier equivalent speed of 32mph. Secondary factors in the crash included the driver's obesity, short stature, and poor occupant-air bag interaction.

Figure 3-36

Case No. 2007-12-180
2000 Dodge Dakota

Table 3-6 tallies the primary and secondary factors in the 10 crashes of the all-others bin. Crashes may have multiple primary and secondary factors. The 10 crashes in this bin involve a total of 20 primary factors and 15 secondary factors. There was no predominant factor. The most common primary factors, coded in two cases each in this bin were excessive instrument panel or toe pan intrusion, underride, limited horizontal structural engagement, and vehicle did not perform well in crash-safety rating programs. The secondary factors seen most often were exceedingly high crash severity, and the air bag bottomed out, each occurring three times.

Table 3-6: Primary and Secondary Factors in Other Crashes

Primary	Secondary	FACTOR
2	1	Excessive IP or toe pan intrusion, or buckling of floor pan
2	0	Underride, limited vertical structural engagement
2	0	Limited horizontal structural engagement
2	0	Vehicle did not perform well in crash-safety rating programs
1	1	Oblique crashes
1	1	Elevated occupant age
1	1	Belt system did not adequately restrain
1	0	Anomaly (unusual crash circumstance)
1	0	Front-to-front incompatibility between two passenger vehicles
1	0	Multiple event crash
1	0	Out-of-position occupant
1	0	Seat did not adequately restrain
1	0	Air bag injured out-of-position occupant (e.g., SCI case)
1	0	"Back-seat bullet"
1	0	Air bag did not deploy
1	0	Post-crash injury complications
0	3	Exceedingly severe crash
0	3	Air bag bottomed out
0	2	Roof, A-pillar, or other upper-compartment intrusion
0	1	Obese occupant (BMI ≥ 30)
0	1	Poor occupant-air bag interaction
0	1	Short-stature occupant

3.8 Summary tally of primary and secondary factors in our 122 cases

Table 3-7 tallies the primary and secondary factors in the 122 fatality cases. There are a total of 186 primary factors and 265 secondary factors in these cases. The single most common primary factor was exceedingly high crash severity (37 primary occurrences). But the next three factors, underride, limited horizontal engagement, and oblique force, all sharing the characteristic of poor structural engagement, appeared a combined 60 times as primary factors. Anomalous crash circumstances, elevated occupant age, the trailer's underride guard and tall, narrow objects are also frequent primary factors.

The single most common factor in our 122 crashes, appearing 6 times as primary and 43 times as secondary, for a total of 49, is upper-compartment intrusion. It is usually only a secondary factor because it is a consequence of "first-cause" factors, the severity or the configuration of the impact. Excessive IP intrusion, the occupant's obesity, poor occupant-air bag interaction, and the air bag bottoming out were common secondary factors (the last, never a primary factor). Many vehicles in the study, although model year 2000 or newer, were actually pre-2000 designs, and their relatively poor structural performance was often a severity-increasing factor, but usually a secondary factor. Front-to-front incompatibility between passenger vehicles and the occupant's short stature were also fairly common as secondary factors.

Table 3-7: Primary and Secondary Factors in All Crashes

Primary	Secondary	FACTOR
37	10	Exceedingly severe crash
23	13	Underride, limited vertical structural engagement
20	8	Limited horizontal structural engagement
17	11	Oblique crashes
17	0	Anomaly (unusual crash circumstance)
16	15	Elevated occupant age
13	2	Trailer's guard did not prevent underride
9	1	Tall, narrow object
6	43	Roof, A-pillar, or other upper-compartment intrusion
4	27	Excessive IP or toe pan intrusion, or buckling of floor pan
3	21	Obese occupant (BMI $\geq$ 30)
3	18	Poor occupant-air bag interaction
2	23	Vehicle did not perform well in crash-safety rating programs
2	10	Front-to-front incompatibility between two passenger vehicles (cars or LTVs)
2	1	Pre-existing medical condition
2	1	Multiple event crash
2	0	Post-crash injury complications
2	0	Post-crash fire resulting in fatal burns
1	10	Belt system did not adequately restrain
1	3	Out-of-position occupant
1	3	Seat did not adequately restrain
1	2	Air bag injured out-of-position occupant (e.g., SCI case)
1	2	"Back-seat bullet" – rear-seat occupant increased the load on the front seat and contributed to seat failure
1	0	Air bag did not deploy
0	27	Air bag bottomed out
0	8	Short-stature occupant
0	3	Steering assembly moved upward
0	1	Air bag switched off
0	1	Belt-caused injury
0	1	Tall or large occupant (not obese)

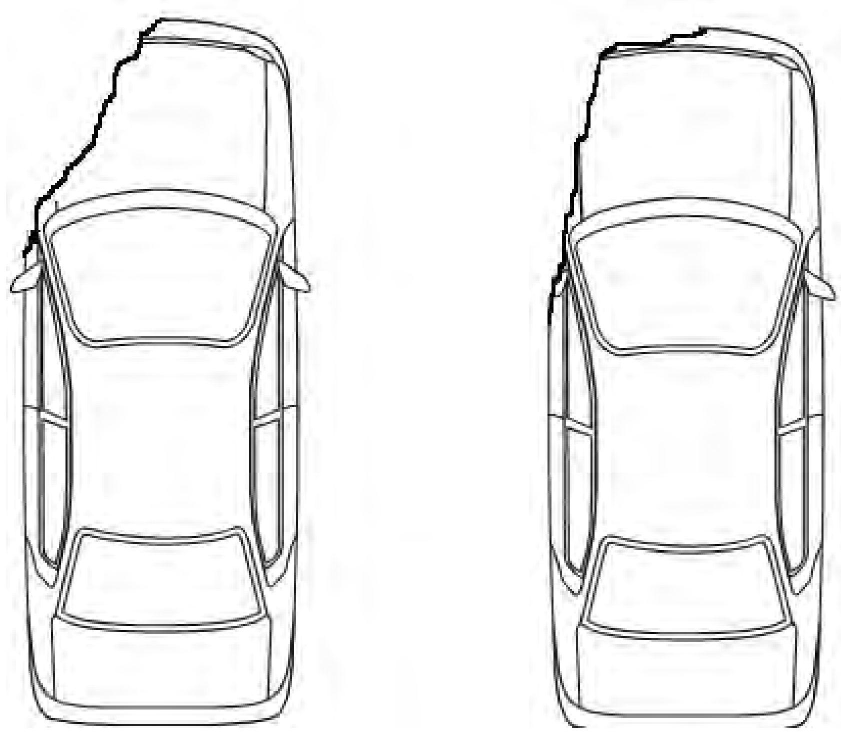
3.9 Roles of heavy vehicles, degree of offset, occupant age, and occupant size

Heavy vehicles: Thirty-three fatalities, accounting for 27 percent of the 122 unweighted CDS cases (and 24% of the weighted cases) involved collisions with tractor-trailers, heavy trucks or buses. In 18 of the fatalities, the case vehicle frontally hit the rear of the heavy vehicle; in 15, the front or the side of the heavy vehicle. Underride was a factor in 16 of the 18 front-to-rear cases and a primary factor in 14 (and "trailer's guard did not prevent underride" was also a primary factor in all those cases, except for one in which the struck vehicle was a school bus, not equipped with an underride guard). Underride was a factor in 11 of the 15 front-to-front/side cases, primary in 8.

89	Did not involve a heavy truck or bus
14	Front of case vehicle hit rear of trailer, truck, or bus; underride a primary factor
2	Front-to-rear; underride a secondary factor
2	Front-to-rear; underride not a factor
8	Front of case vehicle hit front or side of tractor, trailer, truck, or bus; underride a primary factor
3	Front-to-front/side; underride a secondary factor
4	Front-to-front/side; underride not a factor

Fixed objects: In 27 of the 122 fatalities (22% of the unweighted cases, 23% of the weighted cases), the principal impact was with a fixed object.

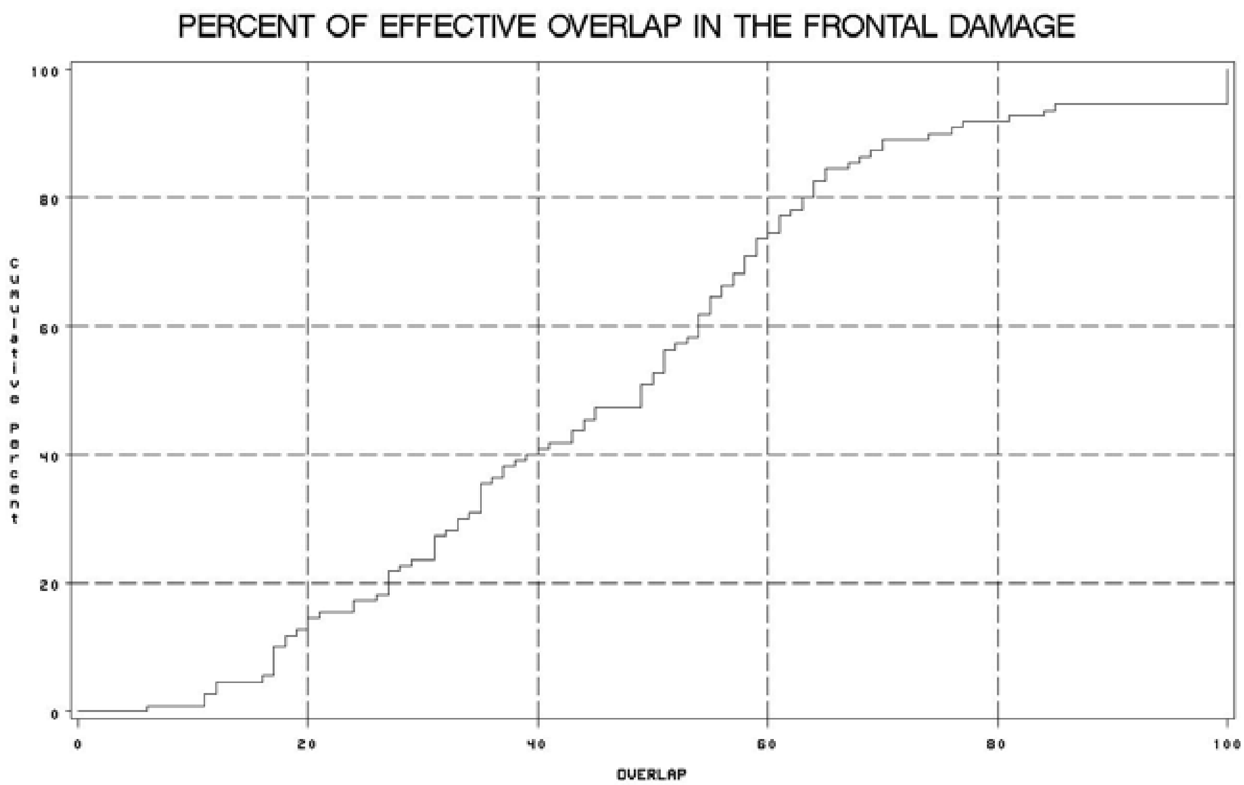
Offset: One way to define the percentage of overlap in a frontal impact is the width of direct damage (DIRDAMW on CDS) divided by the width of the front end (UNENDW). However, this might overstate the amount of effective overlap if the direct damage is shallow across most of its width and then tapers off strongly to one side. For example, both of these cars have direct damage approximately halfway across the front, but the car on the left has extensive engagement while the car on the right has damage more nearly resembling a corner impact.



The team defined the “effective overlap” as follows from CDS data elements:

Step 1: Compute actual % of the front end with direct damage DIRDAMW/UNDENDW
Step 2: Compute extent to which front-end damage tapers off to one side,
2a Take average of $C_1^2, \dots , C_6^2$ (the C_i are squared because energy absorbed is approximately proportional to the square of the crush depth)
2b Divide it by the maximum of $C_1^2, \dots , C_6^2$
2c Multiply by 100, and in the few cases where $L \neq$ UNDENDW, multiply also by L/UNDENDW
Step 3: Take the <u>smaller</u> of the two numbers and round to the nearest integer. This is the “effective overlap,” the proportion of the front end that has real damage.

The graph of the cumulative distribution of effective overlap shows that 25 percent of the impacts had effective overlap of 30 percent or less, 50 percent had effective overlap of 48 percent or less, and 75 percent of the impacts had effective overlap of 60 percent or less.



Let us categorize overlap of 67 percent or more a "full frontal," 25 to 66 percent an "offset frontal," and less than 25 percent a narrow frontal. The distribution for our 122 impacts is

20	Effectively **full-frontal**: "effective overlap" 67-100
66	Effectively **offset** damage on the occupant's side of the vehicle: "effective overlap" 25-66, (and not FLEE or FREE)
18	Effectively **corner** damage on the occupant's side of the vehicle: CDC is FLEE or FLAE[20] (for driver) or FREE or FRAE (for passenger), and/or "effective overlap" 0-24
7	**Centered** impact on narrow, fixed object as evidenced by CDC (FCEW, FCEN, FYEN, FZEN) or by little or no damage at both corners
5	No damage to front end of vehicle (e.g., underride so extreme that only greenhouse is damaged, or vehicle hit greenhouse)
6	Effectively offset or corner damage, but the damage is concentrated on the side away from the fatality

Only 20 of our 122 cases are effectively full frontals, and only 6 have frontal damage concentrated on the side away from the occupant's seat (i.e., right side for driver, left side for passenger).

<u>Occupant age</u>: In 46 of our 122 cases (38%), the occupant's age or pre-existing medical condition was a factor and/or the occupant was 60 years old or older. In 18 of these cases it was a primary factor. (The 13 cases where the occupant was 60+ years old but age is not a factor are crashes so severe that even a young person would not likely have survived – or they involved a type of head injury where vulnerability does not increase too much with age.)

76	Not an older occupant; medical condition not a factor
18	Occupant age or pre-existing medical condition a primary factor (can be any age)
15	Occupant age or medical condition a secondary factor (can be any age)
13	Occupant age 60+, but age not a factor in the crash

<u>Occupant BMI, weight, or height</u>: The occupant's obesity or size was judged to be a primary factor increasing fatality risk in three cases, and a secondary factor in 27 cases. For these judgments, as explained in Section 2.4, there is no specific weight or height limit; the factor is assigned if it contributed to the severity of the injuries. In an additional 26 cases, the occupants' obesity or size was judged not to be a primary or secondary factor, but the occupant was beyond the following limits: obese (BMI ≥30), tall (≥6'2"), short (≤5'2"), large (≥250 pounds), or small (≤100 pounds). Thus, in a total of 56 of our 122 fatalities, the occupants' obesity or size was a primary or secondary factor, and/or exceeded the above limits.

66	Not an obese, tall, short, big, or small occupant
3	Occupant obesity or size a primary factor
27	Occupant obesity or size a secondary factor
26	Occupant obese (BMI ≥30), tall (≥6'2"), short (≤5'2"), large (≥250 pounds), or small (≤100 pounds), but none of these a factor in the crash

[20] A FLAE or FRAE is a corner impact (E in fourth position) with damage not only below the beltline but also above it and up into the greenhouse area of the passenger compartment (A in third position rather than E).

Comparison of CDS and FARS distributions: The 2007 FARS file has information on crash type, occupant age and driver height/weight that may be compared to the weighted distributions of our CDS cases. The national proportions of front-seat occupant fatalities in cars and LTVs that involved a collision with a heavy truck were:

> 12 percent of fatalities in all crashes;
> 16 percent of fatalities in frontal crashes;
> 19 percent of fatalities in frontal crashes with belt use and at seats equipped with air bags; and
> 20 percent of fatalities in frontal crashes, with belts and air bags, in MY 2000+ vehicles.

The proportions where the most harmful event was a collision with a fixed object were:

> 27 percent of fatalities in all crashes;
> 38 percent of fatalities in frontal crashes;
> 28 percent of fatalities in frontal crashes with belt use and at seats equipped with air bags; and
> 28 percent of fatalities in frontal crashes, with belts and air bags, in MY 2000+ vehicles.

Of our 122 CDS cases, weighted by the national sampling factor RATWGT, 24 percent were collisions with heavy trucks and 23 percent were collisions with fixed objects. These are similar to the FARS proportions in late-model vehicles for occupants protected by belts and air bags (20% and 28%, respectively). However, it is noteworthy that on FARS, belted occupants of late-model vehicles have a higher proportion of collisions with heavy trucks and a lower proportion of collisions with fixed objects than other victims of frontal crashes.

The proportions of fatalities age 60 or greater were as follows:

> 21 percent of fatalities in all crashes;
> 24 percent of fatalities in frontal crashes;
> 32 percent of fatalities in frontal crashes with belt use and at seats equipped with air bags; and
> 34 percent of fatalities in frontal crashes, with belts and air bags, in MY 2000+ vehicles.

The last percentage is similar to our weighted CDS cases, where 38 percent of the fatalities were 60 or older. Here, too, the proportion of older occupants on FARS grows as the data are limited to frontal crashes, with belts and air bags, and in late-model vehicles.

FARS has information on the height and weight of drivers, but not passengers. The proportion of driver fatalities who were obese (BMI ≥30), tall (≥6’2”), short (≤5’2”), large (≥250 pounds), or small (≤100 pounds) does not vary much in 2007 FARS:

> 33 percent of fatalities in all crashes;
> 35 percent of fatalities in frontal crashes;
> 37 percent of fatalities in frontal crashes with belt use and at seats equipped with air bags; and
> 36 percent of fatalities in frontal crashes, with belts and air bags, in MY 2000+ vehicles.

Among our weighted CDS cases, a quite similar 31 percent of the drivers were obese, tall, short, large, or small.

In summary, the CDS cases have a high percentage of heavy-truck impacts and older occupants when they are compared to the entire national population of crash fatalities. But when the national population is limited to similar crash conditions – belted occupants of late-model vehicles (all equipped with air bags) in frontal impacts – the CDS and FARS distributions are fairly similar.

CHAPTER 4

CRASH TYPES WE SAW INFREQUENTLY OR NOT AT ALL

As previously discussed, certain primary and secondary factors and crash configurations were common in the study. So now let us take a look at the factors and crash configurations that were not observed as often.

Early in the study it became apparent that very few of the crashes in the study resembled FMVSS, NCAP, or IIHS crash tests. Seat belts, air bags, and energy-absorbing frontal structures are accomplishing their goal in frontal crashes resembling the crash tests. The fatalities that occurred in full frontal or offset-frontal configurations typically had additional issues such as underride, a vulnerable occupant, or exceedingly high severity.

Another situation not encountered often was front-to-front height- or stiffness-incompatibility between two passenger vehicles. It was listed as a primary factor in only two of the 122 cases, Case Nos. 2004-45-113 and 2006-75-98. Both involved a passenger car hitting an SUV; the first was a corner impact and the second exceedingly severe (ΔV = 63 mph). Incompatibility was a secondary factor in 10 cases. Typically, incompatibility appeared as a secondary factor in combination with corner/oblique crashes where there was less structural engagement. In all 12 cases where incompatibility was a primary or secondary factor, the "other" vehicle was not yet designed to the industry's voluntary commitment to geometrically align the front energy-absorbing structure with the bumper zone of passenger cars (discussed in Section 1.4).

Air bags, in general, did not seem to be a large problem in the study. Issues relating to air bags were rarely a primary factor. No cases were found in which an air bag had not been replaced. Case No. 2001-12-116 was the only one where an air bag failed to deploy and that was the primary factor. It is unknown why the air bag did not deploy; however, it is known that the case vehicle had a low-severity frontal impact with one car just before its high-severity head-on collision with another car. An air bag injuring an out-of-position occupant was a primary factor in Case No. 2006-11-220 – a multiple-event crash where an SUV crossed a ditch, throwing the driver out of position, then hit a pole, deploying the air bag – and a secondary factor in two others.

The only air-bag-related issues that showed up in considerable numbers in the study were poor occupant-air bag interaction and bottoming out of the air bag. Poor occupant-air bag interaction was indicated as the primary factor in 3 cases, Nos. 2001-81-117, 2002-42-34, and 2004-49-168. All 3 were oblique impacts, where the occupants' trajectory was not straight ahead into the air bags. It was a secondary factor in 18 crashes: 12 of these were oblique and/or corner impacts, 3 were multiple-event crashes, and 3 involved short-stature occupants in vehicles that were not yet required to meet a test with a 5^{th}-percentile-female ATD. Bottoming out of the air bag was not determined to be a primary factor in any of the cases, but was listed as a secondary factor in 26 cases. The majority of those cases, 14, were categorized in the exceedingly severe/anomaly crash-characteristic bin. The air bag bottoming out was also observed in conjunction with obese occupants and back-seat-bullet cases.

Seat belt misuse was not found to be a primary or a secondary factor. The misuse of an on-off switch for air bags was never a primary factor.

Case No. 2000-12-137 was the only crash where the unexpected performance of the belt and seat was rated a primary factor. In that crash, which involved two frontal impacts, the belt anchorage tore loose and the seat tore loose from its track, apparently on the second impact. On the other hand, there were 10 cases in which belt excursion or poor fit were secondary factors; 7 of those 10 were integrated belt systems, and in 5 cases the occupant's obesity (BMI 31.3 to 47.0) or size (6'4" and 233 pounds) were also rated a secondary factor. Nevertheless, belt performance was only a secondary factor in these 10 cases; 5 were exceedingly severe crashes, and the rest were underrides, corner/oblique impacts, elderly occupants, or multiple-event crashes. There were 3 cases in which the seat's movement within its track during impact was a secondary factor: 1 exceedingly severe crash and 2 corner impacts (1 involving an obese occupant).

Two cases, Nos. 2002-48-222 and 2005-4-119, were judged to have post-crash injury complications as a primary factor. The occupants died 4 to 10 days after the crash from complications of injuries that a younger person in excellent health would normally survive. But even in these 2 cases, as well as all others, proper medical procedures were followed at the site and in the hospital, as far as could be determined. Delayed arrival of EMS did not appear to be an issue in any of the crashes. For example, in Case No. 2002-48-222, the driver had a history of heart disease and stroke. The crash itself was not caused by these conditions and it resulted in severe but normally survivable injuries such as lung contusions; however, the patient subsequently died in the hospital from circulatory disorders – triggered by the crash injuries but most likely also by the pre-existing illness.

"Did not perform well in crash-safety rating programs" was determined to be a secondary factor in 23 cases. But it was selected as a primary factor only twice: Case Nos. 2000-8-226 and 2007-12-180 (see Section 3.7 and Figure 3-36). Almost all of these 25 vehicles were carry-overs from pre-2000 designs and allowed more IP and toe-pan intrusion than the latest models. In Case No. 2007-12-180, the absence of a seat belt pretensioner (a device often present in the latest models) was judged to have allowed forward excursion of the belted driver that, in combination with IP intrusion, contributed to the severity of the driver's contact with the steering assembly.

APPENDIX A

CASE LISTING: BINS, PRIMARY FACTORS, AND SECONDARY FACTORS

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CDS CASE NUMBER 2000-8-226 DRIVER 42yo male 5’11’’ 174 lbs
       CASE VEHICLE           2000 NISSAN ALTIMA 12FYEW5
       DESCRIPTION              Hit bridge pier (BES 49 mph), many fractures, died 10 days later; ‘marginal’ IIHS offset
                                performance
       CRASH CLASSIFICATION   OTHER: DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS
       PRIMARY FACTORS        EXCESSIVE IP OR TOE PAN INTRUSION
                              VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS
       SECONDARY FACTORS      EXCEEDINGLY SEVERE CRASH
                              AIR BAG BOTTOMED OUT

CDS CASE NUMBER 2000-11-30 DRIVER 33yo female 5’3’’ 134 lbs
       CASE VEHICLE           2000 HONDA ODYSSEY 11FDAW9
       DESCRIPTION              Head-on with tractor-trailer, underride through the occupant compartment
       CRASH CLASSIFICATION   EXCEEDINGLY SEVERE
       PRIMARY FACTORS        EXCEEDINGLY SEVERE CRASH
                              UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
       SECONDARY FACTOR       INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2000-11-30 (same as previous) RF PASSENGER 10yo female 4’7’’ 112 lbs
       CASE VEHICLE           2000 HONDA ODYSSEY 11FDAW9
       DESCRIPTION              Head-on with tractor-trailer, underride through the occupant compartment
       CRASH CLASSIFICATION   EXCEEDINGLY SEVERE
       PRIMARY FACTORS        EXCEEDINGLY SEVERE CRASH
                              UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
       SECONDARY FACTOR       INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2000-12-78 DRIVER 45yo male 5’10’’ 189 lbs
       CASE VEHICLE           2000 GMC SIERRA 2500 PICKUP 12FDEW4
       DESCRIPTION              Hit rear of tractor-trailer without underride (ΔV = 54 mph)
       CRASH CLASSIFICATION   EXCEEDINGLY SEVERE
       PRIMARY FACTOR         EXCEEDINGLY SEVERE CRASH
       SECONDARY FACTORS      AIR BAG BOTTOMED OUT
                              BELT OR INTEGRATED SEAT BELT DID NOT ADEQUATELY RESTRAIN

CDS CASE NUMBER 2000-12-137 DRIVER 62yo male 6’1’’ 202 lbs
       CASE VEHICLE           2000 SATURN LS 1FDEW3, ΔV=29 mph[21]
       DESCRIPTION              Hit LeSabre (ΔV = 17 mph, deployment); then hit Lumina (ΔV = 29, anchor & seat track tore
                                loose)
       CRASH CLASSIFICATION   OTHER: SEAT BELT ANCHOR AND SEAT TRACK TORE LOOSE
       PRIMARY FACTORS        ANOMALY: MULTIPLE FRONTAL IMPACTS
                              BELT OR INTEGRATED SEAT BELT DID NOT ADEQUATELY RESTRAIN
                              MULTIPLE-EVENT CRASH
                              SEAT (EXCL INTEGRATED SEAT BELT) DID NOT ADEQUATELY RESTRAIN
       SECONDARY FACTOR       ELEVATED OCCUPANT AGE (62)

CDS CASE NUMBER 2000-43-243 DRIVER 51yo female 5’2’’ 130 lbs
       CASE VEHICLE           2000 CHRYSLER VOYAGER 12FDGW8
       DESCRIPTION              Minivan went under side of semi-trailer
       CRASH CLASSIFICATION   UNDERRODE SIDE OF HEAVY VEHICLE
       PRIMARY FACTORS        INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
                              UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
       SECONDARY FACTORS      none

CDS CASE NUMBER 2000-49-254 DRIVER 41yo male 6’4’’ 233 lbs
       CASE VEHICLE           2000 DODGE RAM 3500 PICKUP 12FDAA7
       DESCRIPTION              Rear-ended semi-trailer; fatal head injuries
       CRASH CLASSIFICATION   UNDERRODE REAR OF HEAVY VEHICLE
       PRIMARY FACTORS        UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
                              TRAILER GUARD DID NOT PREVENT UNDERRIDE
       SECONDARY FACTORS      AIR BAG BOTTOMED OUT
                              BELT OR INTEGRATED SEAT BELT DID NOT ADEQUATELY RESTRAIN
                              VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS
                              TALL OR BIG OCCUPANT (NOT OBESE)

CDS CASE NUMBER 2000-76-139 DRIVER 54yo male 5’5’’ 161 lbs
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[21] ΔV estimates throughout Appendix A are the estimates encoded in CDS, based on pre-2008 WinSMASH, converted to miles per hour and rounded to the nearest integer.

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      CASE VEHICLE          2000 GMC YUKON 12FLAE9
      DESCRIPTION             Corner impact with older-model Ford F-250
      CRASH CLASSIFICATION  CORNER IMPACT
      PRIMARY FACTORS       LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
                            INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
      SECONDARY FACTORS     none

CDS CASE NUMBER 2000-78-80 DRIVER 71yo male 5'7'' 229 lbs
      CASE VEHICLE          2000 DODGE INTREPID 92FYAW4
      DESCRIPTION             Offset front-to-front impact with med/heavy truck towing backhoe
      CRASH CLASSIFICATION  EXCEEDINGLY SEVERE
      PRIMARY FACTOR        EXCEEDINGLY SEVERE CRASH
      SECONDARY FACTORS     INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
                            UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
                            ELEVATED OCCUPANT AGE (71)
                            OBESE (BMI 30 OR MORE)
                            AIR BAG BOTTOMED OUT

CDS CASE NUMBER 2001-11-178 DRIVER 45yo female unknown height 205 lbs
      CASE VEHICLE          2000 MERCURY COUGAR 11FDEW4 ΔV=50 mph
      DESCRIPTION             Offset frontal with Olds Bravada (ΔV = 55 mph); fatal to both drivers
      CRASH CLASSIFICATION  EXCEEDINGLY SEVERE
      PRIMARY FACTOR        EXCEEDINGLY SEVERE CRASH
      SECONDARY FACTORS     FRONT-TO-FRONT INCOMPATIBILITY
                            UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
                            OBESE (BMI 30 OR MORE)
                            AIR BAG BOTTOMED OUT

CDS CASE NUMBER 2001-12-116 DRIVER 41yo male unknown height & weight
      CASE VEHICLE          2000 GMC SONOMA PICKUP 12FYEW5 ΔV=41 mph
      DESCRIPTION             Struck a 1989 Olds Delta 88 head-on
      CRASH CLASSIFICATION  OTHER: AIR BAG DID NOT DEPLOY
      PRIMARY FACTOR        AIR BAG DID NOT DEPLOY
      SECONDARY FACTORS     OBLIQUE CRASH
                            EXCEEDINGLY SEVERE CRASH

CDS CASE NUMBER 2001-13-181 DRIVER 61yo male 5'6'' 240 lbs
      CASE VEHICLE          2002 SUBARU IMPREZA 1FYAW2
      DESCRIPTION             Struck a protruding portion of a truck
      CRASH CLASSIFICATION  ANOMALY
      PRIMARY FACTOR        ANOMALY: HIT UNUSUAL VEHICLE STRUCTURE
      SECONDARY FACTORS     LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
                            INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2001-45-114 DRIVER 49yo female 5'7'' 211 lbs
      CASE VEHICLE          2001 CHRYSLER TOWN & COUNTRY 0FDGW9
      DESCRIPTION             Struck a vehicle that was rolling over
      CRASH CLASSIFICATION  ANOMALY
      PRIMARY FACTOR        ANOMALY: STRUCK BY A ROLLING VEHICLE
      SECONDARY FACTOR      INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2001-41-143 RF PASSENGER 36yo male 5'10'' 150 lbs
      CASE VEHICLE          2000 CHEVROLET BLAZER
      DESCRIPTION             Frontally impacted barrels; then ran over more barrels and overturned; fatal injuries from
                              the rollover
      CRASH CLASSIFICATION  dropped case: rollover primary

CDS CASE NUMBER 2000-49-245 DRIVER 35yo male 5'8'' 189 lbs
      CASE VEHICLE          2000 DODGE DURANGO
      DESCRIPTION             96 mph on an urban road, into a bridge pier, no evasive maneuver or loss of control:
                              apparently intentional
      CRASH CLASSIFICATION  dropped case: apparent suicide

CDS CASE NUMBER 2001-75-113 DRIVER 53yo male 5'7'' 220 lbs
      CASE VEHICLE          2001 TOYOTA AVALON 12FDEW4 ΔV=48 mph
      DESCRIPTION             Oblique impact with 1996 Honda Accord; obese driver went over the steering wheel and
                              bottomed out air bag
      CRASH CLASSIFICATION  OBLIQUE IMPACT
      PRIMARY FACTOR        OBLIQUE CRASH
      SECONDARY FACTORS     OBESE (BMI 30 OR MORE)
                            AIR BAG BOTTOMED OUT

CDS CASE NUMBER 2001-76-111 DRIVER 56yo male 5'3'' 134 lbs
      CASE VEHICLE          2001 NISSAN SENTRA 92FYEW4 ΔV=50 mph
      DESCRIPTION             Oblique impact with 1994 Ford Explorer; much IP, toe pan and A-pillar intrusion
      CRASH CLASSIFICATION  OBLIQUE IMPACT
      PRIMARY FACTOR        OBLIQUE CRASH
      SECONDARY FACTORS     EXCEEDINGLY SEVERE CRASH
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                          INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
                          EXCESSIVE IP OR TOE PAN INTRUSION
                          AIR BAG BOTTOMED OUT
                          SHORT-STATURE OCCUPANT

CDS CASE NUMBER 2001-81-117 DRIVER 52yo male 6' 185 lbs
       CASE VEHICLE           2002 TOYONTA TUNDRA ACCESS CAB 4X4 12FYEW3 ∆V=28 mph
       DESCRIPTION              Oblique offset impact with 1999 Ford E-250 van; much IP, toe pan, and A-pillar intrusion;
                                seat deformation and driver's trajectory caused poor air bag interaction
       CRASH CLASSIFICATION   CORNER AND OBLIQUE IMPACT
       PRIMARY FACTORS        POOR OCCUPANT-AIR BAG INTERACTION
                              OBLIQUE CRASH
       SECONDARY FACTORS      LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
                              UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
                              EXCESSIVE IP OR TOE PAN INTRUSION

CDS CASE NUMBER 2002-2-114 DRIVER 68yo male 6'5'' 268 lbs
       CASE VEHICLE           2000 FORD RANGER SUPERCAB 4X4 12FLEE2 ∆V=11 mph
       DESCRIPTION              Corner impacts with several trees; much IP and toe pan intrusion; obese elderly driver was
                                likely out of position
       CRASH CLASSIFICATION   (1) CORNER IMPACT; (2) TALL, NARROW OBJECT
       PRIMARY FACTORS        LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
                              TALL, NARROW OBJECT
       SECONDARY FACTORS      INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
                              ELEVATED OCCUPANT AGE (68)
                              OBESE (BMI 30 OR MORE)
                              OUT-OF-POSITION OCCUPANT

CDS CASE NUMBER 2002-3-9 DRIVER 48yo male 6'1'' 216 lbs
       CASE VEHICLE           2000 HONDA ACCORD 12FDEW3
       DESCRIPTION              The driver's injuries and the lack of intrusion on driver's side indicate the intoxicated
                                driver was not buckled; RF passenger survived
       CRASH CLASSIFICATION dropped case: unbelted

CDS CASE NUMBER 2002-9-25 DRIVER 66yo male 5'3'' 183 lbs
       CASE VEHICLE           2001 FORD WINDSTAR 0FDAW9
       DESCRIPTION              A 1998 Ford Explorer went airborne and while inverted landed on the occupant compartment
                                of Windstar
       CRASH CLASSIFICATION   ANOMALY
       PRIMARY FACTOR         ANOMALY: STRUCK BY AN AIRBORNE VEHICLE
       SECONDARY FACTORS      INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
                              UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)

CDS CASE NUMBER 2002-9-43 DRIVER 55yo male 5'10'' 141 lbs
       CASE VEHICLE           2001 CHEVROLET CAPRICE 12FYHW5
       DESCRIPTION              Struck rear of semi-trailer; underride severe; head contact to rear of trailer
       CRASH CLASSIFICATION   UNDERRODE REAR OF HEAVY VEHICLE
       PRIMARY FACTORS        UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
                              TRAILER GUARD DID NOT PREVENT UNDERRIDE
       SECONDARY FACTOR       INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2002-9-131 DRIVER 33yo male 5'5'' 174 lbs
       CASE VEHICLE           2001 FORD TAURUS 92FYEW6 ∆V=33 mph
       DESCRIPTION              Oblique impact with Caprice, little structural engagement; driver's head hit steering
                                wheel
       CRASH CLASSIFICATION   OBLIQUE IMPACT
       PRIMARY FACTORS        LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
                              OBLIQUE CRASH
       SECONDARY FACTORS      INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
                              FRONT-TO-FRONT INCOMPATIBILITY
                              UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)

CDS CASE NUMBER 2002-12-186 DRIVER 60yo male 5'7'' 200 lbs
       CASE VEHICLE           2000 PONTIAC SUNFIRE 91FDEW4 EDR ∆V=51 mph
       DESCRIPTION              Hit Lumina (∆V = 51 mph EDR), flail chest
       CRASH CLASSIFICATION   EXCEEDINGLY SEVERE
       PRIMARY FACTOR         EXCEEDINGLY SEVERE CRASH
       SECONDARY FACTORS      ELEVATED OCCUPANT AGE (60)
                              OBESE (BMI 30 OR MORE)
                              VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2002-12-186 (same as previous) RF PASSENGER 60yo female 5'6'' 260 lbs
       CASE VEHICLE           2000 PONTIAC SUNFIRE 91FDEW4 EDR ∆V=51 mph
       DESCRIPTION              Hit Lumina (∆V = 51 mph EDR), brain stem laceration
       CRASH CLASSIFICATION   EXCEEDINGLY SEVERE
       PRIMARY FACTOR         EXCEEDINGLY SEVERE CRASH
       SECONDARY FACTORS      ELEVATED OCCUPANT AGE (60)
                              OBESE (BMI 30 OR MORE)
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VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2002-42-25 RF PASSENGER 29yo female 5'4'' 139 lbs
CASE VEHICLE 2002 JAGUAR X-TYPE 11FDEW4
DESCRIPTION High-speed full frontal with Aerostar minivan (∆V=64 mph); IP intrusion with seat deformation
CRASH CLASSIFICATION EXCEEDINGLY SEVERE
PRIMARY FACTOR EXCEEDINGLY SEVERE CRASH
SECONDARY FACTORS AIR BAG BOTTOMED OUT
SEAT DID NOT ADEQUATELY RESTRAIN

CDS CASE NUMBER 2002-42-34 DRIVER 33yo female 5' 194 lbs
CASE VEHICLE 2001 DODGE INTREPID 11FLEE9
DESCRIPTION Oblique FLEE impact with Infiniti G20; poor restraint interaction due to vehicle deformation and obesity
CRASH CLASSIFICATION CORNER AND OBLIQUE IMPACT
PRIMARY FACTORS LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
OBLIQUE CRASH
SECONDARY FACTORS POOR OCCUPANT-AIR BAG INTERACTION
INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
OBESE (BMI 30 OR MORE)
SEAT (EXCL INTEGRATED SEAT BELT) DID NOT ADEQUATELY RESTRAIN

CDS CASE NUMBER 2002-42-34 (same as previous) RF PASSENGER 61yo female 5'2'' 227 lbs
CASE VEHICLE 2001 DODGE INTREPID 11FLEE9
DESCRIPTION Oblique impact with Infiniti G20; poor occupant interaction with air bag and seat belt
CRASH CLASSIFICATION OBLIQUE IMPACT
PRIMARY FACTORS POOR OCCUPANT-AIR BAG INTERACTION
OBLIQUE CRASH
SECONDARY FACTORS LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
OBESE (BMI 30 OR MORE)

CDS CASE NUMBER 2002-45-16 DRIVER 35yo male 5'9'' 200 lbs
CASE VEHICLE 2000 CHEVROLET S-10 PICKUP 11FDEW6 EDR ∆V=49 mph
DESCRIPTION Struck Explorer (EDR ∆V=49 mph); significant crush of compartment
CRASH CLASSIFICATION EXCEEDINGLY SEVERE
PRIMARY FACTOR EXCEEDINGLY SEVERE CRASH
SECONDARY FACTORS AIR BAG BOTTOMED OUT
VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2002-45-39 DRIVER 32yo female 5'8'' 145 lbs
CASE VEHICLE 2001 PONTIAC BONNEVILLE 12FDEW4
DESCRIPTION Departed road, struck 7 trees: 5 sideswipes, then 2 frontals; team believes driver's head was near or outside window and struck a tree before the car struck anything frontally
CRASH CLASSIFICATION dropped case: sideswipe primary

CDS CASE NUMBER 2002-45-135 DRIVER 16yo male 5'7'' 150 lbs
CASE VEHICLE 2000 MAZDA 626 12FZEW4 ∆V=42 mph
DESCRIPTION Hit tree; driver died, 5 others survived; unrestrained occupant behind driver
CRASH CLASSIFICATION OTHER: BACK-SEAT BULLET
PRIMARY FACTOR BACK-SEAT BULLET
SECONDARY FACTORS EXCEEDINGLY SEVERE CRASH
EXCESSIVE IP OR TOE PAN INTRUSION
AIR BAG BOTTOMED OUT

CDS CASE NUMBER 2002-47-39 DRIVER 44yo female 5' 169 lbs
CASE VEHICLE 2000 FORD TAURUS 12FDEW5 ∆V=53 mph
DESCRIPTION Hit Honda Accord head-on; crash killed 6 people in 3 vehicles
CRASH CLASSIFICATION EXCEEDINGLY SEVERE
PRIMARY FACTOR EXCEEDINGLY SEVERE CRASH
SECONDARY FACTORS OBESE (BMI 30 OR MORE)
EXCESSIVE IP OR TOE PAN INTRUSION
AIR BAG BOTTOMED OUT

CDS CASE NUMBER 2002-47-134 DRIVER 61yo male 5'8'' 189 lbs
CASE VEHICLE 2002 CHEVROLET ASTRO CARGO VAN 92FDAW7 ∆V=70 mph
DESCRIPTION Hit bridge pier (∆V = 70 mph)
CRASH CLASSIFICATION EXCEEDINGLY SEVERE
PRIMARY FACTOR EXCEEDINGLY SEVERE CRASH
SECONDARY FACTORS EXCESSIVE IP OR TOE PAN INTRUSION
VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2002-48-222 DRIVER 62yo female 5'4'' 134 lbs
CASE VEHICLE 2001 HONDA ACCORD 12FDEW3 ∆V=38 mph
DESCRIPTION Hit LeBaron (∆V = 38 mph); 62yo driver with heart disease & previous stroke; AIS 4 chest injury; died 10 days later from hemorrhagic & cardiogenic shock
CRASH CLASSIFICATION VULNERABLE OCCUPANT
PRIMARY FACTORS PRE-EXISTING MEDICAL CONDITION
POST-CRASH INJURY COMPLICATIONS

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       SECONDARY FACTORS      ELEVATED OCCUPANT AGE (62)
                              AIR BAG BOTTOMED OUT
                              SHORT-STATURE OCCUPANT

CDS CASE NUMBER 2002-49-100 DRIVER 66yo female 5'6'' 167 lbs
       CASE VEHICLE           2000 CHRYSLER TOWN & COUNTRY 12FYEW6 ΔV=49 mph(?)
       DESCRIPTION              Mostly-centered tree impact, much IP and steering assembly intrusion
       CRASH CLASSIFICATION   TALL, NARROW OBJECT
       PRIMARY FACTORS        ELEVATED OCCUPANT AGE (66)
                              TALL, NARROW OBJECT
       SECONDARY FACTORS      EXCESSIVE IP OR TOE PAN INTRUSION
                              AIR BAG BOTTOMED OUT
                              STEERING COLUMN MOVED UPWARD
                              VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2002-75-53 RF PASSENGER 71yo female 4'11'' 119 lbs
       CASE VEHICLE           2000 TOYOTA 4RUNNER 4X4 11FDEW2 ΔV=14 mph
       DESCRIPTION              Hit a car (ΔV = 14 mph); passenger with lung and liver cancer sustained fatal head and
                                chest injuries
       CRASH CLASSIFICATION   VULNERABLE OCCUPANT
       PRIMARY FACTOR         PRE-EXISTING MEDICAL CONDITION
       SECONDARY FACTOR       OBLIQUE CRASH

CDS CASE NUMBER 2002-76-97 RF PASSENGER 18yo male 5'11'' 180 lbs
       CASE VEHICLE           2001 CHEVROLET CAVALIER 1FDEW5 ΔV=53 mph
       DESCRIPTION              Offset frontal with 1992 Pontiac Bonneville (ΔV = 68 mph)
       CRASH CLASSIFICATION   EXCEEDINGLY SEVERE
       PRIMARY FACTOR         EXCEEDINGLY SEVERE CRASH
       SECONDARY FACTORS      OBLIQUE CRASH
                              INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
                              EXCESSIVE IP OR TOE PAN INTRUSION
                              VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2003-2-141 DRIVER 39yo male 6' 185 lbs
       CASE VEHICLE           2000 HONDA CIVIC 12FDEW5 ΔV=53 mph
       DESCRIPTION              Head-on with Kia Sportage (ΔV = 62 mph)
       CRASH CLASSIFICATION   EXCEEDINGLY SEVERE
       PRIMARY FACTOR         EXCEEDINGLY SEVERE CRASH
       SECONDARY FACTORS      FRONT-TO-FRONT INCOMPATIBILITY
                              AIR BAG BOTTOMED OUT
                              VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2003-8-223 DRIVER 49yo male 5'11'' 200 lbs
       CASE VEHICLE           2000 FORD E-150 CARGO VAN 12FZEW2
       DESCRIPTION              Moderate impact with pole, then rolled and burned; impaired driver did not exit burning
                                vehicle
       CRASH CLASSIFICATION   ANOMALY
       PRIMARY FACTORS        ANOMALY: TRAPPED IN BURNING VEH DUE TO ROLL, BAC, MEDICAL CONDITION
                              POST-CRASH FIRE, FATAL BURNS
       SECONDARY FACTOR       PRE-EXISTING MEDICAL CONDITION

CDS CASE NUMBER 2003-9-47 DRIVER 27yo male 5'4'' 165 lbs
       CASE VEHICLE           2001 FORD F-150 PICKUP 32FDAW6
       DESCRIPTION              Head on with heavy Navistar truck; fatal to all 3 occupants of the Ford
       CRASH CLASSIFICATION   EXCEEDINGLY SEVERE
       PRIMARY FACTOR         EXCEEDINGLY SEVERE CRASH
       SECONDARY FACTORS      UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
                              AIR BAG BOTTOMED OUT
                              VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2003-11-18 DRIVER 49yo male 5'8'' 130 lbs
       CASE VEHICLE           2001 SUBARU FORESTER 0FDAW9
       DESCRIPTION              Snowmobile went airborne and struck greenhouse of Forester
       CRASH CLASSIFICATION   ANOMALY
       PRIMARY FACTOR         ANOMALY: STRUCK BY AN AIRBORNE VEHICLE
       SECONDARY FACTOR       INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2003-42-61 RF PASSENGER 47yo male 5'5'' 205 lbs
       CASE VEHICLE           2002 VW JETTA 32FDEW2
       DESCRIPTION              Struck the rear of a Mitsubishi Fuso single-unit truck
       CRASH CLASSIFICATION   UNDERRODE REAR OF HEAVY VEHICLE
       PRIMARY FACTORS        UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
                              TRAILER GUARD DID NOT PREVENT UNDERRIDE
       SECONDARY FACTOR       INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
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CDS CASE NUMBER 2003-48-158 RF PASSENGER 81yo female 5’7’’ 161 lbs
CASE VEHICLE 2002 TOYOTA TACOMA XTRACAB PICKUP 11FDEW3 △V=29 mph
DESCRIPTION Front-to-front with Ford F-150 (△V = 28 mph); 81 yo female passenger with thoracic injuries from side surfaces
CRASH CLASSIFICATION VULNERABLE OCCUPANT
PRIMARY FACTOR ELEVATED OCCUPANT AGE (81)
SECONDARY FACTOR AIR BAG SWITCHED OFF

CDS CASE NUMBER 2003-49-158 RF PASSENGER 16yo male 6’1’’ 117 lbs
CASE VEHICLE 2001 CHEVROLET MALIBU
DESCRIPTION 2 right-side and 1 frontal impact; passenger’s fatal injuries from right-side surfaces attributable to the side impacts
CRASH CLASSIFICATION dropped case: side impact primary

CDS CASE NUMBER 2003-73-59 DRIVER 63yo male 6’1’’ 200 lbs
CASE VEHICLE 2001 CHEVROLET MONTE CARLO
DESCRIPTION Frontally impacted pole; then ran off embank-ment and overturned; fatal head injuries occurred during the rollover
CRASH CLASSIFICATION dropped case: rollover primary

CDS CASE NUMBER 2003-76-134 DRIVER 46yo male 5’10’’ 194 lbs
CASE VEHICLE 2001 DODGE INTREPID 11F9AW9
DESCRIPTION Struck a tractor-trailer head-on; underride with massive intrusion
CRASH CLASSIFICATION EXCEEDINGLY SEVERE
PRIMARY FACTORS EXCEEDINGLY SEVERE CRASH
UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
SECONDARY FACTORS POOR OCCUPANT-AIR BAG INTERACTION
OBLIQUE CRASH

CDS CASE NUMBER 2003-79-139 DRIVER 18yo male 5’5’’ 141 lbs
CASE VEHICLE 2000 CHEVROLET 3500 CARGO VAN 12FDAW7
DESCRIPTION Struck rear of stopped semi-trailer; severe underride caused significant IP, toe pan, and A-pillar intrusion
CRASH CLASSIFICATION UNDERRODE REAR OF HEAVY VEHICLE
PRIMARY FACTORS UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
TRAILER GUARD DID NOT PREVENT UNDERRIDE
SECONDARY FACTORS INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
EXCESSIVE IP OR TOE PAN INTRUSION

CDS CASE NUMBER 2003-81-41 DRIVER 46yo male 5’11’’ 185 lbs
CASE VEHICLE 2003 CHEVROLET S-10 MAXICAB PICKUP 12FDEW6
DESCRIPTION Head-on impact with armored truck; intoxicated driver was fleeing the scene of earlier minor impact with other vehicle
CRASH CLASSIFICATION EXCEEDINGLY SEVERE
PRIMARY FACTOR EXCEEDINGLY SEVERE CRASH
SECONDARY FACTORS UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
AIR BAG BOTTOMED OUT

CDS CASE NUMBER 2003-81-44 DRIVER 19yo male 5’10’’ 132 lbs
CASE VEHICLE 2003 DODGE NEON 12FLEE8
DESCRIPTION Hit tree with front left corner; damage continued along left side as vehicle rotated around tree; intruding tree struck driver’s head
CRASH CLASSIFICATION CORNER IMPACT
PRIMARY FACTOR LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
SECONDARY FACTORS POOR OCCUPANT-AIR BAG INTERACTION
INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
TALL, NARROW OBJECT

CDS CASE NUMBER 2004-2-62 DRIVER 81yo female 5’10’’ 169 lbs
CASE VEHICLE 2000 HONDA ACCORD 12FLEE2 △V=14 mph
DESCRIPTION Corner impact with front of 1989 Dodge Dynasty; 81yo driver had belt-caused fatal chest injuries
CRASH CLASSIFICATION (1) VULNERABLE OCCUPANT; (2) CORNER IMPACT
PRIMARY FACTOR ELEVATED OCCUPANT AGE (81)
SECONDARY FACTORS POOR OCCUPANT-AIR BAG INTERACTION
LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT

CDS CASE NUMBER 2004-2-74 DRIVER 58yo female 5’2’’ 141 lbs
CASE VEHICLE 2003 CHEVROLET MALIBU 0FDGW9
DESCRIPTION Vehicle went off the road and rolled ¼ turn to the right; then it frontally impacted a tree; roof intrusion caused fatal injuries
CRASH CLASSIFICATION ANOMALY
PRIMARY FACTOR ANOMALY: STRUCK TREE WHILE ROLLING OVER
SECONDARY FACTOR INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2004-9-62 DRIVER 70yo male 5’11’’ 211 lbs
CASE VEHICLE 2001 TOYOTA AVALON 81FYEW5 △V=44 mph

DESCRIPTION Hit tree; driver died of chest injuries attributed to steering wheel resulting from IP intrusion
CRASH CLASSIFICATION TALL, NARROW OBJECT
PRIMARY FACTOR TALL, NARROW OBJECT
SECONDARY FACTOR ELEVATED OCCUPANT AGE (70)
EXCESSIVE IP OR TOE PAN INTRUSION

CDS CASE NUMBER 2004-9-224 DRIVER 19yo female 5'4'' 119 lbs
CASE VEHICLE 2000 CHEVROLET CAVALIER
DESCRIPTION Vehicle rolled down embankment
CRASH CLASSIFICATION dropped case: rollover primary

CDS CASE NUMBER 2004-11-119 DRIVER 65yo male 6' 293 lbs
CASE VEHICLE 2002 CHEVROLET TRACKER 0FDAW7
DESCRIPTION Toyota Corolla rolled into the Tracker, impacting A-pillar
CRASH CLASSIFICATION ANOMALY
PRIMARY FACTOR ANOMALY: STRUCK BY A ROLLING VEHICLE
SECONDARY FACTOR INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2004-41-15 RF PASSENGER 78yo female 5'7'' 130 lbs
CASE VEHICLE 2000 TOYOTA COROLLA 11FYEW3 ∆V=28 mph
DESCRIPTION RF passenger died from chest injuries attributed to the seat belt (∆V = 23 mph); oblique, offset crash with an Eclipse
CRASH CLASSIFICATION VULNERABLE OCCUPANT
PRIMARY FACTOR ELEVATED OCCUPANT AGE (78)
SECONDARY FACTOR OBLIQUE CRASH

CDS CASE NUMBER 2004-42-113 DRIVER 23yo male 5'10'' 200 lbs
CASE VEHICLE 2004 DODGE STRATUS 12FLAA9
DESCRIPTION Struck rear of semi-trailer; underride severe with no engagement of primary structure
CRASH CLASSIFICATION UNDERRODE REAR OF HEAVY VEHICLE
PRIMARY FACTORS UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
TRAILER GUARD DID NOT PREVENT UNDERRIDE
SECONDARY FACTOR INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2004-43-253 DRIVER 31yo male 5'10'' 194 lbs
CASE VEHICLE 2004 HONDA ACCORD 11FDAA7
DESCRIPTION Struck front of heavy truck; obliquity taxed structure and diminished restraint performance
CRASH CLASSIFICATION OBLIQUE IMPACT
PRIMARY FACTOR OBLIQUE CRASH
SECONDARY FACTORS POOR OCCUPANT-AIR BAG INTERACTION
LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
EXCESSIVE IP OR TOE PAN INTRUSION

CDS CASE NUMBER 2004-43-291 DRIVER 33yo female 5'3'' 176 lbs
CASE VEHICLE 2003 DODGE CARAVAN 12FDEW3
DESCRIPTION Offset front-to-front impact with heavy truck; underride; substantial deformation of IP and steering column
CRASH CLASSIFICATION OTHER: UNDERRODE FRONT OF HEAVY TRUCK
PRIMARY FACTORS LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
SECONDARY FACTORS none

CDS CASE NUMBER 2004-45-113 DRIVER 37yo male 6'4'' 180 lbs
CASE VEHICLE 2000 HONDA CIVIC 1FYEW4 ∆V=26 mph
DESCRIPTION Struck Dodge Durango with corner; large greenhouse intrusion; head injury
CRASH CLASSIFICATION (1) CORNER IMPACT; (2) OTHER: INCOMPATIBILITY
PRIMARY FACTORS LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
FRONT-TO-FRONT INCOMPATIBILITY
SECONDARY FACTORS INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
AIR BAG BOTTOMED OUT

CDS CASE NUMBER 2004-47-83 RF PASSENGER 76yo female 5'6'' 180 lbs
CASE VEHICLE 2003 CHEVROLET SILVERADO PICKUP 12FREW5
DESCRIPTION Off road and into large tree; major IP intrusion and seat deformation for RFP
CRASH CLASSIFICATION (1) CORNER IMPACT; (2) TALL, NARROW OBJECT
PRIMARY FACTORS LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
TALL, NARROW OBJECT
SECONDARY FACTOR EXCEEDINGLY SEVERE CRASH
ELEVATED OCCUPANT AGE (76)
EXCESSIVE IP OR TOE PAN INTRUSION
INTEGRATED SEAT BELT DID NOT ADEQUATELY RESTRAIN
SEAT DID NOT ADEQUATELY RESTRAIN

CDS CASE NUMBER 2004-48-58 DRIVER 36yo male 6' 189 lbs
CASE VEHICLE 2002 GMC DENALI 11FDAW6 ∆V=22 mph

DESCRIPTION	Struck above frame rails by airborne Chevrolet Lumina; substantial IP intrusion of three feet
CRASH CLASSIFICATION	ANOMALY
PRIMARY FACTORS	UNDERRIDE (LIMITED VERTICAL ENGAGEMENT) ANOMALY: STRUCK BY AN AIRBORNE VEHICLE
SECONDARY FACTORS	none

CDS CASE NUMBER 2004-49-106 DRIVER 30yo male 5’6’’ 183 lbs

CASE VEHICLE	2004 FORD MUSTANG 21FDAW7 ΔV=52 mph
DESCRIPTION	Head-on with F-250 carrying steel pipes on its roof
CRASH CLASSIFICATION	EXCEEDINGLY SEVERE AND ANOMALY
PRIMARY FACTORS	EXCEEDINGLY SEVERE CRASH ANOMALY: PIPES ON OTHER VEH ENTERED CASE VEH
SECONDARY FACTOR	INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2004-49-106 (same as previous) RF PASSENGER 26yo female 4’9’’ 125 lbs

CASE VEHICLE	2004 FORD MUSTANG 21FDAW7 ΔV=52 mph
DESCRIPTION	Head-on with F-250 carrying steel pipes on its roof
CRASH CLASSIFICATION	EXCEEDINGLY SEVERE AND ANOMALY
PRIMARY FACTORS	EXCEEDINGLY SEVERE CRASH ANOMALY: PIPES ON OTHER VEH ENTERED CASE VEH
SECONDARY FACTOR	INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2004-49-168 RF PASSENGER 56yo female 5’6’’ 189 lbs

CASE VEHICLE	2004 MERCEDES S430 1FREW2 ΔV=19 mph
DESCRIPTION	Oblique impact with Camry (ΔV = 19 mph); passenger’s head hit A-pillar
CRASH CLASSIFICATION	OBLIQUE IMPACT
PRIMARY FACTORS	POOR OCCUPANT-AIR BAG INTERACTION OBLIQUE CRASH
SECONDARY FACTOR	ELEVATED OCCUPANT AGE (56)

CDS CASE NUMBER 2004-50-32 RF PASSENGER 65yo female 5’2’’ 145 lbs

CASE VEHICLE	2001 SUBARU FORESTER 12FRAE9
DESCRIPTION	Hit pole with right corner; much IP <u>and</u> side structure intrusion
CRASH CLASSIFICATION	(1) CORNER IMPACT; (2) TALL, NARROW OBJECT
PRIMARY FACTOR	LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT TALL, NARROW OBJECT
SECONDARY FACTOR	ELEVATED OCCUPANT AGE (65) EXCESSIVE IP OR TOE PAN INTRUSION

CDS CASE NUMBER 2004-50-147 DRIVER 80yo female 5’2’’ 119 lbs

CASE VEHICLE	2001 HONDA CIVIC 12FDEW2
DESCRIPTION	Hit a car (ΔV = 25 mph); 80-year-old 5’2’’ driver had belt-caused fatal chest injuries
CRASH CLASSIFICATION	VULNERABLE OCCUPANT
PRIMARY FACTOR	ELEVATED OCCUPANT AGE (80)
SECONDARY FACTORS	BELT-CAUSED INJURIES SHORT-STATURE OCCUPANT

CDS CASE NUMBER 2004-73-147 DRIVER 58yo male 5’8’’ 165 lbs

CASE VEHICLE	2002 PONTIAC MONTANA 12FDAW6 ΔV=59 mph
DESCRIPTION	Impact with bed of pickup truck causing A-pillar impact with frame of struck vehicle
CRASH CLASSIFICATION	ANOMALY
PRIMARY FACTOR	ANOMALY: STRUCK BED OF YAWING PICKUP TRUCK
SECONDARY FACTORS	EXCEEDINGLY SEVERE CRASH INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2004-73-165 DRIVER 52yo male 6’1’’ 299 lbs

CASE VEHICLE	2002 FORD EXPLORER 12FDAA6
DESCRIPTION	Struck rear of semi-trailer; underride severe; driver died of head and chest injuries sourced to steering wheel
CRASH CLASSIFICATION	UNDERRODE REAR OF HEAVY VEHICLE
PRIMARY FACTORS	UNDERRIDE (LIMITED VERTICAL ENGAGEMENT) TRAILER GUARD DID NOT PREVENT UNDERRIDE
SECONDARY FACTORS	EXCEEDINGLY SEVERE CRASH INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2004-73-241 DRIVER 52yo male 5’11’’ 154 lbs

CASE VEHICLE	2004 NISSAN ALTIMA 11FLEE8 ΔV=30 mph
DESCRIPTION	Hit body-on-frame passenger car (11FLEE), driver sustained head injuries from intruding A-pillar
CRASH CLASSIFICATION	CORNER AND OBLIQUE IMPACT
PRIMARY FACTORS	LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT OBLIQUE CRASH
SECONDARY FACTORS	POOR OCCUPANT-AIR BAG INTERACTION EXCEEDINGLY SEVERE CRASH INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH FRONT-TO-FRONT INCOMPATIBILITY

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CDS CASE NUMBER 2004-76-57 DRIVER 19yo female 5'5'' 220 lbs
       CASE VEHICLE            2002 CHEVROLET CAVALIER 91FYEW4 EDR ∆V=62 mph
       DESCRIPTION               Hit a concrete porch (∆V = 62 mph EDR); 19-year-old driver had fatal head injuries
       CRASH CLASSIFICATION    EXCEEDINGLY SEVERE
       PRIMARY FACTOR          EXCEEDINGLY SEVERE CRASH
       SECONDARY FACTORS       INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
                               OBESE (BMI 30 OR MORE)
                               VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2004-76-157 DRIVER 68yo male 5'6'' 185 lbs
       CASE VEHICLE            2002 CHEVROLET CAVALIER 12FDEW5 EDR ∆V=53 mph
       DESCRIPTION               Struck a Ford Explorer (∆V = 53 mph EDR); 68 yo driver sustained chest injuries from
                                 steering wheel
       CRASH CLASSIFICATION    EXCEEDINGLY SEVERE
       PRIMARY FACTOR          EXCEEDINGLY SEVERE CRASH
       SECONDARY FACTOR        FRONT-TO-FRONT INCOMPATIBILITY
                               ELEVATED OCCUPANT AGE (68)
                               VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2004-79-49 DRIVER 72yo female 5'1'' 330 lbs
       CASE VEHICLE            2001 TOYOTA CAMRY 12FYAW6
       DESCRIPTION               Struck a Ford van (∆V = 18 mph); minimal intrusion to occupant compartment; driver
                                 sustained broken ribs
       CRASH CLASSIFICATION    VULNERABLE OCCUPANT
       PRIMARY FACTORS         ELEVATED OCCUPANT AGE (72)
                               OBESE (BMI 30 OR MORE)
       SECONDARY FACTORS       POOR OCCUPANT-AIR BAG INTERACTION
                               SHORT-STATURE OCCUPANT

CDS CASE NUMBER 2004-79-244 DRIVER 70yo male 5'9'' 299 lbs
       CASE VEHICLE            2003 CADILLAC DeVILLE 12FDEW4
       DESCRIPTION               Struck a Ford Escape (∆V = 23 mph); passenger-side offset crash; driver sustained fatal
                                 chest injuries from steering wheel
       CRASH CLASSIFICATION    VULNERABLE OCCUPANT
       PRIMARY FACTORS         ELEVATED OCCUPANT AGE (70)
                               OBESE (BMI 30 OR MORE)
       SECONDARY FACTORS       none

CDS CASE NUMBER 2004-82-16 RF PASSENGER 25yo female 5'3'' 117 lbs
       CASE VEHICLE            2000 VW JETTA 12FZAW9
       DESCRIPTION               Front right corner impacted the left rear corner of a parked trailer
       CRASH CLASSIFICATION    UNDERRODE REAR OF HEAVY VEHICLE
       PRIMARY FACTORS         LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
                               UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
                               TRAILER GUARD DID NOT PREVENT UNDERRIDE
       SECONDARY FACTORS       none

CDS CASE NUMBER 2005-2-54 DRIVER 60yo female 5'6'' 299 lbs
       CASE VEHICLE            2004 DODGE NEON 12FLEE6 ∆V=16 mph
       DESCRIPTION               Hit Escort, relatively low-speed corner impact (FLEE); driver (age 60, weight 300)
                                 sustained chest injuries from steering wheel
       CRASH CLASSIFICATION    (1) CORNER IMPACT; (2) VULNERABLE OCCUPANT
       PRIMARY FACTOR          LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
       SECONDARY FACTORS       ELEVATED OCCUPANT AGE (60)
                               OBESE (BMI 30 OR MORE)
                               VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2005-4-119 DRIVER 86yo male 6' 189 lbs
       CASE VEHICLE            2003 CHEVROLET IMPALA 1FDEW3 ∆V=23 mph
       DESCRIPTION               Struck Hyundai Elantra (∆V = 23 mph); minimal intrusion; 86 yo driver fractured femur;
                                 died 85 hours later
       CRASH CLASSIFICATION    OTHER: POST-CRASH INJURY COMPLICATIONS
       PRIMARY FACTORS         ELEVATED OCCUPANT AGE (86)
                               POST-CRASH INJURY COMPLICATIONS
       SECONDARY FACTORS       none

CDS CASE NUMBER 2005-9-64 RF PASSENGER 24yo male 6' 205 lbs
       CASE VEHICLE            2004 BMW M3 32FDEW4
       DESCRIPTION               Struck multiple trees with right side, then a large tree with front
       CRASH CLASSIFICATION    ANOMALY
       PRIMARY FACTOR          ANOMALY: MULTIPLE EVENTS PITCHED OCC TOWARD A-PILLAR
       SECONDARY FACTORS       POOR OCCUPANT-AIR BAG INTERACTION
                               INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
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CDS CASE NUMBER 2005-9-189 DRIVER 43yo male 6'2'' 262 lbs
CASE VEHICLE 2005 FORD ESCAPE 4X4 12FDAW9
DESCRIPTION Rear-ended school bus; severe underride
CRASH CLASSIFICATION UNDERRODE REAR OF HEAVY VEHICLE
PRIMARY FACTORS INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
SECONDARY FACTORS none

CDS CASE NUMBER 2005-43-231 DRIVER 31yo male 6' 200 lbs
CASE VEHICLE 2000 JEEP CHEROKEE 11FLEE9
DESCRIPTION Hit tree with left corner, then rolled; severe roof and toe pan intrusion (characteristic corner-to-tree damage)
CRASH CLASSIFICATION (1)CORNER IMPACT; (2) TALL, NARROW OBJECT
PRIMARY FACTORS LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
TALL, NARROW OBJECT
SECONDARY FACTORS INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2005-45-116 RF PASSENGER 87yo female 4'7'' 97 lbs
CASE VEHICLE 2003 DODGE NEON 12FREE2 ∆V=14 mph
DESCRIPTION Struck a culvert (∆V = 14 mph); 87 yo passenger; likely poor belt fit due to short stature (4'7'')
CRASH CLASSIFICATION VULNERABLE OCCUPANT
PRIMARY FACTOR ELEVATED OCCUPANT AGE (87)
SECONDARY FACTORS POOR OCCUPANT-AIR BAG INTERACTION
BELT DID NOT ADEQUATELY RESTRAIN
AIR BAG INJURED OUT-OF-POSITION OCCUPANT
VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS
SHORT-STATURE OCCUPANT

CDS CASE NUMBER 2005-45-142 DRIVER 63yo female 5'7'' 125 lbs
CASE VEHICLE 2003 ACURA TL 12FYEW5 ∆V=44 mph
DESCRIPTION Offset frontal with 1984 Chevrolet cargo van (∆V = 51 mph)
CRASH CLASSIFICATION EXCEEDINGLY SEVERE
PRIMARY FACTOR EXCEEDINGLY SEVERE CRASH
SECONDARY FACTORS OBLIQUE CRASH
INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2005-45-196 DRIVER 69yo male unknown height 224 lbs
CASE VEHICLE 2005 CHEVROLET IMPALA 12FDEW3 ∆V=24 mph
DESCRIPTION Oblique impact with front of 2005 Nissan Murano; 69yo driver had belt-caused injuries and died 16 days later (unbelted 67yo RF passenger survived)
CRASH CLASSIFICATION (1) VULNERABLE OCCUPANT; (2) OBLIQUE IMPACT
PRIMARY FACTOR ELEVATED OCCUPANT AGE (69)
SECONDARY FACTOR OBLIQUE CRASH

CDS CASE NUMBER 2005-47-102 DRIVER 22yo male 5'10'' 229 lbs
CASE VEHICLE 2001 FORD F-150 CREW CAB PICKUP 92FYEW6
DESCRIPTION Severe offset impact with 1992 Ford Explorer; much IP, toe pan, and A-pillar intrusion; driver was obese
CRASH CLASSIFICATION CORNER IMPACT
PRIMARY FACTORS LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
EXCEEDINGLY SEVERE CRASH
SECONDARY FACTORS INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
OBESE (BMI 30 OR MORE)
EXCESSIVE IP OR TOE PAN INTRUSION
VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2005-47-134 DRIVER 44yo female 5'4'' 114 lbs
CASE VEHICLE 2002 PONTIAC FIREBIRD 12FLEW3 ∆V=34 mph
DESCRIPTION Oblique impact with 2000 Ford Explorer; stiffness and height mismatch between 2 passenger vehicles contributed to IP intrusion
CRASH CLASSIFICATION OBLIQUE IMPACT
PRIMARY FACTOR OBLIQUE CRASH
SECONDARY FACTORS FRONT-TO-FRONT INCOMPATIBILITY
VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2005-47-137 DRIVER 19yo female 5'3'' 114 lbs
CASE VEHICLE 2001 FORD MUSTANG 11FDAW6
DESCRIPTION Struck rear of stopped semi-trailer; impact speed higher than this study's typical rear impact with a trailer; severe intrusion
CRASH CLASSIFICATION UNDERRODE REAR OF HEAVY VEHICLE
PRIMARY FACTORS UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
TRAILER GUARD DID NOT PREVENT UNDERRIDE
SECONDARY FACTORS EXCEEDINGLY SEVERE CRASH
INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2005-49-205 DRIVER 44yo male 5'11'' 220 lbs
CASE VEHICLE 2001 FORD TAURUS

DESCRIPTION Sideswipe + frontal pole impact + rollover; insufficient injury/contact data to determine if the frontal was the critical event, or what primary factors were involved
CRASH CLASSIFICATION dropped case: insufficient information

CDS CASE NUMBER 2005-50-125 DRIVER 41yo male 5’1’’ 194 lbs
CASE VEHICLE 2002 PONTIAC GRAND PRIX 12FYEW6 ΔV=53 mph
DESCRIPTION Struck Lexus LS 430 (V=53 mph); sustained large IP intrusion; thoracic trauma
CRASH CLASSIFICATION EXCEEDINGLY SEVERE
PRIMARY FACTOR EXCEEDINGLY SEVERE CRASH
SECONDARY FACTORS EXCESSIVE IP OR TOE PAN INTRUSION
STEERING COLUMN MOVED UPWARD
VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2005-72-36 DRIVER 35yo male 5’10’’ 198 lbs
CASE VEHICLE 2004 CHEVROLET CAVALIER 12FDAW9
DESCRIPTION Struck rear of trailer and underrode; sustained severe windshield header intrusion
CRASH CLASSIFICATION UNDERRODE REAR OF HEAVY VEHICLE
PRIMARY FACTOR TRAILER GUARD DID NOT PREVENT UNDERRIDE
SECONDARY FACTORS INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)

CDS CASE NUMBER 2005-74-138 DRIVER 47yo female 5’3’’ 161 lbs
CASE VEHICLE 2005 TOYOTA COROLLA 12FDEW6 ΔV=60 mph
DESCRIPTION Offset frontal with Mercedes S320 (ΔV=60 mph); thoracic trauma
CRASH CLASSIFICATION EXCEEDINGLY SEVERE
PRIMARY FACTOR EXCEEDINGLY SEVERE CRASH
SECONDARY FACTORS EXCESSIVE IP OR TOE PAN INTRUSION
AIR BAG BOTTOMED OUT

CDS CASE NUMBER 2005-75-170 DRIVER 64yo female 5’1’’ 150 lbs
CASE VEHICLE 2002 FORD MUSTANG 12FDAW9
DESCRIPTION Offset frontal with motor coach; large IP intrusion; neck and thoracic trauma
CRASH CLASSIFICATION EXCEEDINGLY SEVERE
PRIMARY FACTOR EXCEEDINGLY SEVERE CRASH
SECONDARY FACTORS EXCESSIVE IP OR TOE PAN INTRUSION
AIR BAG BOTTOMED OUT

CDS CASE NUMBER 2005-79-139 DRIVER 74yo female 5’4’’ 134 lbs
CASE VEHICLE 2000 HONDA ACCORD 12FYEN3
DESCRIPTION Jumped curb and struck light pole; 74 yo female had thoracic injuries from air bag
CRASH CLASSIFICATION VULNERABLE OCCUPANT
PRIMARY FACTOR ELEVATED OCCUPANT AGE (74)
SECONDARY FACTORS AIR BAG INJURED OUT-OF-POSITION OCCUPANT
OUT-OF-POSITION OCCUPANT
MULTIPLE-EVENT CRASH

CDS CASE NUMBER 2005-81-69 DRIVER 22yo female 5’5’’ 224 lbs
CASE VEHICLE 2005 ACURA RSX
DESCRIPTION Hit by car in front and by tractor-trailer in L side; fatal injuries attributed to left-side surfaces during the side impact
CRASH CLASSIFICATION dropped case: side impact primary

CDS CASE NUMBER 2006-3-121 DRIVER 76yo female 5’3’’ 112 lbs
CASE VEHICLE 2003 HONDA ACCORD
DESCRIPTION 76 yo driver apparently died from disease with onset prior to low-speed crash on quiet cul-de-sac
CRASH CLASSIFICATION dropped case: died precrash

CDS CASE NUMBER 2006-4-45 DRIVER 19yo female 5’3’’ 130 lbs
CASE VEHICLE 2001 SATURN SC 91FDEW3
DESCRIPTION Struck approaching tractor-trailer while making a left turn; oblique impact with underride; header and IP intrusion
CRASH CLASSIFICATION (1) OBLIQUE IMPACT; (2) OTHER: UNDERRODE FRONT OF HEAVY TRUCK
PRIMARY FACTORS OBLIQUE CRASH
UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
SECONDARY FACTOR INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2006-9-59 DRIVER 35yo male 5’2’’ 194 lbs
CASE VEHICLE 2006 FORD ESCAPE 4X4 92FYEW4 ΔV=38 mph
DESCRIPTION Struck 2003 Chevrolet Malibu; oblique impact resulted in A-pillar, header, and roof-rail intrusion
CRASH CLASSIFICATION OBLIQUE IMPACT
PRIMARY FACTOR OBLIQUE CRASH
SECONDARY FACTORS POOR OCCUPANT-AIR BAG INTERACTION
INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
SHORT-STATURE OCCUPANT

CDS CASE NUMBER 2006-11-150 RF PASSENGER 17yo female 5’9’’ 147 lbs

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CASE VEHICLE          2002 CHEVROLET TRAILBLAZER 12FDEW4
DESCRIPTION             Struck a tractor-trailer in the rear; fatal head injury
CRASH CLASSIFICATION  UNDERRODE REAR OF HEAVY VEHICLE
PRIMARY FACTORS       UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
                      TRAILER GUARD DID NOT PREVENT UNDERRIDE
SECONDARY FACTOR      BACK-SEAT BULLET

CDS CASE NUMBER 2006-11-163 DRIVER 35yo male 5'11'' 163 lbs
CASE VEHICLE          2006 LINCOLN ZEPHYR 12FDAA9
DESCRIPTION             Struck rear of semi-trailer; impact not too severe; underride severe
CRASH CLASSIFICATION  UNDERRODE REAR OF HEAVY VEHICLE
PRIMARY FACTORS       UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
                      TRAILER GUARD DID NOT PREVENT UNDERRIDE
SECONDARY FACTOR      INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2006-11-220 DRIVER 70yo female 5'10'' 161 lbs
CASE VEHICLE          2004 GMC YUKON XL 12FDEW4
DESCRIPTION             Crossed ditch, throwing driver out of position; then hit pole
CRASH CLASSIFICATION  OTHER: AIR BAG INJURED OUT-OF-POSITION DRIVER
PRIMARY FACTORS       AIR BAG INJURED OUT-OF-POSITION OCCUPANT
                      OUT-OF-POSITION OCCUPANT
SECONDARY FACTOR      BELT OR INTEGRATED SEAT BELT DID NOT ADEQUATELY RESTRAIN

CDS CASE NUMBER 2006-12-161 DRIVER 30yo male 6'1'' 244 lbs
CASE VEHICLE          2005 CHRYSLER TOWN & COUNTRY 12FDEK5
DESCRIPTION             Oblique offset impact with Silverado; damage continued along left side as vehicles rotated
CRASH CLASSIFICATION  OBLIQUE IMPACT
PRIMARY FACTOR        OBLIQUE CRASH
SECONDARY FACTORS     POOR OCCUPANT-AIR BAG INTERACTION
                      INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
                      EXCESSIVE IP OR TOE PAN INTRUSION

CDS CASE NUMBER 2006-41-64 DRIVER 78yo female 5'4'' 183 lbs
CASE VEHICLE          2005 LEXUS ES-300 12FDEW4
DESCRIPTION             Centered tree impact (∆V ≈ 30 mph) apparently delayed deployment of the air bag
CRASH CLASSIFICATION  TALL, NARROW OBJECT
PRIMARY FACTORS       LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
                      ELEVATED OCCUPANT AGE (78)
                      TALL, NARROW OBJECT
SECONDARY FACTORS     OBESE (BMI 30 OR MORE)
                      AIR BAG BOTTOMED OUT

CDS CASE NUMBER 2006-41-132 DRIVER 73yo male 5'11'' 183 lbs
CASE VEHICLE          2006 TOYOTA HIGHLANDER
DESCRIPTION             Chain collision - but all the major injuries attributable to the rear impact
CRASH CLASSIFICATION  dropped case: rear impact primary

CDS CASE NUMBER 2006-45-59 DRIVER 23yo female 5'6'' 141 lbs
CASE VEHICLE          2005 FORD FOCUS 12FDEK5
DESCRIPTION             Oblique offset impact with Lexus IS-300; driver's trajectory into intruding center IP
CRASH CLASSIFICATION  OBLIQUE IMPACT
PRIMARY FACTOR        OBLIQUE CRASH
SECONDARY FACTORS     POOR OCCUPANT-AIR BAG INTERACTION
                      EXCESSIVE IP OR TOE PAN INTRUSION

CDS CASE NUMBER 2006-49-23 DRIVER 26yo female 5'2'' 304 lbs
CASE VEHICLE          2003 NISSAN ALTIMA
DESCRIPTION             Team believes seat belts were stowed at the time of the impact; they locked in that
                        position and pretensioner fired, but the driver wasn't wearing them
CRASH CLASSIFICATION  dropped case: unbelted

CDS CASE NUMBER 2006-49-137 DRIVER 19yo male 5'3'' 119 lbs
CASE VEHICLE          2002 PONTIAC AZTEK 12FLAE7 ∆V=34 mph
DESCRIPTION             Struck pole with LF corner; severe IP and header intrusion
CRASH CLASSIFICATION  (1) CORNER IMPACT; (2) TALL, NARROW OBJECT
PRIMARY FACTORS       LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
                      INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
                      TALL, NARROW OBJECT
SECONDARY FACTORS     POOR OCCUPANT-AIR BAG INTERACTION
                      EXCESSIVE IP OR TOE PAN INTRUSION
                      VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2006-49-201 DRIVER 52yo female 5'2'' 257 lbs
CASE VEHICLE          2006 KIA RIO 12FDEW4
DESCRIPTION             Rear-ended semi-trailer (BES 52 mph); good performance of trailer's underride guard, but
                        impact just too severe
CRASH CLASSIFICATION  EXCEEDINGLY SEVERE
PRIMARY FACTOR        EXCEEDINGLY SEVERE CRASH
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SECONDARY FACTORS OBESE (BMI 30 OR MORE)
AIR BAG BOTTOMED OUT
BELT DID NOT ADEQUATELY RESTRAIN
SHORT-STATURE OCCUPANT

CDS CASE NUMBER 2006-50-83 DRIVER 28yo male 5'2'' 110 lbs
CASE VEHICLE 2000 HYUNDAI TIBURON 12FLAE9 ΔV=18 mph
DESCRIPTION Corner impact with Jeep Grand Cherokee
CRASH CLASSIFICATION CORNER IMPACT
PRIMARY FACTORS LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
SECONDARY FACTORS FRONT-TO-FRONT INCOMPATIBILITY
UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2006-72-142 DRIVER 25yo male 5'11'' 174 lbs
CASE VEHICLE 2006 FORD MUSTANG
DESCRIPTION Side impact with pole and frontal impact with barrier; driver hit head on pole during side-impact event
CRASH CLASSIFICATION dropped case: side impact primary

CDS CASE NUMBER 2006-73-71 DRIVER 65yo male 5'11'' 229 lbs
CASE VEHICLE 2003 JEEP GRAND CHEROKEE 12FREW4 ΔV=28 mph
DESCRIPTION Hit rear of Saturn LS, then hit pole; air bag deployed on first impact; highest Delta V on pole impact
CRASH CLASSIFICATION ANOMALY
PRIMARY FACTORS ANOMALY: MULTIPLE FRONTAL IMPACTS
MULTIPLE-EVENT CRASH
SECONDARY FACTORS ELEVATED OCCUPANT AGE
OBESE (BMI 30 OR MORE)
VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2006-75-22 RF PASSENGER 27yo male 6'4'' 189 lbs
CASE VEHICLE 2006 MITSUBISHI ECLIPSE 12FZAW6
DESCRIPTION Centered impact with tree; impact missed car's frame rails; severe intrusion
CRASH CLASSIFICATION TALL, NARROW OBJECT
PRIMARY FACTORS TALL, NARROW OBJECT
EXCESSIVE IP OR TOE PAN INTRUSION
SECONDARY FACTORS none

CDS CASE NUMBER 2006-75-23 DRIVER 22yo male 5'5'' 139 lbs
CASE VEHICLE 2005 MITSUBISHI LANCER 12FLEE7 ΔV=34 mph
DESCRIPTION Corner impact with GMC Suburban; head and neck injuries
CRASH CLASSIFICATION CORNER IMPACT
PRIMARY FACTORS LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
SECONDARY FACTORS FRONT-TO-FRONT INCOMPATIBILITY
UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)

CDS CASE NUMBER 2006-75-96 DRIVER 31yo male 5'8'' 134 lbs
CASE VEHICLE 2000 CHRYSLER CONCORDE 12FYEW4 ΔV=24 mph
DESCRIPTION Oblique impact with 2006 Toyota Solara; much IP and toe pan intrusion; seat deformed due to 'back-seat bullet'
CRASH CLASSIFICATION OBLIQUE IMPACT
PRIMARY FACTORS OBLIQUE CRASH
EXCESSIVE IP OR TOE PAN INTRUSION
SECONDARY FACTORS AIR BAG BOTTOMED OUT
BELT OR INTEGRATED SEAT BELT DID NOT ADEQUATELY RESTRAIN
BACK-SEAT BULLET
VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2006-75-98 DRIVER 25yo female 5'8'' 161 lbs
CASE VEHICLE 2001 CHEVROLET MALIBU 11FDAW7 ΔV=63 mph
DESCRIPTION High-speed oblique impact with 1994 Jeep Cherokee (ΔV = 63 mph); stiffness and height mismatch caused much IP and toe pan intrusion
CRASH CLASSIFICATION EXCEEDINGLY SEVERE
PRIMARY FACTORS EXCEEDINGLY SEVERE CRASH
FRONT-TO-FRONT INCOMPATIBILITY
SECONDARY FACTORS OBLIQUE CRASH
UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
EXCESSIVE IP OR TOE PAN INTRUSION
AIR BAG BOTTOMED OUT

CDS CASE NUMBER 2006-78-62 DRIVER 50yo female 5'6'' 114 lbs
CASE VEHICLE 2000 DODGE RAM QUAD CAB PICKUP 69FDAW6
DESCRIPTION Struck the right rear tires of a semi-trailer and underrode it; severe intrusion; post-crash fire
CRASH CLASSIFICATION UNDERRODE SIDE OF HEAVY VEHICLE

PRIMARY FACTOR UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
SECONDARY FACTOR VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

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CDS CASE NUMBER 2006-78-132 DRIVER 66yo female 5’5’’ 130 lbs
       CASE VEHICLE           2003 FORD F-250 CREW CAB 4X4 PICKUP 12FDAW6
       DESCRIPTION              Severe oblique front-to-front impact with Kenworth tractor pulling a semi-trailer;
                                underride caused much IP intrusion
       CRASH CLASSIFICATION   EXCEEDINGLY SEVERE
       PRIMARY FACTORS        EXCEEDINGLY SEVERE CRASH
                              UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
       SECONDARY FACTORS      POOR OCCUPANT-AIR BAG INTERACTION
                              OBLIQUE CRASH
                              INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
                              EXCESSIVE IP OR TOE PAN INTRUSION

CDS CASE NUMBER 2006-81-39 RF PASSENGER 62yo male 5’11’’ 220 lbs
       CASE VEHICLE           2006 TOYOTA COROLLA 31FDEW4 ∆V=24 mph
       DESCRIPTION              Frontally impacted embankment, rolled 3 quarter turns, and landed on its right side;
                                passenger was 62yo and obese
       CRASH CLASSIFICATION   ANOMALY
       PRIMARY FACTOR         ANOMALY: STRUCK UNUSUAL OBJECT & OVERTURNED
       SECONDARY FACTORS      ELEVATED OCCUPANT AGE (62)
                              OBESE (BMI 30 OR MORE)

CDS CASE NUMBER 2006-82-4 DRIVER 47yo male 5’5’’ 222 lbs
       CASE VEHICLE           2003 CHEVROLET SILVERADO PICKUP 12FDEW4 EDR ∆V=51 mph
       DESCRIPTION              Severe head-on impact with 2003 Ford F-250 carrying 2,000 lbs. of cargo (EDR ∆V = 51 mph);
                                much IP and toe pan intrusion
       CRASH CLASSIFICATION   EXCEEDINGLY SEVERE
       PRIMARY FACTORS        EXCEEDINGLY SEVERE CRASH
                              ANOMALY: 2000 POUNDS CARGO IN OTHER VEHICLE
       SECONDARY FACTORS      OBESE (BMI 30 OR MORE)
                              EXCESSIVE IP OR TOE PAN INTRUSION
                              AIR BAG BOTTOMED OUT
                              BELT OR INTEGRATED SEAT BELT DID NOT ADEQUATELY RESTRAIN

CDS CASE NUMBER 2007-2-139 DRIVER 79yo female 5’7’’ 150 lbs
       CASE VEHICLE           2001 NISSAN SENTRA 12FYEW5 ∆V=24 mph
       DESCRIPTION              Offset impact with 2001 Jeep Cherokee; 79yo driver sat close to steering wheel as
                                evidenced by air bag related injuries
       CRASH CLASSIFICATION   VULNERABLE OCCUPANT
       PRIMARY FACTOR         ELEVATED OCCUPANT AGE (79)
       SECONDARY FACTORS      FRONT-TO-FRONT INCOMPATIBILITY
                              AIR BAG BOTTOMED OUT

CDS CASE NUMBER 2007-5-21 DRIVER 48yo female 5’9’’ 191 lbs
       CASE VEHICLE           2006 HONDA PILOT
       DESCRIPTION              Contact points and injury patterns (roof, steering wheel, L side) more characteristic of
                                an unbelted than a belted 5’9” driver
       CRASH CLASSIFICATION   dropped case: unbelted

CDS CASE NUMBER 2007-9-63 DRIVER 60yo male 6’5’’ 279 lbs
       CASE VEHICLE           2006 TOYOTA AVALON 12FDAA8
       DESCRIPTION              Struck a tractor-trailer in the rear; extensive header and IP intrusion
       CRASH CLASSIFICATION   UNDERRODE REAR OF HEAVY VEHICLE
       PRIMARY FACTORS        UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
                              TRAILER GUARD DID NOT PREVENT UNDERRIDE
       SECONDARY FACTOR       INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2007-11-39 DRIVER 64yo male 5’10’’ 249 lbs
       CASE VEHICLE           2006 SUBARU OUTBACK 12FYAA9
       DESCRIPTION              High-speed impact into the right rear corner of a medium-heavy truck (U-haul type)
       CRASH CLASSIFICATION   EXCEEDINGLY SEVERE
       PRIMARY FACTOR         EXCEEDINGLY SEVERE CRASH
       SECONDARY FACTORS      INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
                              UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
                              TRAILER GUARD DID NOT PREVENT UNDERRIDE

CDS CASE NUMBER 2007-11-72 DRIVER 18yo male 5’9’’ 136 lbs
       CASE VEHICLE           2002 HONDA ACCORD 72FDAW6 ∆V=85 mph
       DESCRIPTION              Struck a tree (∆V = 85 mph)
       CRASH CLASSIFICATION   EXCEEDINGLY SEVERE
       PRIMARY FACTOR         EXCEEDINGLY SEVERE CRASH
       SECONDARY FACTORS      EXCESSIVE IP OR TOE PAN INTRUSION
                              STEERING COLUMN MOVED UPWARD

CDS CASE NUMBER 2007-11-135 DRIVER 80yo male 5’10’’ 150 lbs
       CASE VEHICLE           2004 CHEVROLET MALIBU 12FCEW3
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DESCRIPTION Ran off road and struck 3 trees; probably out-of-position prior to main impact; contacted steering wheel rim
CRASH CLASSIFICATION VULNERABLE OCCUPANT
PRIMARY FACTOR ELEVATED OCCUPANT AGE (80)
SECONDARY FACTOR OUT-OF-POSITION OCCUPANT

CDS CASE NUMBER 2007-12-180 DRIVER 56yo female 5’3’’ 180 lbs
CASE VEHICLE 2000 DODGE DAKOTA QUAD CAB PICKUP 81FDEW4 ΔV=42 mph
DESCRIPTION Head-on with Ford F-250; IP intrusion, no pretensioners, short driver; fatal chest injury from steering assembly
CRASH CLASSIFICATION OTHER: DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS
PRIMARY FACTORS EXCESSIVE IP OR TOE PAN INTRUSION
VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS
SECONDARY FACTORS POOR OCCUPANT-AIR BAG INTERACTION
OBESE (BMI 30 OR MORE)
SHORT-STATURE OCCUPANT

CDS CASE NUMBER 2007-41-61 DRIVER 57yo female 5’7’’ 251 lbs
CASE VEHICLE 2002 HONDA ACCORD
DESCRIPTION 57yo, obese driver had a heart attack shortly before this minor front-to-rear impact with a stopped BMW
CRASH CLASSIFICATION dropped case: died of disease

CDS CASE NUMBER 2007-42-9 DRIVER 46yo male 5’10’’ 222 lbs
CASE VEHICLE 2004 INFINITI FX35 12FDAW9
DESCRIPTION High speed frontal impact with the rear corner of a motor home triggered a rollover; driver sustained fatal chest injuries from the steering wheel
CRASH CLASSIFICATION EXCEEDINGLY SEVERE
PRIMARY FACTOR EXCEEDINGLY SEVERE CRASH
SECONDARY FACTORS POOR OCCUPANT-AIR BAG INTERACTION
UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
TRAILER GUARD DID NOT PREVENT UNDERRIDE
OBESE (BMI 30 OR MORE)

CDS CASE NUMBER 2007-47-61 DRIVER 58yo male 5’10’’ 299 lbs
CASE VEHICLE 2005 HONDA CRV 12FYAW9
DESCRIPTION Corner impact with Silverado 2500; pickup truck pocketed the Honda’s door; driver hit head on its hood
CRASH CLASSIFICATION CORNER AND OBLIQUE IMPACT
PRIMARY FACTORS LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
SECONDARY FACTORS OBLIQUE CRASH
INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2007-47-119 DRIVER 36yo male 5’9’’ 180 lbs
CASE VEHICLE 2001 DODGE RAM 1500 QUAD CAB PICKUP 81FDAW6
DESCRIPTION High-speed oblique impact into the side of a heavy trailer coming from the opposite direction
CRASH CLASSIFICATION EXCEEDINGLY SEVERE
PRIMARY FACTOR EXCEEDINGLY SEVERE CRASH
SECONDARY FACTORS OBLIQUE CRASH
INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH
VEHICLE DID NOT PERFORM WELL IN CRASH-SAFETY RATING PROGRAMS

CDS CASE NUMBER 2007-48-186 DRIVER 66yo male 5’6’’ 150 lbs
CASE VEHICLE 2003 TOYOTA TACOMA DOUBLE CAB PICKUP 11FDEW4 ΔV=40 mph
DESCRIPTION Oblique impact with Lincoln Town Car (ΔV = 40 mph); 8’’ of steering wheel and IP intrusion; fatal head and chest injuries from steering wheel
CRASH CLASSIFICATION OBLIQUE IMPACT
PRIMARY FACTOR OBLIQUE CRASH
SECONDARY FACTORS POOR OCCUPANT-AIR BAG INTERACTION
EXCEEDINGLY SEVERE CRASH
ELEVATED OCCUPANT AGE

CDS CASE NUMBER 2007-49-165 DRIVER 50yo male 6’ 240 lbs
CASE VEHICLE 2001 FORD TAURUS 12FZEN3 ΔV=27 mph
DESCRIPTION Frontally impacted a concrete barrier and trees, resulting in a fire; driver died from burns, not impact trauma
CRASH CLASSIFICATION ANOMALY
PRIMARY FACTORS ANOMALY: POST-CRASH FIRE
POST-CRASH FIRE, FATAL BURNS
SECONDARY FACTOR LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT

CDS CASE NUMBER 2007-49-180 RF PASSENGER 57yo male 5’8’’ 134 lbs
CASE VEHICLE 2006 CHRYSLER PT CRUISER
DESCRIPTION Road debris set in motion by another vehicle penetrated the windshield and killed RF passenger; no frontal impact or other crash event
CRASH CLASSIFICATION dropped case: projectile flew into vehicle

CDS CASE NUMBER 2007-72-101 DRIVER 71yo female 5'11'' 255 lbs

CASE VEHICLE 2001 BUICK LeSABRE 12FYEW2
DESCRIPTION Hit 2 cars and 3 trees at low severity/minimal interior intrusion; chest injuries probably from belt load
CRASH CLASSIFICATION VULNERABLE OCCUPANT
PRIMARY FACTORS ELEVATED OCCUPANT AGE (71)
OBESE (BMI 30 OR MORE)
SECONDARY FACTOR POOR OCCUPANT-AIR BAG INTERACTION

CDS CASE NUMBER 2007-72-126 DRIVER 82yo male 6' 200 lbs

CASE VEHICLE 2005 FORD FOCUS 12FLEE5 ∆V=23 mph
DESCRIPTION Struck large tree with corner; 82 yo male driver
CRASH CLASSIFICATION (1) VULNERABLE OCCUPANT; (2) CORNER IMPACT
PRIMARY FACTOR ELEVATED OCCUPANT AGE (82)
SECONDARY FACTOR LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT

CDS CASE NUMBER 2007-73-37 DRIVER 46yo male 6'2'' 246 lbs

CASE VEHICLE 2000 TOYOTA CELLICA 12FDAW9
DESCRIPTION Struck rear of trailer with right front; underride with > 61 cm header intrusion
CRASH CLASSIFICATION UNDERRODE REAR OF HEAVY VEHICLE
PRIMARY FACTORS UNDERRIDE (LIMITED VERTICAL ENGAGEMENT)
TRAILER GUARD DID NOT PREVENT UNDERRIDE
SECONDARY FACTOR INTRUSION OF ROOF, A-PILLAR OR EXTERIOR OBJ/VEH

CDS CASE NUMBER 2007-73-137 DRIVER 52yo male 5'11'' 145 lbs

CASE VEHICLE 2005 DODGE STRATUS 1FYAW7 ∆V=51 mph
DESCRIPTION Offset frontal (∆V=51 mph) with Chevrolet Blazer; severe intrusion and obliquity
CRASH CLASSIFICATION EXCEEDINGLY SEVERE
PRIMARY FACTORS OBLIQUE CRASH
EXCEEDINGLY SEVERE CRASH
SECONDARY FACTORS LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
FRONT-TO-FRONT INCOMPATIBILITY
EXCESSIVE IP OR TOE PAN INTRUSION

CDS CASE NUMBER 2007-74-107, VEHICLE NO. 1, DRIVER 20yo female 5'4'' 161 lbs

CASE VEHICLE 2000 FORD TAURUS 12FDEW5 ∆V=59 mph
DESCRIPTION Full-frontal head-on (∆V=59 mph)
CRASH CLASSIFICATION EXCEEDINGLY SEVERE
PRIMARY FACTOR EXCEEDINGLY SEVERE CRASH
SECONDARY FACTORS EXCESSIVE IP OR TOE PAN INTRUSION
AIR BAG BOTTOMED OUT

CDS CASE NUMBER 2007-74-147 (same as previous), VEHICLE NO. 2, DRIVER 62yo male 6'2'' 330 lbs

CASE VEHICLE 2000 BUICK PARK AVENUE 12FDEW5 ∆V=47 mph
DESCRIPTION Full-frontal head-on (∆V=47 mph); all-belts-to-seat with obese occupants
CRASH CLASSIFICATION EXCEEDINGLY SEVERE
PRIMARY FACTOR EXCEEDINGLY SEVERE CRASH
SECONDARY FACTORS OBESE (BMI 30 OR MORE)
EXCESSIVE IP OR TOE PAN INTRUSION
AIR BAG BOTTOMED OUT
INTEGRATED SEAT BELT DID NOT ADEQUATELY RESTRAIN

CDS CASE NUMBER 2007-74-147 (same as previous 2), VEHICLE NO. 2, RF PASSENGER 62yo female 5'7'' 200 lbs

CASE VEHICLE 2000 BUICK PARK AVENUE 12FDEW5 ∆V=47 mph
DESCRIPTION Full-frontal head-on (∆V=47 mph); all-belts-to-seat with obese occupants
CRASH CLASSIFICATION EXCEEDINGLY SEVERE
PRIMARY FACTOR EXCEEDINGLY SEVERE CRASH
SECONDARY FACTORS OBESE (BMI 30 OR MORE)
INTEGRATED SEAT BELT DID NOT ADEQUATELY RESTRAIN

CDS CASE NUMBER 2007-78-24 DRIVER 27yo male 5'1'' 130 lbs

CASE VEHICLE 2000 NISSAN FRONTIER PICKUP 1FYAW9
DESCRIPTION Crossed centerline and impacted side of trailer near wheel/axle assembly
CRASH CLASSIFICATION (1) UNDERRODE SIDE OF HEAVY VEHICLE; (2) CORNER IMPACT
PRIMARY FACTOR LIMITED HORIZONTAL STRUCTURAL ENGAGEMENT
SECONDARY FACTOR EXCESSIVE IP OR TOE PAN INTRUSION

CDS CASE NUMBER 2007-81-57 DRIVER 35yo male 5'9'' 191 lbs

CASE VEHICLE 2006 FORD F-150 SUPERCAB 4X4 PICKUP
DESCRIPTION Truck ran off road, leaning and yawing; right-front fender contacted sign post at high speed; post cut thru engine compartment
CRASH CLASSIFICATION dropped case: side impact primary

APPENDIX B

INDEX OF CASES IN EACH BIN

Exceedingly severe crash and/or anomaly

As the only bin:

Exceedingly severe crash 2000-11-30 (2 fatalities), 2000-12-78, 2000-78-80, 2001-11-178, 2002-12-186 (2 fatalities), 2002-42-25, 2002-45-16, 2002-47-39, 2002-47-134, 2002-76-97, 2003-2-141, 2003-9-47, 2003-76-134, 2003-81-41, 2004-76-57, 2004-76-157, 2005-45-142, 2005-50-125, 2005-74-138, 2005-75-170, 2006-49-201, 2006-75-98, 2006-78-132, 2006-82-4, 2007-11-39, 2007-11-72, 2007-42-9, 2007-47-119, 2007-73-137, 2007-74-107 (3 fatalities)

Anomaly 2001-13-181, 2001-45-114, 2002-9-25, 2003-8-223, 2003-11-18, 2004-2-74, 2004-11-119, 2004-48-58, 2004-73-147, 2005-9-64, 2006-73-71, 2006-81-39, 2007-49-165

Exceedingly severe crash and anomaly 2004-49-106 (2 fatalities)

Corner and/or oblique impact

As the only or primary bin:

Corner impact 2000-76-139, 2002-2-114, 2003-81-44, 2004-45-113, 2004-47-83, 2004-50-32, 2005-2-54, 2005-43-231, 2005-47-102, 2006-49-137, 2006-50-83, 2006-75-23,

Corner and oblique impact 2001-81-117, 2002-42-34 (driver), 2004-73-241, 2007-47-61

Oblique impact 2001-75-113, 2001-76-111, 2002-9-131, 2002-42-34 (RF passenger), 2004-43-253, 2004-49-168, 2005-47-134, 2006-4-45, 2006-9-59, 2006-12-161, 2006-45-59, 2006-75-96, 2007-48-186

As the secondary bin: 2004-2-62, 2005-45-196, 2007-72-126, 2007-78-24

Underrode rear/side of heavy vehicle

As the only or primary bin:

Underrode rear of heavy vehicle 2000-49-254, 2002-9-43, 2003-42-61, 2003-79-139, 2004-42-113, 2004-73-165, 2004-82-16, 2005-9-189, 2005-47-137, 2005-72-36, 2006-11-150, 2006-11-163, 2007-9-63, 2007-73-37

Underrode side of heavy vehicle 2000-43-243, 2006-78-62, 2007-78-24

Vulnerable occupant

As the only or primary bin: 2002-48-222, 2002-75-53, 2003-48-158, 2004-2-62, 2004-41-15, 2004-50-147, 2004-79-49, 2004-79-244, 2005-45-116, 2005-45-196, 2005-79-139, 2007-2-139, 2007-11-135, 2007-72-101, 2007-72-126

As the secondary bin: 2005-2-54

Tall, narrow object

As the only or primary bin: 2002-49-100, 2004-9-62, 2006-41-64, 2006-75-22

As the secondary bin: 2002-2-114, 2004-47-83, 2004-50-32, 2005-43-231, 2006-49-137

Other

As the only or primary bin:

- Did not perform well in crash-safety rating programs 2000-8-226, 2007-12-180
- Seat belt anchor and seat track tore loose 2000-12-137
- Air bag did not deploy 2001-12-116
- Back-seat bullet 2002-45-135
- Underrode front of heavy truck 2004-43-291
- Post-crash injury complications 2005-4-119
- Air bag injured out-of-position driver 2006-11-220

As the secondary bin: 2004-45-113, 2006-4-45

APPENDIX C

INDEX OF CASES EXHIBITING EACH FACTOR

<u>Factors describing the crash configuration or partners</u>

Exceedingly severe crash
As a primary factor: 2000-11-130 (2 fatalities), 2000-12-78, 2000-78-80, 2001-11-178, 2002-12-186 (2 fatalities), 2002-42-25, 2002-45-16, 2002-47-39, 2002-47-134, 2002-76-97, 2003-2-141, 2003-9-47, 2003-76-134, 2003-81-41, 2004-49-106 (2 fatalities), 2004-76-57, 2004-76-157, 2005-45-142, 2005-47-102, 2005-50-125, 2005-74-138, 2005-75-170, 2006-49-201, 2006-75-98, 2006-78-132, 2006-82-4, 2007-11-39, 2007-11-72, 2007-42-9, 2007-47-119, 2007-73-137, 2007-74-107 (3 fatalities)
As a secondary factor: 2000-8-226, 2001-12-116, 2001-76-111, 2002-45-135, 2004-47-83, 2004-73-147, 2004-73-165, 2004-73-241, 2005-47-137, 2007-48-186

Underride
As a primary factor: 2000-11-130 (2 fatalities), 2000-43-243, 2000-49-254, 2002-9-43, 2003-42-61, 2003-76-134, 2003-79-139, 2004-42-113, 2004-43-291, 2004-48-58, 2004-73-165, 2004-82-16, 2005-9-189, 2005-47-137, 2006-4-45, 2006-11-150, 2006-11-163, 2006-78-62, 2006-78-132, 2007-9-63, 2007-47-61, 2007-73-37
As a secondary factor: 2000-78-80, 2001-11-178, 2001-81-117, 2002-9-25, 2002-9-131, 2003-9-47, 2003-81-41, 2005-72-36, 2006-50-83, 2006-75-23, 2006-75-98, 2007-11-39, 2007-42-9

Trailer's guard did not prevent underride
As a primary factor: 2000-49-254, 2002-9-43, 2003-42-61, 2003-79-139, 2004-42-113, 2004-73-165, 2004-82-16, 2005-47-137, 2005-72-36, 2006-11-150, 2006-11-163, 2007-9-63, 2007-73-37
As a secondary factor: 2007-11-39, 2007-42-9

Limited horizontal structural engagement
As a primary factor: 2000-76-139, 2002-2-114, 2002-9-131, 2002-42-34 (driver), 2003-81-44, 2004-43-291, 2004-45-113, 2004-47-83, 2004-50-32, 2004-73-241, 2004-82-16, 2005-2-54, 2005-43-231, 2005-47-102, 2006-41-64, 2006-49-137, 2006-50-83, 2006-75-23, 2007-47-61, 2007-78-24
As a secondary factor: 2001-13-181, 2001-81-117, 2002-42-34 (RF passenger), 2004-2-62, 2004-43-253, 2007-49-165, 2007-72-126, 2007-73-137

Tall, narrow object
As a primary factor: 2002-2-114, 2002-49-100, 2004-9-62, 2004-47-83, 2004-50-32, 2005-43-231, 2006-41-64, 2006-49-137, 2006-75-22
As a secondary factor: 2003-81-44

Oblique crash
As a primary factor: 2001-75-113, 2001-76-111, 2001-81-117, 2002-9-131, 2002-42-34 (2 fatalities), 2004-43-253, 2004-49-168, 2004-73-241, 2005-47-134, 2006-4-45, 2006-9-59, 2006-12-161, 2006-45-59, 2006-75-96, 2007-48-186, 2007-73-137
As a secondary factor: 2001-12-116, 2002-75-53, 2002-76-97, 2003-76-134, 2004-41-15, 2005-45-142, 2005-45-196, 2006-75-98, 2006-78-132, 2007-47-61, 2007-47-119

Front-to-front incompatibility
As a primary factor: 2004-45-113, 2006-75-98
As a secondary factor: 2001-11-178, 2002-9-131, 2003-2-141, 2004-73-241, 2004-76-157, 2005-47-134, 2006-50-83, 2006-75-23, 2007-2-139, 2007-73-137

Anomaly
As a primary factor: 2000-12-137, 2001-13-181, 2001-45-114, 2002-9-25, 2003-8-223, 2003-11-18, 2004-2-74, 2004-11-119, 2004-48-58, 2004-49-106 (2 fatalities), 2004-73-147, 2005-9-64, 2006-73-71, 2006-81-39, 2006-82-4, 2007-49-165

Multiple-event crash
As a primary factor: 2000-12-137, 2006-73-71
As a secondary factor: 2005-79-139

Post-crash fire resulting in fatal burns
As a primary factor: 2003-8-223, 2007-49-165

Out-of-position occupant
As a primary factor: 2006-11-220
As a secondary factor: 2002-2-114, 2005-79-139, 2007-11-135

Factors describing performance of the restraint systems in the case vehicle

Poor occupant-air bag interaction
As a primary factor: 2001-81-117, 2002-42-34 (RF passenger), 2004-49-168
As a secondary factor: 2002-42-34 (driver), 2003-76-134, 2003-81-44, 2004-2-62, 2004-43-253, 2004-73-241, 2004-79-49, 2005-9-64, 2005-45-116, 2006-9-59, 2006-12-161, 2006-45-59, 2006-49-137, 2006-78-132, 2007-12-180, 2007-42-9, 2007-48-186, 2007-72-101

Belt system did not adequately restrain
As a primary factor: 2000-12-137
As a secondary factor: 2000-12-78, 2000-49-254, 2004-47-83, 2005-45-116, 2006-11-220, 2006-49-201, 2006-75-96, 2006-82-4, 2007-74-107 (2 fatalities in one vehicle)

Air bag bottomed out
As a secondary factor: 2000-8-226, 2000-12-78, 2000-49-254, 2000-78-80, 2001-11-178, 2001-75-113, 2001-76-111, 2002-42-25, 2002-45-16, 2002-45-135, 2002-47-39, 2002-48-222, 2002-49-100, 2003-2-141, 2003- 9-47, 2003-81-41, 2004-45-113, 2005-74-138, 2005-75-170, 2006-41-64, 2006-49-201, 2006-75-96, 2006-75-98, 2006-82-4, 2007-2-139, 2007-74-107 (both drivers)

Air bag injured out-of-position occupant
As a primary factor: 2006-11-220
As a secondary factor: 2005-45-116, 2005-79-139

Air bag did not deploy
As a primary factor: 2001-12-116

Belt-caused injury
As a secondary factor: 2004-50-147

Factors describing performance of the structure or other components of the case vehicle

Roof, A-pillar or other upper-component intrusion
As a primary factor: 2000-43-243, 2000-76-139, 2005-9-189, 2006-49-137, 2006-50-83, 2006-75-23
As a secondary factor: 2000-11-130 (2 fatalities), 2000-78-80, 2001-13-181, 2001-45-114, 2001-76-111, 2002-2-114, 2002-9-25, 2002-9-43, 2002-9-131, 2002-42-34 (driver only), 2002-76-97, 2003-11-18, 2003-42-61, 2003-79-139, 2003-81-44, 2004-2-74, 2004-11-119, 2004-42-113, 2004-43-253, 2004-45-113, 2004-49-106 (2 fatalities), 2004-73-147, 2004-73-165, 2004-73-241, 2004-76-57, 2005-9-64, 2005-43-231, 2005-45-142, 2005-47-102, 2005-47-137, 2005-72-36, 2006-4-45, 2006-9-59, 2006-11-163, 2006-12-161, 2006-78-132, 2007-9-63, 2007-11-39, 2007-47-61, 2007-47-119, 2007-73-37

Excessive IP or toe-pan intrusion, or buckling of the floor pan
As a primary factor: 2000-8-226, 2006-75-22, 2006-75-96, 2007-12-180
As a secondary factor: 2001-76-111, 2001-81-117, 2002-45-135, 2002-47-39, 2002-47-134, 2002-49-100, 2002-76-97, 2003-79-139, 2004-9-62, 2004-43-253, 2004-47-83, 2004-50-32, 2005-47-102, 2005-50-125, 2005-74-138, 2005-75-170, 2006-12-161, 2006-45-59, 2006-49-137, 2006-75-98, 2006-78-132, 2006-82-4, 2007-11-72, 2007-73-137, 2007-74-107 (both drivers), 2007-78-24

Vehicle did not perform well in crash-safety rating programs
As a primary factor: 2000-8-226, 2007-12-180
As a secondary factor: 2000-49-254, 2002-12-186 (2 fatalities), 2002-45-16, 2002-47-134, 2002-49-100, 2002-76-97, 2003-2-141, 2003-9-47, 2004-76-57, 2004-76-157, 2005-2-54, 2005-43-231, 2005-45-116, 2005-47-102, 2005-47-134, 2005-50-125, 2006-49-137, 2006-50-83, 2006-73-71, 2006-75-96, 2006-78-62, 2007-47-119

Seat did not adequately restrain
As a primary factor: 2000-12-137
As a secondary factor: 2002-42-25, 2002-42-34, 2004-47-83

Steering assembly moved upward
As a secondary factor: 2002-49-100, 2005-50-125, 2007-11-72

Factors describing intrinsic occupant vulnerability

Elevated occupant age
As a primary factor: 2002-49-100, 2003-48-158, 2004-2-62, 2004-41-15, 2004-50-147, 2004-79-49, 2004-79-244, 2005-4-119, 2005-45-116, 2005-45-196, 2005-79-139, 2006-41-64, 2007-2-139, 2007-11-135, 2007-72-101, 2007-72-126
As a secondary factor: 2000-12-137, 2000-78-80, 2002-2-114, 2002-12-186 (2 fatalities), 2002-48-222, 2004-9-62, 2004-47-83, 2004-49-168, 2004-50-32, 2004-76-157, 2005-2-54, 2006-73-71, 2006-81-39, 2007-48-186

Obese occupant
As a primary factor: 2004-79-49, 2004-79-244, 2007-72-101
As a secondary factor: 2000-78-80, 2001-11-178, 2001-75-113, 2002-2-114, 2002-12-186 (2 fatalities), 2002-42-34 (2 fatalities), 2004-76-57, 2005-2-54, 2005-47-102, 2006-41-64, 2006-49-201, 2006-73-71, 2006-81-39, 2006-82-4, 2007-12-180, 2007-42-9, 2007-74-107 (2 fatalities in one vehicle)

Pre-existing medical condition
As a primary factor: 2002-48-222, 2002-75-53
As a secondary factor: 2003-8-223

Post-crash injury complications
As a primary factor: 2002-48-222, 2005-4-119

Short-stature occupant
As a secondary factor: 2001-76-111, 2002-48-222, 2004-50-147, 2004-79-49, 2005-45-116, 2006-9-59, 2006-49-201, 2007-12-180

Tall or large occupant (not obese)
As a secondary factor: 2000-49-254

Factors describing actions by people that increased somebody's injury risk

Back-seat bullet
As a primary factor: 2002-45-135
As a secondary factor: 2006-11-150, 2006-75-96

Air bag switched off
As a secondary factor: 2003-48-158

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