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Fatality Reduction by Seat Belts in The Center Rear Seat and Comparison of Occupants' Relative Fatality Risk at Various Seating Positions

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16. Abstract

In 2002, Anton's Law (Public Law 107-318) directed NHTSA to require 3-point belts for each rear seating position – including center rear seats – in new passenger motor vehicles by September 1, 2007. Manufacturers had begun installing 3-point belts at the center rear seats in some makes and models as early as 1994 and completed the transition from lap belts to 3-point belts on time. Double-pair comparison and logistic regression analyses of FARS data for 1990 to 2014 show that 3-point belts are highly effective in the center rear seats: Buckling up reduces passengers' fatality risk by an estimated 58 percent in passenger cars (95% confidence bounds: 41% to 69%) and by 75 percent in LTVs (confidence bounds: 63% to 84%). In cars of the 1960s and 70s, when few people buckled up, the rear seats were substantially safer than the front seats for unrestrained occupants, and the center rear seat even safer than the outboard rear seats. These differences between seats have substantially diminished over the past 30 years. Statistical analyses of FARS do not show statistically significant mitigation of fatality risk for outboard rear or center rear seats of passenger cars relative to the driver's or right front seats, for belted occupants of the same age and gender. Corresponding analyses of LTVs show reduced fatality risk for the right front and right rear seats relative to the driver's seat; however, they do not show significant advantages for the outboard rear or center rear seats relative to the right front seats.

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LIST OF ABBREVIATIONS

AIS	Abbreviated Injury Scale
CAC	certified-advanced compliant frontal air bag
CDS	Crashworthiness Data System of NASS
CR3PT	center rear 3-point belt
CFR	Code of Federal Regulations
CR	center rear [seating position]
CUV	crossover utility vehicle
CY	calendar year
df	degrees of freedom
FARS	Fatality Analysis Reporting System, a census of fatal crashes in the United States since 1975
FMVSS	Federal Motor Vehicle Safety Standard
GES	General Estimates System of NASS
GVWR	gross vehicle weight rating (specified by the manufacturer, equals the vehicle's curb weight plus maximum recommended loading)
IIHS	Insurance Institute for Highway Safety
LTV	light trucks and vans, includes pickup trucks, SUVs, CUVs, minivans, and full-size vans
MY	model year
NASS	National Automotive Sampling System, a probability sample of police-reported crashes in the United States since 1979, investigated in detail
NCAP	New Car Assessment Program: safety ratings of new vehicles issued by NHTSA since 1979
NOPUS	National Occupant Protection Use Survey
NTSB	National Transportation Safety Board
ObdR	outboard rear [seating positions]
RF	right front [seating position]
SAS	statistical and database management software produced by SAS Institute, Inc.
UEF	universal exaggeration factor for belt effectiveness estimates after seat belt laws
VIN	Vehicle Identification Number

EXECUTIVE SUMMARY

Three-point seat belts are a safety technology whose high fatality-reducing effectiveness has repeatedly been demonstrated by statistical analyses of crash data for outboard front- and rear-seat occupants. Before 2005, the 3-point belts were only required at all outboard seats of passenger cars and LTVs (light trucks and vans, including SUVs) in the United States, while lap belts, an ostensibly less effective device, were allowed for center rear seats. Anton's Law, Public Law 107-318 (December 4, 2002) directed NHTSA to require 3-point belts for each rear seating position – i.e., including center rear seats – in passenger motor vehicles with a GVWR of 10,000 pounds or less. NHTSA amended FMVSS No. 208, "Occupant crash protection," to require the phase-in of 3-point belts in center rear seats in nearly all new passenger vehicles to start on September 1, 2005, and to be completed by September 1, 2007. In fact, manufacturers had already developed and begun installing 3-point belts at center rear seats of many vehicles well in advance of the new requirement.

NHTSA's Fatality Analysis Reporting System for 1990 through 2014 now has enough crash data to estimate the fatality-reducing effectiveness of 3-point belts for center rear seat passengers.[1] This report presents double-pair comparison analyses and logistic regression analyses estimating belt effectiveness, based on 1,512 FARS cases of center rear seat passengers riding in vehicles equipped with a 3-point belt at that seating position. The report also presents effectiveness analyses of the lap belt alone for center rear seat passengers and it updates estimates of the effectiveness of 3-point belts for outboard rear seat passengers.

The statistical analyses show that 3-point belts are highly effective and that they significantly reduce fatality risk for center rear seat passengers of both cars and LTVs.[2] The lap belt alone also significantly reduces fatality risk; however, 3-point belts are likely more effective than the lap belt alone in cars.[3] As in previous studies, 3-point belts continue to significantly reduce fatality risk for outboard rear seat passengers of cars and LTVs:

Passenger cars	Estimated Fatality Reduction (%)	95% Confidence Bounds
Center rear seat		
3-point belt	58	41 to 69
Lap belt only	48	33 to 59
Outboard rear seat		
3-point belt	54	51 to 57

[1] Fatality-reducing effectiveness = (unrestrained fatality rate – belted fatality rate) / unrestrained fatality rate.
[2] Throughout this report, except where specified otherwise, "significantly" denotes statistical significance at the two-sided .05 level.
[3] Effectiveness is borderline-significantly higher for 3-point belts than for lap belt only in passenger cars (at the 1-sided .05 level in a model that does not control for occupant age and gender).

LTVs	Estimated Fatality Reduction (%)	95% Confidence Bounds
Center rear seat		
3-point belt	75	63 to 84
Lap belt only	73	66 to 78
Outboard rear seat		
3-point belt	75	73 to 77

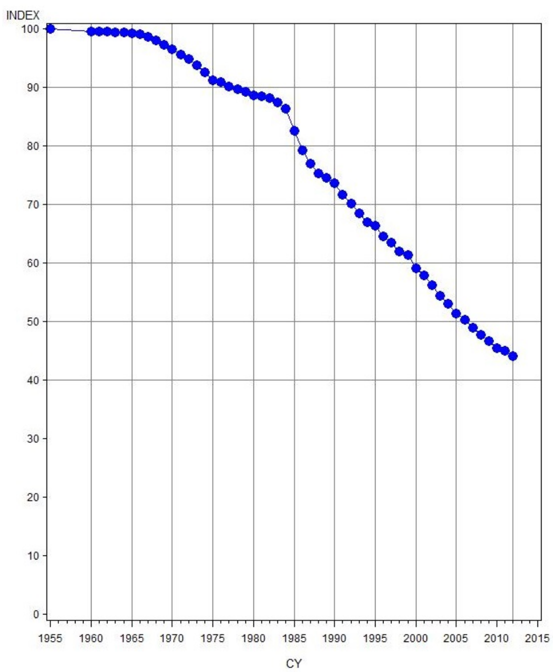
The FARS database also permits a reevaluation of the relative safety of the various seating positions in vehicles of model years 1990 to 2015 in calendar years 1990 through 2014. In cars of the 1960s and 70s, when few people buckled up, early studies based on unrestrained occupants found that the outboard rear seats were substantially (26%) safer than the front seats and the center rear seat even safer than the outboard rear seats (37% lower risk than in the front seat). However, during the past 30 years, a number of safety technologies – such as frontal air bags, belt pretensioners, and load limiters – have been introduced exclusively or primarily at the front seating positions.

Because most people buckle up nowadays, the reevaluation addresses the risk of belted occupants, not unrestrained occupants. Statistical analyses of the FARS 1990-to-2014 database estimate "adjusted fatality risk ratios" that measure the relative risk, in all crash modes combined, for belted occupants of the same age and gender at two different seating positions. All drivers and right front passengers in this analysis had frontal air bags available to them. Thus, the comparisons being made here are a 3-point manual belted driver with a frontal air bag and all other safety equipment available to them, compared to a 3-point manual belted right front passenger with a frontal air bag and all other safety equipment available to them, compared to a 3-point manual belted rear seat passenger at the left, right, or center rear seating positions with all other safety equipment available to them. The risk for a belted driver is indexed to 1.000; the adjusted risk ratios for belted passengers at the various seating positions are computed relative to the driver. The lower the risk ratio, the safer that passenger seating position relative to the driver. The adjusted risk ratios for the various seating positions in a passenger car are:

PASSENGER CARS Seating Position	Adjusted Fatality Risk Ratio	95% Confidence Bounds
Driver	indexed to 1.000	
Right front	.998	.971 to 1.080
Outboard rear	1.017	.957 to 1.080
Left rear	1.016	.945 to 1.094
Right rear	1.014	.949 to 1.084
Center rear (3-point belted)	.838	.628 to 1.119

The differences between seating positions have substantially diminished for belted occupants of passenger cars. The adjusted risk index does not differ significantly from 1.000 at any of the various seating positions, as evidenced by the lower 95-percent confidence bound being smaller than 1.000 and the upper bound being larger than 1.000. In fact, the estimated risk ratios are very close to 1.000 at the right front and outboard rear seats. At the center rear seat, the point estimate is somewhat lower (.838), but due to the limited data at that seating position, it is not significantly lower than 1.000.

FIGURE 1: VEHICULAR FATALITY-RISK INDEX BY CALENDAR YEAR (1955 = 100)
BASED ON PERCENT OF POTENTIAL FATALITIES SAVED BY VEHICLE SAFETY TECHNOLOGIES



Of course, it is important to note that in **absolute** terms, passenger cars and LTVs have both become much safer at all seating positions. Figure 1, based on a 2015 NHTSA report, shows that the overall, absolute decrease in the occupant fatality risk from CY 1955-1960 to CY 2012, due to increased belt use, air bags, ESC, and the other FMVSS, was 56 percent.[4] This rising tide of safety benefited everyone: absolute risk decreased substantially at all seating positions, but not necessarily by exactly equal amounts. If safety improvements help front seat occupants even more than they help rear seat passengers, the **relative** gap between the rear and front seats can diminish even while absolute safety improves for both.

Corresponding analyses for belted occupants of LTVs show significantly lower fatality risk ratios, relative to the driver, for the right front seat (.936), the outboard rear seats (.886) and, especially, the right rear seat (.813) – in contrast to passenger cars, where these positions all have indices close to 1.000.

[4] Kahane, C. J. (2015, January). *Lives saved by vehicle safety technologies and associated Federal Motor Vehicle Safety Standards, 1960 to 2012 – passenger cars and LTVs – with reviews of 26 FMVSS and the effectiveness of their associated safety technologies in reducing fatalities, injuries, and crashes* (Report No. DOT HS 812 069, p. xxvii). Washington, DC: National Highway Traffic Safety Administration. Available at crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812069.

LTVs Seating Position	Adjusted Fatality Risk Ratio	95% Confidence Bounds
Driver	indexed to 1.000	
Right front	.936	.905 to .968
Outboard rear	.886	.834 to .943
Left rear	.980	.906 to 1.060
Right rear	.813	.746 to .887
Center rear (3-point belted)	.918	.585 to 1.440

The detailed analyses of this report show that the distribution of crash types in LTVs is different from cars, in a manner that could favor both the right-side and the rear-seat occupants (and, thus, doubly favor the right rear seat passenger). Side impacts – where right-side occupants may be at higher risk because of the exceptional severity of left-turn-across-traffic collisions – account for a lower proportion of fatalities in LTVs than in cars, because LTVs often have higher and stronger side structures than cars. Frontal impacts and, especially, rollovers are relatively more prevalent in LTVs. Front-seat occupants are at higher risk in frontal impacts because they sit closer to the impact point and their section of the occupant compartment can be compromised due to intrusion; left-side occupants may also be at higher risk because of the severity of head-on, offset collisions of two vehicles approaching one another, where the damage tends to be concentrated towards the left front. Rear-seat occupants of passenger cars are at relatively high risk in rear impacts, but rear-seat occupants of many LTVs are protected, to some extent, by structure behind them (e.g., the bed of a pickup truck). The risk ratios tabulated above are averages for occupants of all ages; however, a detailed analysis of belted passengers 50 and older does show significantly higher risk in the outboard rear seats than in the right front seats of cars and LTVs.

This report is not a study of child passenger safety. The findings on belt effectiveness and the relative risk of the various seating positions pertain almost exclusively to adult and adolescent occupants. NHTSA continues to recommend that child passengers 12 years old and younger ride in the rear seats, protected by an age-appropriate restraint system.

1. Fatality reduction by seat belts in the center and outboard rear seats

1.1 Anton's Law and the transition to 3-point belts in center rear seats

Before 2005, the 3-point belts were only required at all outboard seats of passenger cars and LTVs in the United States, while lap belts, an ostensibly less effective device, were allowed for center rear seats. Anton's Law, Public Law 107-318 (December 4, 2002) directed NHTSA to require 3-point belts for each rear seating position – i.e., including center rear seats – in passenger motor vehicles with a GVWR of 10,000 pounds or less. NHTSA amended FMVSS No. 208, "Occupant crash protection," to require the phase-in of 3-point belts in center rear seats in all new passenger vehicles to start on September 1, 2005, and to be completed by September 1, 2007.[5] In practice, manufacturers had already begun installing 3-point belts at center rear seats of many vehicles well in advance of the new requirement.

Let us step back a few decades and review the transition from lap belts to 3-point belts at the various seating positions. During the 1960s, researchers observed that the lap belts in cars at that time could not, by themselves, prevent an outboard front seat occupant from contacting potential injury sources such as the steering assembly, the instrument panel, or the windshield header. FMVSS No. 208, "Occupant crash protection," originally required, effective January 1, 1968, lap belts at each designated seating position in passenger cars only, plus shoulder belts at the outboard front seats if lap belts alone could not prevent dummies from contacting the windshield header in static tests.[6] Since it was uncertain that a lap belt could always keep the dummy from contacting the windshield header in the static test, the rule, in effect, required the front outboard seat of new passenger cars to be equipped with lap and shoulder belts by January 1, 1968. The implicit requirement of lap and shoulder belts became explicit effective January 1, 1972, at which time FMVSS No. 208 also required locking retractors and a 30 mph crash test with dummies at the outboard front seats.[7] NHTSA required integral 3-point belts and disallowed separate lap belts and shoulder harnesses at the outboard front seats effective September 1, 1973[8] and had completed extending all of these requirements to LTVs with a GVWR up to 10,000 pounds effective September 1, 1981.[9]

The rear seating positions were presumably exempted from 3-point belts because a lap-belted rear seat passenger, unlike a front seat occupant, would not be exposed to contact with the steering assembly, instrument panel, or windshield header; instead, the passenger might contact relatively benign surfaces such as the padded back of the front seat. However, an influential 1986 report by the National Transportation Safety Board identified a different shortcoming of the lap belt alone, if it is not supplemented with a shoulder belt. Lap-belted rear seat passengers had a high risk of abdominal injuries and head injuries in frontal crashes. They experienced a

[5] 69 Fed. Reg. 70904 (December 8, 2004); some types of seats are exempt (side-facing seats) or may have a detachable shoulder harness rather than a 3-point belt (some types of folding or removable seats).
[6] 31 Fed. Reg. 15212 (December 3, 1966); 32 Fed. Reg. 2414 (February 3, 1967).
[7] 36 Fed. Reg. 4600 (March 10, 1971); 49 CFR, Part 571.208 S4.1.1.
[8] 38 Fed. Reg. 38 (June 20, 1973): 16072 (June 20, 1973); 49 CFR, Part 571.208 S4.1.2.
[9] 40 Fed. Reg. 28805 (July 9, 1975); 49 CFR, Part 571.208 S4.2.1.

concentrated force of the lap belt on their abdomens; their upper bodies rotated over the lap belt at a high velocity.[10]

Soon after that report, NHTSA initiated rulemaking to amend FMVSS No. 208, extending the superior protection of 3-point belts, as compared to lap belts alone, to the outboard rear seats. Cars had to have 3-point belts at the outboard rear seating positions, effective December 11, 1989, and LTVs, starting September 1, 1991.[11] In NHTSA's statistical evaluation, published in 1999, Morgan confirmed that 3-point belts were more effective than lap belts for rear seat occupants, reducing overall fatality risk by an estimated 44 percent in passenger cars and by 73 percent in LTVs, and largely eliminating the high risk of abdominal injury seen with lap belts.[12] Belts are much more effective in LTVs than passenger cars because seat belts are highly effective in preventing occupant ejection in rollover crashes: a much higher proportion of LTV fatalities than passenger car fatalities were the result of rollover crashes (in this database, where most of the vehicles were not yet equipped with electronic stability control, curtain bags that deploy in rollovers, or upgraded roof strength).[13]

The 1980s rulemaking, however, did not yet require 3-point belts for center rear seats – even though the risk of abdominal injury with a lap belt alone as well as other shortcomings of lap belts would appear to be similar in the outboard and center seats. "Given the relatively small projected benefits related to center seating positions and the potential costs and technical difficulties associated with anchoring the shoulder portion of the belt at the center seating position, NHTSA decided [at that time] against mandating lap/shoulder belts for any rear seat other than forward-facing outboard seats."[14] Specifically, nobody had yet designed a 3-point belt for a center occupant, at least not in the United States. By contrast, 3-point belts at the outboard rear seats had already been standard equipment on makes and models such as Volvo (since 1971), Mercedes (since 1974) and Honda Accord (since 1982). The upper anchor of the shoulder belt for an outboard rear seat can be located on one of the pillars in the side structure of the vehicle, similar to the outboard front seats. But for the center rear seat, the upper anchor would have to be somewhere in the middle of the vehicle, behind the center seat or built into the seat itself. Also, the center rear seat had low occupancy. FARS data for 1991, for example, show 43 right front seat passengers and 22 outboard rear seat passengers per 100 cars, but only 4 center rear seat passengers – and ¼ of them are small children, less than 5 years old, who would ride in a child restraint held in place by a lap belt and would not need the shoulder belt (and some child

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[10] National Transportation Safety Board. (1986). *Performance of lap belts in 26 frontal crashes*. (Report No. NTSB/SS-86/03). Washington, DC: Author. Available at http://mvhap.org/mvhappdfs/laprestraint.ntsb.study.26crashes.7.28.86.pdf

[11] From December 11, 1989 to August 31, 1990, cars were allowed separate lap and shoulder belts as an alternative to 3-point belts, but nobody exercised that option; 54 Fed. Reg. 25275 (June 14, 1989), 54 Fed. Reg. 46257 (November 2, 1989); 49 CFR, Parts 571.208 S4.1.4.2 and S4.2.4. The requirement does not apply to some types of seats/vehicles.

[12] Morgan, C. (1999, June). *Effectiveness of lap/shoulder belts in the back outboard seating positions*. (Report No. DOT HS 808 945). Washington, DC: National Highway Traffic Safety Administration. Available at crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/808945.

[13] Kahane, C. J. (2000, December). *Fatality reduction by safety belts for front-seat occupants of cars and light trucks: Updated and expanded estimates based on 1986-99 FARS data*. (Report No. DOT HS 809 199). Washington, DC: National Highway Traffic Safety Administration. Pp. 26-33. Available at crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/809199

[14] 68 Fed. Reg. 46546 (August 6, 2003).

restraints of that era might not even have been as well secured with a 3-point belt as with a lap belt alone). Thus, action on the outboard rear seats involved substantially less lead time and affected a much larger population.

At about the same time as NHTSA's rulemaking on outboard rear seats, engineers at Volvo developed the first practicable 3-point belt for the center rear seat. It involved placing the upper anchorage for the shoulder belt on the back package shelf (which extends from near the top of the rear seat back to the structure beneath rear window) – and assuring that this shelf was strong enough to withstand the forces that an occupant might exert on the shoulder belt during a crash.

In MY 1994, 3-point belts for the center rear seat became standard equipment on all passenger cars Volvo sold in the United States; also on the Saab 900. In 1996: Lincoln Continental and Toyota Avalon. In 1997: several additional makes and models, including the high-sales Ford Taurus and Toyota Camry sedans.

Four alternative designs have been used for 3-point belts in the center rear seat:

- The upper anchorage may be located on the back package shelf (as in the Volvo design), provided that the shelf is made strong enough to withstand forces exerted by the occupant through the belt (see Figure 2);
- If there is no back package shelf, but the area immediately behind the seat is not needed for other passengers or cargo, the anchor can be attached to the floor frame, with the shoulder belt extending from the floor over the top of the seat back;
- The anchor can be attached to the roof of the vehicle, with the shoulder belt extending down from the roof; or
- The belt system, including the upper anchorage may be integrated into the seat structure. This would require some redesign and reinforcement of the seat structure and, possibly, stiffening the floor structure under the center seat. Either of these last two alternatives are practicable if the area behind the seat is needed for other passengers or cargo – e.g., in the second row of an SUV or van that has three rows of seats.[15]

[15] NHTSA. (2003, July). *Preliminary economic assessment: costs and benefits of putting a shoulder belt in the center seats of passenger cars and light trucks* (Docket No. NHTSA-2003-15817-0002, p. 30). Washington, DC: Author. Available at www.regulations.gov/contentStreamer?documentId=NHTSA-2003-15817-0002&attachmentNumber=1&disposition=attachment&contentType=pdf; NHTSA. (2004, June). *Final economic assessment and regulatory flexibility analysis: Cost and benefits of putting a shoulder belt in the center seats of passenger cars and light trucks* (Docket No. NHTSA-2004-18726-0002, pp. 31-32). Washington, DC: Author. Available at www.regulations.gov/contentStreamer?documentId=NHTSA-2004-18726-0002&attachmentNumber=1&disposition=attachment&contentType=pdf

Figure 2: Center Rear 3-Point Belt With Upper Anchorage on the Back Package Shelf[16]

Anton's Law, which was signed on December 4, 2002, addressed several issues in occupant protection.[17] The mandate for 3-point belts at each rear seating position is just one of the law's eight sections. In fact, "Anton," in whose memory the law is dedicated, was not a passenger in a center rear seat.[18] NHTSA issued its NPRM for 3-point belts in center rear seats on August 6, 2003 and a final rule on December 8, 2004, amending FMVSS No. 208 to require the 3-point belts, with a phase-in schedule starting on September 1, 2005, and ending by September 1, 2007.[19] Even before the rulemaking process, manufacturers had already installed 3-point belts at center rear seats on the majority of new passenger cars by MY 2001 and LTVs by MY 2003. During the phase-in period and for some years before it, NHTSA encouraged the voluntary installation of 3-point belts by advising the public, via the agency's *Buying a Safer Car* and *Buying a Safer Car for Child Passengers* brochures, which make-models were already equipped with 3-point belts at center rear seats and explaining that this was a desirable safety feature.

The appendix of this report lists all makes and models of passenger cars and LTVs with a GVWR < 10,000 pounds that were equipped with 3-point belts at center rear seats before MY 2008, indicating the first model year when the belts were standard equipment. LTVs include pickup trucks, SUVs, and vans. SUVs include crossover utility vehicles as well as the truck-based type. SUVs and vans may have more than one center rear seat – e.g., in the second, third, or additional rows. However, if a row (e.g., the second row in some minivans) has only two seats, neither of them is a "center" seat even if one of them is separated by an aisle from the right side of the vehicle. They are both "outboard" seats and would have already been equipped with 3-point belts by MY 1992. From MY 2008 onwards, any new car or LTV that has a center rear

[16] Photograph by NHTSA.
[17] Text available at www.congress.gov/107/plaws/publ318/PLAW-107publ318.pdf
[18] Charles, N. (2001, August 20). Anton's law. *People, 56*.
[19] *68* Fed. Reg. 46546 (August 6, 2003); 69 Fed. Reg. 70904 (December 8, 2004).

seats is equipped with 3-point belts at those seats. The information in the appendix derives primarily from www.safercar.gov and www.cars.com.

In 2004 Arbogast, Durbin, Kallan, and Winston of Children's Hospital of Philadelphia presented an early statistical analysis with promising results, based on data collected from 1998 through 2002 by their Partners for Child Passenger Safety program. When crashes involving child passengers are reported to insurance companies, investigators telephone the driver or parent to find out about the child's restraint use and injuries, with follow-ups to hospitals for more details on serious injuries. The risk of serious injury to belted children in the center rear seat was a statistically significant 81 percent lower if that seat was equipped with a lap shoulder belt than if it was equipped with a lap belt alone.[20]

NHTSA's evaluation plans of 2004 and 2008 stated that the agency would consider statistical analyses of FARS data to estimate the fatality-reducing effectiveness of 3-point belts in the center rear seat.[21] This evaluation has been a long time coming because, until now, there was not enough FARS data for statistically meaningful results.

In addition to analyzing 3-point belts in the center rear seat, the evaluation will also estimate the effect of the lap belt alone in earlier vehicles not yet equipped with 3-point belts. It will statistically compare the effectiveness of 3-point belts and lap belts. It will also update estimates of 3-point belt effectiveness in the outboard rear seats, based on the latest FARS data.

1.2 Analysis method and database

Since the mid-1980s, fatality-reducing effectiveness estimates for occupant protection requiring activation (namely, buckling up), such as seat belts or child safety seats, have usually been based on **double-pair comparison** analyses of FARS data. NHTSA started FARS, a census of the fatal traffic crashes in the United States, in 1975. Double-pair comparison is valuable because it allows the direct use of FARS data, which has a much higher number of fatalities than any other crash files. A second major advantage is that double-pair comparison implicitly "adjusts" or "controls" for the differences in the severity of crashes involving belted and unrestrained occupants. Under the right circumstances, it can separate belt effectiveness from other factors

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[20] Arbogast, K. B., Durbin, D. R., Kallan, M. J., & Winston, F. K. (2004, September). Evaluation of pediatric use patterns and performance of lap shoulder belt systems in the center rear. *Forty-Eighth Annual Proceedings of American Association for Automotive Medicine*. Morton Grove, IL: American Association for Automotive Medicine.

[21] NHTSA. (2004, January). *National Highway Traffic Safety Administration evaluation program plan, calendar years 2004-2007* (Report No. DOT HS 809 699). Washington, DC: Author. Available at crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/809699; Allen, K., Dang, J. N., Doyle, C. T., Kahane, C. J., Roth, J. R., & Walz, M. C. (2008, August). *Evaluation program plan, 2008-2012* (Report No. DOT HS 810 983). Washington, DC: National Highway Traffic Safety Administration. Available at crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/810983.

that influence fatality risk, such as an occupant's age, the type and severity of the crash, or the overall crashworthiness of the vehicle.[22]

This analysis will estimate the fatality-reducing effectiveness of 3-point belts and also of lap belts for center rear (CR) seat passengers of cars and LTVs. The analyses are limited to passengers 5 years or older, because small children under 5 should not be riding restrained only by belts, and if they are, the shoulder belt is unlikely to be of much value to them. In fact, even 5-year-olds and many children for some years beyond that should not buckle up with belts alone. NHTSA strongly urges that child passengers sit in child safety seats or booster seats appropriate for their weight, size, and age until they are ready to "graduate" to 3-point belts. The only reason that the analysis includes children as young as 5 is for consistency and comparability with past NHTSA evaluations of belt effectiveness (which were conducted before booster seats were widely used and most 5-year-olds were buckled with belts alone, if they were restrained at all).

The database needed for the analysis comprises FARS cases of vehicles occupied by a driver and a CR passenger (and perhaps other occupants), where at least one and possibly both the driver and the CR passenger were fatalities. Because almost all vehicles with 3-point belts at the CR seats are also equipped with a frontal air bag for a driver, all analyses will be limited to vehicles with driver air bags (even the analyses of CR lap belt effectiveness). Because driver air bags did not appear in large numbers until MY 1990, the analyses are limited to MY 1990 through 2015 vehicles in CY 1990 through 2014 FARS data.

FARS data for CY 1990 to 2014 and MY 1990 to 2015 includes 874 cases of cars and 638 LTVs equipped with 3-point belts at the CR seat and with a frontal air bag for the driver, occupied by a driver and a CR passenger, at least one or possibly both fatalities, also meeting the following conditions:

- The make, model, and MY must be decodable from the first 12 characters of the VIN, using the VIN-decode programs which have been developed by NHTSA's Evaluation Division through MY 2013 (exception: all MY 2014 and 2015 vehicles will be included if BODY_TYP indicates they are cars or LTVs, because we know these vehicles have 3-point belts at the CR seats; BODY_TYP will also be the basis for classifying them as cars or LTVs);
    - LTVs with a GVWR > 10,000 pounds are excluded from the analysis, because they are not subject to the Anton's law requirements;
- The availability of a frontal air bag for the driver and a 3-point belt at the CR seat is likewise derived from the VIN (or from the VIN-decoded make-model, or from the model year);

[22] Partyka, S. C. (1984). *Restraint use and fatality risk for infants and toddlers*. Washington, DC: National Highway Traffic Safety Administration; Evans, L. (1986a). Double pair comparison – a new method to determine how occupant characteristics affect fatality risk in traffic crashes. *Accident Analysis and Prevention*, *18*, pp. 217-227; Evans, L. (1986b). The effectiveness of safety belts in preventing fatalities. *Accident Analysis and Prevention*, *18*, pp. 229-241; Kahane, C. J. (1986, February). *An evaluation of child passenger safety: The effectiveness and benefits of safety seats*. (Report No. DOT HS 806 890). Washington, DC: National Highway Traffic Safety Administration. Available at crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/806890; Partyka, S. C. (1988, May). Belt effectiveness in pickup trucks and passenger cars by crash direction and accident year. In *Papers on Adult Seat Belts – Effectiveness and Use* (Report No. DOT HS 807 285). Washington, DC: National Highway Traffic Safety Administration; Kahane, 2000.

- The driver's and CR passenger's age and gender are known in FARS; the CR passenger must be at least 5 years old;
- Restraint use must be known for the driver and the CR passenger. Child passengers riding in child safety seats or booster seats are excluded (because this is an effectiveness evaluation of the belt without additional safety equipment). Cases with unknown belt use for the driver, CR passenger, or both are excluded. The driver's and CR passenger's restraint-use code, REST_USE has to be 0 (in CY 1986 to 2009 only), 1, 2, 3, 7 (in CY 2010 to 2014 only), 8 (restraint used type not specified – but only for occupants 10 or older, so as to exclude any younger occupant who might have been in a safety seat or booster seat) or 13; 0 or 7 mean unbelted, the other codes mean belted;
    - Having established that the vehicle is equipped with 3-point belts at the CR seat, we will count passengers with REST_USE = 1, 2, 3, 8, or 13 as having used 3-point belts, even if the REST_USE value says "lap belt only."
- The driver's belt must be the 3-point type; vehicles with automatic 2-point belts for the driver are excluded;
- If FARS says 2 or more people occupied the same seating position, the case is not included in the analysis; and
- LTVs may have a center seating position in the second and the third row of seats; if so, they may contribute up to 2 records to the analysis – one consisting of the driver and the center seat passenger of the second row (SEAT_POS = 22), one consisting of the driver and the center seat passenger of the third row (SEAT_POS = 32).[23]

Likewise, FARS data for CY 1990 to 2014 and MY 1990 to 2007 includes 1,805 cases of cars and 2,280 LTVs equipped with lap belts only at the CR seat and with a frontal air bag for the driver, occupied by a driver and a CR passenger, at least one or possibly both fatalities, also meeting the previous conditions. Here, too, having established the type of CR belt based on the VIN-decoded make-model and model year, we will count all belted passengers as lap-belted only, even if the REST_USE value says "lap and shoulder belt." Thus the number of cases with lap belt only is about twice as large as the number with 3-point belts for cars (1,805 versus 874), but four times as large for LTVs (2,280 versus 638), because cars transitioned to 3-point belts a few years earlier, on the average, than LTVs.

1.3 Basic double-pair comparison for center rear seats

Here is an example of a basic double-pair comparison analysis to estimate fatality reduction by seat belts, specifically by 3-point belts in the center rear seats of passenger cars. It is based on the 874 vehicle cases where a car was equipped with 3-point belts at the CR seat; the car had a driver and a CR passenger 5 or older (and perhaps other occupants), neither with unknown belt use, the CR passenger not in a booster or child safety seat, and at least one or possibly both occupants a fatality. (There will be corresponding analyses for lap belts in cars, 3-point belts in LTVs, and lap belts in LTVs.) Table 1 counts the 874 vehicle cases, based on each occupant's belt use (as reported in FARS) and survival:

[23] Passengers in the fourth or higher rows of seats of full-size vans are not included in the analyses. As stated above, when the second or third row have only two seats, they are outboard seats and would not be coded 22 or 32 in FARS.

Table 1: Vehicles by CR and Driver Belt Use and Survival Status, Cars With 3-Point CR Belts
(Cars with a driver and a CR passenger, at least one a fatality, FARS 1990 to 2014)

Vehicles	CR Died Driver Survived	CR Survived Driver Died	Both Died
Both unrestrained	84	122	49
CR belted, driver unrestrained	6	30	3
CR unrestrained, driver belted	229	78	55
Both belted	73	111	34

Table 2 tallies fatality counts rather than vehicle cases by adding the "both died" column to each of the preceding columns. There are 1,015 fatalities (533 CR passengers and 482 drivers) in the 874 cars, classified as follows:

Table 2: Fatalities by Belt Use and Seating Position
(Cars with 3-point CR belts, with a driver and CR passenger, FARS 1990 to 2014)

Fatalities	CR Fatalities	Driver Fatalities	CR/Driver Risk Ratio
Both unrestrained	133	171	0.778
CR belted, driver unrestrained	9	33	0.273
CR unrestrained, driver belted	284	133	2.135
Both belted	107	145	0.738

In these cars with 3-point CR belts: (1) unrestrained CR passengers have approximately ¾ the risk of unrestrained drivers in the same crash; (2) belted CR passengers likewise have approximately ¾ the risk of belted drivers in the same crash; and (3) if one occupant buckled up and the other did not, whoever buckled up has substantially lower risk than the one who did not.

The four rows of data in Table 2 allow two double-pair comparisons for computing the effectiveness of 3-point belts for CR passengers. The first double-pair comparison is obtained by using the first two rows of data in Table 2:

		CR Fatalities	Driver Fatalities	CR/Driver Risk Ratio
CR unrestrained	Driver unrestrained	133	171	0.778
CR belted	Driver unrestrained	9	33	0.273

The control group is the unrestrained driver. The estimated fatality reducing **effectiveness** for buckling up the CR passenger is:

$$\frac{\text{Risk ratio for unrestrained CR} - \text{Risk ratio for belted CR}}{\text{Risk ratio for unrestrained CR}}$$

= 1 - (0.273/0.778) = 64.9 percent.[24]

The second estimate uses the last two rows of data in Table 2:

		CR Fatalities	Driver Fatalities	CR/Driver Risk Ratio
CR unrestrained	Driver belted	284	133	2.135
CR belted	Driver belted	107	145	0.738

The control group is the belted driver. The estimated fatality reducing effectiveness for the belted CR passenger is:

1 - (0.738/2.135) = 65.4 percent.

The two control groups produce quite similar estimates, as they ought to: effectiveness should be the same relative to any valid control group used for the comparisons – if it varies substantially, then at least one of those comparison groups is not a valid control group. The next task is to develop a weighting procedure that combines the two estimates into a single number. In Table 2, the actual number of CR passenger fatalities is:

Actual CR passenger fatalities = 133 + 9 + 284 + 107 = 533

The first and third numbers in that sum are unrestrained passengers, the second and fourth, belted. However, if every CR passenger had been unrestrained, that sum would have increased to:

All-unrestrained CR passenger fatalities = 133 + (0.778 x 33) + 284 + (2.135 x 145) = 752.25

(Here, 33 was the number of unrestrained driver fatalities that accompanied the 9 belted CR passengers and .778 is the risk ratio of unrestrained CR passenger to unrestrained driver fatalities; 145 is the number of belted driver fatalities that accompanied the 107 belted CR passengers and 2.135 is the risk ratio of unrestrained CR passenger to belted driver fatalities.) On the other hand, if every CR passenger had buckled up, the sum would have dropped to:

All-belted CR passenger fatalities = (0.273 x 171) + 9 + (0.738 x 133) + 107 = 260.84

[24] In a database that is a census or probability sample of crashes of all severities and outcomes, such as a State crash file, effectiveness is defined as the percent reduction in P(death): 1 – P(fatality | CR belted) / P(fatality | CR unbelted). Evans (1986a) demonstrated that double-pair comparison analysis of FARS generates an equivalent effectiveness estimate.

The overall effectiveness of 3-point belts for CR passengers is:

$$(752.25 - 260.84) / 752.25 = 65.3 \text{ percent},$$

which is a weighted average of the two separate double-pair comparisons (64.9% and 65.4%, the latter based on a much larger number of cases; the weighting factors are implicit in the preceding formulas to estimate "all-unrestrained CR passenger fatalities" and "all-belted CR passenger fatalities").

Similarly, the basic double-pair comparison analyses generated effectiveness estimates of 52.9 percent for the lap belt alone in the CR seat of passenger cars; 74.7 percent for 3-point belts in LTVs; and 72.4 percent for the lap belt alone in LTVs.

There is an additional complication for double-pair comparison analyses of belt effectiveness for **drivers and right front seat passengers**, when they are based on FARS data from CY 1986 and later. There is evidence that the reported belt use of crash survivors at those two seating positions should not be taken at face value in States with seat belt laws for those two seating positions:

> "Specifically, New York was the first [S]tate to enact a belt use law, effective December 1, 1984. After a brief 'wait and see,' 21 [S]tates, including 9 of the 10 most populous [S]tates had belt laws effective by August 1986 for front-seat occupants of passenger cars. For the first time, unbelted people had a tangible incentive – avoidance of a fine – to report that they were belted. NHTSA hypothesized that uninjured or slightly injured occupants are often up and about before police arrive at the crash scene. Since the investigating officer is not an eye-witness to their belt use, they have an opportunity – and now also a motive – to say they wore belts, even if they hadn't. Mortally injured occupants may be in their original post-crash location when police arrive, often allowing direct observation of belt use. Thus, NHTSA believes belt use of fatalities is reported without net biases on FARS before and after belt laws. However, after the laws, belt use of survivors is over-reported. A bias has apparently been introduced in the reporting of this one data element, for survivors, as a consequence of belt use laws."[25]

The observed effectiveness of belts in the front seats is higher than in analyses of earlier calendar years of FARS data, even for vehicles of the same model years. Specifically, NHTSA's 2000 evaluation of front seat belts found that 3-point belts reduced drivers' fatality risk in MY 1975-to-1985 passenger cars by 47.81 percent in CY 1977-to-1985 FARS data and were observed to "reduce" fatality risk by 61.89 percent in CY 1986-to-1999 FARS data. The hypothesis is that the first estimate is the actual fatality reduction for belts in MY 1975-to-1985 cars, whereas the second is biased upwards by inaccurate belt use reporting of survivors in FARS in response to belt use laws. The evaluation empirically defined the "Universal Exaggeration Factor" (UEF) to be the relative difference of the two estimates: UEF = (100 - 47.81) / (100 - 61.89) = 1.369. All estimates based on FARS data after CY 1985 are adjusted downwards by the UEF to make them comparable to estimates from earlier data.[26]

In her 1999 report, however, Morgan argued that the UEF was unnecessary and inappropriate for analyses of belt effectiveness for outboard **rear seat passengers**. Above all, there were no laws

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[25] Kahane, 2000, pp. 2-3.
[26] *Ibid.*, pp. 10-19.

requiring use of seat belts in the rear seat, except for pre-teens and teenagers up to 16 years or less in some States. There was little tangible incentive to report passengers as belted. Furthermore, the reported belt use of rear-seat crash survivors in the 1994 FARS was nearly the same as the actual, observed rear-seat belt use in the 1994 NOPUS survey (the most recent survey of rear-seat belt use on the road at the time of Morgan's analysis). In other words, crash survivors in FARS did not appear to be overreporting belt use.[27]

This situation may be changing. As of 2012, 27 States and the District of Columbia had laws requiring the use of seat belts by rear seat passengers of all ages – although in 10 of those States, they were "secondary" laws (where law enforcement officers may issue a ticket for not wearing a seat belt only when there is another citable traffic infraction). Nevertheless, the reported belt use of surviving rear-seat passengers in FARS has actually become substantially lower than the observed use on NOPUS: from 2007 through 2012, belt use ranged from only 46 to 52 percent for FARS rear-seat survivors, but from 70 to 76 percent in NOPUS. There is still little evidence that rear seat passengers have begun to overreport belt use.[28] This report, like Morgan's, will not apply the UEF to belt effectiveness estimates for rear seat passengers.

1.4 Significance testing and adjustment for age and gender with LOGISTIC

The SAS procedure LOGISTIC is useful for testing the statistical significance of the observed belt-effectiveness estimates and generating confidence bounds for them. For example, the basic double-pair comparison for 3-point belts in the CR seat, covered in the preceding section, can be refashioned as a logistic regression that performs exactly the same analysis. In the double-pair comparison, there were 874 vehicle cases, resulting in 1,015 fatalities, distributed as shown in Table 2 of the preceding section.

Each of those 1,015 fatality cases furnishes one data point to the logistic regression, which will have one dependent variable and two independent variables:

- CENREAR is the dependent variable (= 1 if this specific fatality case is a CR passenger, = 2 if it is a driver);
- The two independent variables are:
  - BELT2[29] (= 1 if the CR passenger of the vehicle in which this fatality occurred is belted, = 0 if unrestrained); and
  - BELT1 (= 1 if the driver of the vehicle in which the fatality occurred is belted, = 0 if unrestrained)

[27] Morgan, 1999, pp. 6-8 and 51-52.
[28] Pickrell, T. M. (2014, January). *Occupant restraint use in 2012: Results from the National Occupant Protection Use Survey Controlled Intersection Study.* (Report No. DOT HS 811 872, pp 6-7). Washington, DC: National Highway Traffic Safety Administration. Available at crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811872
[29] The FARS variable PER_TYP = 2 for passengers, = 1 for drivers: thus, BELT2 and BELT1, respectively.

The initial logistic regression model for the dependent variable CENREAR includes only the two independent variables BELT2 and BELT1, no interaction terms. The regression coefficients and their statistics are:

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-0.2502	0.1113	5.0549	0.0246
BELT2	**1**	**-1.0604**	**0.1523**	**48.4431**	**<.0001**
BELT1	1	1.0080	0.1454	48.0464	<.0001

As stated above, the dependent variable is CENREAR: given a fatally-injured occupant in these vehicles where CR passengers and drivers sit together, is this occupant a CR passenger or a driver? The negative intercept indicates that, all else being equal, fatality risk is somewhat lower for the CR passenger than for the driver. The key result is the statistically significant, strongly negative (-1.0604) coefficient for BELT2 ($\chi^2 = 48.44$; χ^2 needs to be 3.84 or larger for statistical significance at the two-sided .05 level). It says that use of the 3-point belt by the CR passenger reduces the odds that the fatality will be the CR passenger – i.e., 3-point belts significantly reduce CR passengers' fatality risk in cars. The significant positive (1.0080) coefficient for BELT1 ($\chi^2 = 48.05$) says that belt use by the driver increases the odds that, in this particular database, the fatality will be the CR passenger – i.e., belts save drivers' lives; in this database where either the CR passenger or the driver (but only occasionally both) is a fatality, the survival of the driver in this crash means that the CR passenger must have been a fatality (because the only vehicles included in the analysis are those where at least one of these two people died).

The coefficient for BELT2 is the key result, because it translates directly into a point estimate for the effectiveness of 3-point belts:

$$1 - \exp(-1.0604) = 65.4 \text{ percent}$$

which is almost identical to the estimate computed by the double-pair comparison analysis in the preceding section (65.3%).[30] Furthermore, the coefficient for BELT2 and its standard error (0.1523) can be used to obtain 95-percent confidence bounds for effectiveness:

$$1 - \exp(-1.0604 \pm 1.96 \text{x} 0.1523) = 53 \text{ to } 74 \text{ percent}^{31}$$

[30] The regression coefficient -1.0604 for BELT2 estimates that a belted CR passenger's log odds ratio of "failure" (the fatality being a CR passenger) to "success" (the fatality being a driver) is on the average -1.0604 lower than for an unrestrained CR passenger. In other words, exp(-1.0604) is the average value of: the risk ratio for belted CR passengers relative to the driver control group divided by the risk ratio for unrestrained CR passengers relative to the driver control group. 1 - exp(-1.0604) is belt effectiveness, defined the same way as in the double-pair comparison analysis. The slight difference in the overall estimate (65.4% for logistic regression versus 65.3% for double-pair comparison) is because the two methods weight the cases in a slightly different way.

The point estimate and 95-percent confidence bounds may also be obtained directly from the "Odds Ratio Estimates" section of the PROC LOGISTIC printout by subtracting the statistics for BELT2 from 1 (e.g., 1 – 0.346 = 65.4 percent):

```
                  Odds Ratio Estimates

                   Point          95% Wald
     Effect      Estimate      Confidence Limits

     BELT2         0.346        0.257       0.467
     BELT1         2.740        2.061       3.644
```

The initial regression model, however, can be improved by adding independent variables to control for demographic differences in the belted and unrestrained populations. Driver age and gender are the two demographic variables reported for virtually all person-level records on FARS and known to have significant association with vulnerability to fatal injury. (Height and weight are only reported for drivers on FARS, not passengers.) Among the 874 CR passenger cases in the analysis, the average age of the 257 belted passengers was 21 years, whereas the 617 unbelted passengers averaged 24 years. The lower age of the belted passengers may reflect pre-teen and young teenage children riding with their parents or other adults, who make sure the children buckle up. The relationship of age and fatality risk is not uniform: the data suggest a steady increase in risk, given the same physical insult, for each year that an occupant is over 21, but also an increase for each year that a young occupant is under 18, with peak survivability for the 18-to-21 year old group.[32] The regression can control for the passenger's age by adding two independent variables:

- AGING2 = age – 21 if the passenger is older than 21, = 0 otherwise
- YOUTHFUL2 = 18 – age if the passenger is younger than 18, = 0 otherwise

Among the 874 cases, 58 percent of the belted passengers were females, but only 51 percent of the unrestrained – consistent with the historical pattern of higher belt use by females at all seating positions.[33] The data show higher risk for females than males of the same age, given the same physical insult, at most ages. The effect varies somewhat with age, with females' risk increment peaking for people 18 to 35 years old.[34] The effect of gender, however, is generally

[31] FARS is a census of fatalities, not a simple random sample. Nevertheless, in NHTSA evaluations and analyses, standard statistical tests are often applied to FARS data with the implicit rationale that the United States is a "sample" of a hypothetical population of thousands of countries, each essentially similar to the United States, with the same types of vehicles and drivers, and each with its own fatal crash experience. If effectiveness were to be computed by the same method in each of those countries, using each country's FARS-like database, we would expect the effectiveness estimates to range between 53 and 74 percent in 95 percent of those countries.

[32] Evans, L. (1991). *Traffic safety and the driver.* New York: Van Nostrand Reinhold, pp. 25-28; Kahane, C. J. (2013, May). *Injury vulnerability and effectiveness of occupant protection technologies for older occupants and women* (Report No. DOT HS 811 766). Washington, DC: National Highway Traffic Safety Administration. Available at crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811766

[33] Pickrell, 2014, p. 3.

[34] Evans, 1991, pp. 20-25; Kahane, 2013.

small relative to the effect of age; in the interest of not overfitting the data, only a simple, uniform gender effect will be modeled by adding one more independent variable:

- FEMALE2 = 1 if the passenger is female, = 0 if male

The drivers of these 874 vehicles have been the explicit or implicit control group in all the analyses. Ideally, the control group should look the same for the two groups of interest we are comparing, namely, belted passengers and unrestrained passengers. But for the 257 belted **passengers**, the average age of their **driver** was 35 and 49 percent of the drivers were females whereas for the 617 unrestrained passengers, the average age of their driver was only 28 and only 31 percent of these drivers were female. Again, this may reflect that the youngest passengers (most often belted) frequently ride in a vehicle driven by their mothers, who are a generation older, whereas late-teen and young-adult passengers (less often belted) frequently ride with their age peers, with one of the young men driving. Although, of course, the age and gender of the driver has little or no direct effect on the injury vulnerability of a passenger, it very much has a **statistical** effect in these FARS analyses. As stated above, either the CR passenger or the driver (but only occasionally both) is a fatality; therefore, any factor that reduces the fatality risk of the driver, such as being a young adult male, must increase the likelihood that the CR passenger was a fatality in this crash (because the only vehicles included in the analysis are those where at least one of these two people died). The regression should have three additional "mirror" variables pertaining to the driver's age and gender:

- AGING1 = age – 21 if the driver is older than 21, = 0 otherwise
- YOUTHFUL1 = 18 – age if the driver is younger than 18, = 0 otherwise
- FEMALE1 = 1 if the driver is female, = 0 if male

The YOUTHFUL1 variable might not add much to the analysis, because drivers can, at most, only be a few years younger than 18 (whereas passengers may be as young as 5 in this database). Nevertheless, it is included because it "mirrors" the potentially important YOUTHFUL2 variable.

No interaction terms (such as BELT2*AGING2) are included. Such a term would estimate a different belt effectiveness depending on the age of the passenger – estimates that would likely not be statistically meaningful, given the limited data. Instead, the only purpose of the model is first-order, linear corrections of the demographic biases in the data. Here are the regression coefficients when the six new variables are added to the preceding logistic regression model:

Cars, CR Passengers, 3-Point Belts

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-0.2562	0.1389	3.4028	0.0651
BELT2	**1**	**-0.8562**	**0.1659**	**26.6355**	**<.0001**
BELT1	1	1.0045	0.1485	45.7297	<.0001
AGING2	1	0.0355	0.00769	21.3058	<.0001
YOUTHFUL2	1	-0.00951	0.0208	0.2093	0.6473
FEMALE2	1	0.0663	0.1360	0.2379	0.6257
AGING1	1	-0.0292	0.00712	16.8184	<.0001
YOUTHFUL1	1	0.00263	0.1202	0.0005	0.9825
FEMALE1	1	0.0380	0.1495	0.0646	0.7994

The coefficient for BELT2 has diminished from -1.0604 in the initial regression to -0.8562, although it is still statistically significant ($\chi^2 = 26.64$). Essentially, the new regression has corrected for a double bias in favor of belts, namely, the belted passengers being **younger** than the unrestrained passengers, and yet their drivers being **older** than the people who drove the unrestrained passengers. The corrections are reflected by the strong ($\chi^2 = 21.31$) positive coefficient for AGING2 and the strong ($\chi^2 = 16.82$) negative coefficient for AGING1. In this regression, the other four new independent variables YOUTHFUL2, FEMALE2, YOUTHFUL1, and FEMALE1 do not have significant effects ($\chi^2 < 3.84$); they could have been omitted with little change in the BELT2 coefficient. However, in subsequent, parallel regressions (car/lap belt, LTV/3-point belt, and LTV/lap belt, plus analyses of 3-point belts for outboard rear occupants) these variables often have significant effects, so they are also retained here for methodological consistency.[35]

After controlling for age and gender, the best estimate of fatality reduction by **3-point belts** for CR passengers of **cars** (a single estimate representing the average effectiveness across all age groups and both genders), obtained from the coefficient for BELT2, is:

$$1 - \exp(-0.8562) = 58 \text{ percent}$$

The standard error of the BELT2 coefficient is 0.1659, which is a modest increase from the 0.1523 in the preceding regression without control variables. The absence of a large increase in the standard error is a reassuring indication that BELT2 is not particularly collinear with the control variables. The 95-percent confidence bounds are obtained from the coefficient for BELT2 (-.8562) and its standard error (0.1659):

$$1 - \exp(-0.8562 \pm 1.96 \text{x} 0.1659) = 41 \text{ to } 69 \text{ percent}$$ [36]

[35] Max-rescaled R-square for the model as a whole improves from .099 with no control variables to .142 with the AGING variables, with little further gain for YOUTHFUL and FEMALE. Other model diagnostics such as the AIC, the Wald test of the global null hypothesis, and % concordant pairs show a similar pattern.

[36] When YOUTHFUL2, FEMALE2, YOUTHFUL1, and FEMALE1 are omitted from the regression model, the point estimate is likewise 58% and its confidence bounds are 43% to 69%.

The parallel analysis of the **lap belt only** for CR passengers of **cars** is based on approximately double the data: 2,063 fatality cases in 1,805 vehicles. Here are the regression coefficients:

Cars, CR Passengers, Lap Belt Only
Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-0.2977	0.0904	10.8582	0.0010
BELT2	**1**	**-0.6504**	**0.1242**	**27.4378**	**<.0001**
BELT1	1	0.7923	0.0985	64.6962	<.0001
AGING2	1	0.0306	0.00481	40.5142	<.0001
YOUTHFUL2	1	0.0233	0.0136	2.9144	0.0878
FEMALE2	1	0.0644	0.0927	0.4825	0.4873
AGING1	1	-0.0262	0.00425	38.0108	<.0001
YOUTHFUL1	1	0.00761	0.0641	0.0141	0.9054
FEMALE1	1	-0.1051	0.0976	1.1585	0.2818

The -0.6504 coefficient for BELT2 is statistically significant (χ^2 = 27.44). The best estimate of fatality reduction by **lap belts** for CR passengers of **cars** is 1 – exp(-0.6504) = 48 percent. Its confidence bounds are 1 – exp(-0.6504 ± 1.96x0.1242) = 33 to 59 percent.

The analysis of **3-point belts** for **LTVs** is based on the smallest sample among the analyses, because the transition to 3-point belts took place somewhat later than in cars: 708 fatality cases in 638 vehicles. As stated above, with LTVs a single vehicle might generate two passenger-driver pairs if it had second-row-center and third-row-center seats and both were occupied (but this happens infrequently) and each of those pairs would contribute two fatality cases if the driver and passenger were both fatalities (rare). The regression coefficients are:

LTVs, CR Passengers, 3-Point Belts
Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-0.6946	0.1998	12.0870	0.0005
BELT2	**1**	**-1.4023**	**0.2121**	**43.7053**	**<.0001**
BELT1	1	1.6022	0.1943	67.9801	<.0001
AGING2	1	0.0570	0.00844	45.5459	<.0001
YOUTHFUL2	1	0.0595	0.0254	5.4954	0.0191
FEMALE2	1	0.2289	0.1737	1.7363	0.1876
AGING1	1	-0.0395	0.00766	26.6168	<.0001
YOUTHFUL1	1	0.0462	0.1739	0.0705	0.7905
FEMALE1	1	-0.1468	0.1847	0.6315	0.4268

In this regression, the YOUTHFUL2 effect is statistically significant. The -1.4023 coefficient for BELT2 is of even greater magnitude than the corresponding effect in passenger cars (-0.8562); it is statistically significant (χ^2 = 43.71). The best estimate of fatality reduction by **3-point belts** for

CR passengers of **LTVs** is 1 - exp(-1.4023) = 75 percent. Its confidence bounds are 1 - exp(-1.4023 ± 1.96x0.2121) = 63 to 84 percent.

There are 2,574 fatality cases in 2,280 vehicles available for the analysis of **lap belts** in **LTVs**. Here are the regression coefficients:

LTVs, CR Passengers, Lap Belt Only
Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-0.6370	0.0940	45.9038	<.0001
BELT2	**1**	**-1.2947**	**0.1142**	**128.4718**	**<.0001**
BELT1	1	1.4142	0.0940	226.1700	<.0001
AGING2	1	0.0400	0.00389	105.5172	<.0001
YOUTHFUL2	1	0.0277	0.0125	4.9236	0.0265
FEMALE2	1	0.1938	0.0885	4.7957	0.0285
AGING1	1	-0.0294	0.00391	56.6262	<.0001
YOUTHFUL1	1	0.0380	0.0850	0.2000	0.6547
FEMALE1	1	-0.0336	0.0941	0.1274	0.7212

YOUTHFUL2 and FEMALE2 both have significant effects. The -1.2947 coefficient for BELT2 is statistically significant (χ^2 = 128.47). The best estimate of fatality reduction by **lap belts** for CR passengers of **LTVs** is 1 - exp(-1.2947) = 73 percent. Its confidence bounds are 1 - exp(-1.2947 ± 1.96x0.1142) = 66 to 78 percent.

One caveat with confidence bounds estimated by PROC LOGISTIC is that they assume the data points are all independent observations. This is not always the case. For example, when, occasionally, the driver and CR passenger of a vehicle are both fatalities, that vehicle case supplies two data points to the regression, one with CENREAR = 1 and the other with CENREAR = 2; or if an LTV has CR passengers in both the second and third rows, it could supply two data points to the regression, one with the driver and the second-row CR passenger, another with the same driver but the third-row CR passenger. To check that PROC LOGISTIC does not systematically underestimate sampling error, alternative confidence bounds have been estimated by a jackknife procedure that takes into account that the observations are not fully independent. It is essentially the same procedure that will be used later in this report, in Section 2.4, except that here the statistic of interest is belt effectiveness (expressed as a log odds ratio) rather than the risk ratio of two seating positions (also expressed as a log odds ratio in Section 2.4). The jackknife confidence bounds are almost identical to those from PROC LOGISTIC; they do not suggest PROC LOGISTIC has understated error (the logistic confidence bounds will remain our principal estimate of error because they are computed in the closed form, whereas the jackknife estimates can vary depending on what random numbers were generated to initiate the procedure):

CONFIDENCE BOUNDS	Logistic	Jackknife
Passenger cars		
3-point belts	41 to 69	42 to 69
Lap belt only	33 to 59	32 to 60
LTVs		
3-point belts	63 to 84	62 to 84
Lap belt only	66 to 78	66 to 78

1.5 Are 3-point belts more effective than lap belts?

The preceding analyses estimated that 3-point belts reduce fatality risk in the center rear seat of passenger cars by 58 percent, whereas the lap belt alone, only 48 percent. Given the relatively limited number of FARS cases involving center rear seat passengers, can we conclude that 3-point belts are significantly more effective than the lap belt alone? The question is addressed by combining the 874 vehicle cases of cars equipped with 3-point belts at the CR seat and the 1,805 vehicle cases with lap belts only into a single data set and running a logistic regression – but with one additional independent variable.

- CR3PT = 1 if the CR seat is equipped with 3-point belts, = 0 if equipped with lap belt only

More importantly, the regression will also contain the interaction term BELT2*CR3PT (literally, the product of the two variables, BELT2 and CR3PT, each of which has only the values 0 and 1) and its "mirror" term BELT1*CR3PT.[37] The various regression coefficients will be of little interest. The key statistic is the significance test for the BELT2*CR3PT interaction term, namely, is belt use significantly more beneficial when the CR seat is equipped with 3-point belts (i.e., when BELT2 = 1 and CR3PT = 1)? Here are the regression results:

Cars, CR Passengers, Increment for 3-Point Belts Over Lap Belts

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-0.2890	0.0836	11.9535	0.0005
BELT2	1	-0.6183	0.1221	25.6350	<.0001
BELT2*CR3PT	**1**	**-0.2999**	**0.1944**	**2.3808**	**0.1228**
BELT1	1	0.7859	0.0978	64.5559	<.0001
BELT1*CR3PT	1	0.2207	0.1751	1.5894	0.2074
CR3PT	1	0.0288	0.1306	0.0485	0.8256
AGING2	1	0.0322	0.00406	62.9630	<.0001
YOUTHFUL2	1	0.0131	0.0114	1.3231	0.2500
FEMALE2	1	0.0648	0.0765	0.7166	0.3973
AGING1	1	-0.0271	0.00365	55.1397	<.0001
YOUTHFUL1	1	0.00897	0.0565	0.0253	0.8737
FEMALE1	1	-0.0650	0.0815	0.6356	0.4253

[37] One reason for including the "mirror" term BELT1*CR3PT is that the coefficients for BELT1 were different in the preceding regression for cars with 3-point CR belts (1.0045) and cars with lap-only CR belts (0.7923).

The coefficient for BELT2*CR3PT is not statistically significant ($\chi^2 = 2.38$). However, a simpler model without the age and gender variables generates a BELT2*CR3PT coefficient that is significant at the one-sided .05 level ($\chi^2 = 3.08$; χ^2 needs to be 2.71 or larger for statistical significance at the one-sided .05 level and 3.84 or larger for statistical significance at the two-sided .05 level):

Cars, CR Passengers, Increment for 3-Point Belts Over Lap Belts
(Without age and gender variables)
Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-0.3054	0.0660	21.3899	<.0001
BELT2	1	-0.7244	0.1153	39.4392	<.0001
BELT2*CR3PT	**1**	**-0.3355**	**0.1911**	**3.0826**	**0.0791**
BELT1	1	0.7720	0.0948	66.3269	<.0001
CR3PT*BELT1	1	0.2355	0.1736	1.8408	0.1749
CR3PT	1	0.0553	0.1294	0.1824	0.6693

Whereas NHTSA's usual criterion is significance at the two-sided .05 level, significance at the one-sided .05 level may be sufficient here for at least a tentative conclusion from the still limited data that 3-point belts are more effective than lap belts alone – because nobody seriously suggests that the lap belt alone could be more effective than a 3-point belt (the second "side" of a two-sided test).

For **LTVs**, the preceding analyses estimated that 3-point belts reduce fatality risk by 75 percent, lap belts alone, by 73 percent. These estimates are quite close and, especially in view of the limited data with 3-point belts in LTVs, unlikely to be significantly different. Indeed, the regression analysis generates a non-significant coefficient for BELT2*CR3PT ($\chi^2 = 0.04$; the simpler model without the age and gender variables likewise generates a non-significant $\chi^2 = 0.17$). Rollover is a main contributor to fatalities in LTVs, more so than in passenger cars. Effectiveness of both lap belts and lap/shoulder belts is very high and quite similar in rollovers. Thus, the overall effectiveness of lap belts in LTVs will also be close to lap/shoulder belts.[38]

[38] Morgan, 1999, pp. xi and 45-46; Kahane, 2000, pp. 26-33. Electronic stability control prevents a large proportion of the rollovers in cars and, especially, LTVs. A lower proportion of fatal crashes being rollovers could eventually result in somewhat lower future estimates of overall belt effectiveness, especially in LTVs. However, in our database, 71% of the LTVs and 86% of the cars equipped with 3-point CR belts (and over 99% of the cars and LTVs equipped with lap-only CR belts) were not yet equipped with ESC.

LTVs, CR Passengers, Increment for 3-Point Belts Over Lap Belts

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-0.6456	0.0894	52.1817	<.0001
BELT2	1	-1.3097	0.1141	131.7498	<.0001
BELT2*CR3PT	**1**	**-0.0449**	**0.2287**	**0.0386**	**0.8443**
BELT1	1	1.4201	0.0941	227.9517	<.0001
CR3PT*BELT1	1	0.1283	0.2067	0.3850	0.5349
CR3PT	1	0.0125	0.1613	0.0060	0.9385
AGING2	1	0.0433	0.00353	150.5782	<.0001
YOUTHFUL2	1	0.0341	0.0112	9.2812	0.0023
FEMALE2	1	0.1963	0.0787	6.2193	0.0126
AGING1	1	-0.0315	0.00348	81.8324	<.0001
YOUTHFUL1	1	0.0377	0.0762	0.2448	0.6207
FEMALE1	1	-0.0573	0.0837	0.4690	0.4935

1.6 Updated effectiveness estimates for 3-point belts in the outboard rear seats

Morgan's 1999 statistical evaluation for NHTSA estimated that 3-point belts reduce overall fatality risk for **outboard** rear seat occupants by 44 percent in passenger cars (90% confidence bounds: 38% to 50%) and by 73 percent in LTVs (90% confidence bounds: 64% to 79%).[39] The analysis was based on FARS data from CY 1988 through mid-1997 and included cars and LTVs of MY 1985 through 1996.

Now, 17 years later, the estimates may be updated with a much larger database of the recent crash experience of more up-to-date vehicles. To allow the most direct comparison of belt effectiveness in the center rear and outboard rear seats, the new analysis for the outboard rear (ObdR) seats will be exactly parallel to the analyses for the center rear seat in Sections 1.2, 1.3, and 1.4. Specifically, it is based on:

- MY 1990 through 2015 vehicles in CY 1990 through 2014 FARS data;
- Fatality risk of ObdR passengers relative to drivers of the same vehicle;
- ObdR passengers 5 years or older;
- Limited to vehicles equipped with frontal air bags and 3-point belts for the driver, 3-point belts for ObdR passengers; and
- The same logistic regression models as in Section 1.4

In other words, the new database only partly overlaps the 1999 evaluation. Both databases include MY 1990-to-1996 vehicles with frontal air bags for the driver, but not the earlier vehicles not yet equipped with air bags; both databases include CY 1990 through 1997, but not CY 1988 and 1989.

[39] Morgan, 1999, pp. 29 and 89. At that time, NHTSA evaluations generally specified 90% confidence bounds; 95% confidence bounds would be approximately one-fifth wider.

Table 3 sets up the basic double-pair comparison analysis of 3-point belts for ObdR passengers of cars (not used for the effectiveness estimates), comparable to Table 2 for CR passengers in Section 1.3. The number of belted fatality cases of ObdR passengers in Table 3 (362 + 4,003 = 4,365) is about 38 times as large as the 116 belted CR fatality cases in Table 2 – because: (1) there are 2 outboard positions per row of seats (left and right) that can potentially supply cases, but at most 1 center seat per row; (2) occupancy of the ObdR seats is much higher than the CR seats; (3) every vehicle in the database is equipped with 3-point belts at the ObdR seats, but only the newer vehicles are equipped with 3-point belts at the CR seat; and (4) belt use is higher in the ObdR seats than in the CR seat. Because the database is much larger, the confidence bounds for the estimates will be narrower.

Table 3: Fatalities by Belt Use and Seating Position
(Cars with 3-point ObdR belts, with a driver and ObdR passenger, FARS 1990 to 2014)

Fatalities	ObdR Fatalities	Driver Fatalities	ObdR/Driver Risk Ratio
Both unrestrained	3,787	4,602	0.823
ObdR belted, driver unrestrained	362	1,226	0.295
ObdR unrestrained, driver belted	4,905	2,367	2.072
Both belted	4,003	4,224	0.948

The logistic regression model for passenger cars uses the same variables as the model in Section 1.4 that estimates effectiveness of center rear seat belts, controlling for age and gender. The regression is based on 25,476 fatality cases. Here are the coefficients:

Cars, ObdR Passengers, 3-Point Belts
Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-0.2551	0.0254	101.2592	<.0001
BELT2	**1**	**-0.7806**	**0.0309**	**636.8512**	**<.0001**
BELT1	1	0.9212	0.0306	905.8300	<.0001
AGING2	1	0.0370	0.00118	979.6997	<.0001
YOUTHFUL2	1	0.0182	0.00458	15.7847	<.0001
FEMALE2	1	0.0974	0.0280	12.0793	0.0005
AGING1	1	-0.0286	0.00117	593.8841	<.0001
YOUTHFUL1	1	0.00277	0.0226	0.0151	0.9023
FEMALE1	1	-0.0766	0.0293	6.8217	0.0090

The coefficient for BELT2 is -0.7806 (slightly lower magnitude than the -0.8562 in the regression for CR passengers). It is statistically significant ($\chi^2 = 636.85$). All of the control variables except YOUTHFUL1 have significant effects in the expected directions (being older than 21, younger than 18, and/or female increases fatality risk). After controlling for age and gender, the best estimate of fatality reduction by **3-point belts** for ObdR passengers of **cars**, obtained from the coefficient for BELT2, is:

$$1 - \exp(-0.7806) = 54 \text{ percent}$$

Its 95-percent confidence bounds are obtained from the coefficient for BELT2 and its standard error (0.0293):

$$1 - \exp(-0.7806 \pm 1.96 \text{x} 0.0309) = 51 \text{ to } 57 \text{ percent}$$

The regression coefficients for LTVs are:

LTVs, ObdR Passengers, 3-Point Belts

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-0.5134	0.0369	193.7092	<.0001
BELT2	**1**	**-1.3757**	**0.0402**	**1168.4290**	**<.0001**
BELT1	1	1.5196	0.0404	1413.5946	<.0001
AGING2	1	0.0366	0.00137	710.4585	<.0001
YOUTHFUL2	1	0.0318	0.00530	35.8947	<.0001
FEMALE2	1	0.1502	0.0357	17.7048	<.0001
AGING1	1	-0.0284	0.00146	377.7001	<.0001
YOUTHFUL1	1	0.0716	0.0343	4.3659	0.0367
FEMALE1	1	-0.1054	0.0376	7.8740	0.0050

The coefficient for BELT2 is statistically significant (χ^2 = 1168.43). After controlling for age and gender, the best estimate of fatality reduction by **3-point belts** for ObdR passengers of **LTVs** is:

$$1 - \exp(-1.3757) = 75 \text{ percent}$$

Its 95-percent confidence bounds are

$$1 - \exp(-1.3757 \pm 1.96 \text{x} 0.0402) = 73 \text{ to } 77 \text{ percent}$$

Here, too, a caveat with the confidence bounds is that PROC LOGISTIC assumes the data points are independent observations. This is not the case when a vehicle has more than one ObdR passenger (e.g., a left rear and a right rear passenger) or when the driver and an ObdR passenger of a vehicle are both fatalities. Again, alternative confidence bounds have been estimated by a jackknife procedure that takes into account that the observations are not fully independent. These bounds are almost identical to the logistic bounds; they do not suggest PROC LOGISTIC has understated error:

CONFIDENCE BOUNDS	Logistic	Jackknife
Passenger cars	51 to 57	51 to 57
LTVs	73 to 77	72 to 77

Comparison with NHTSA's 1999 evaluation: The updated belt effectiveness estimate for cars (54%) appears to be higher than the 1999 result (44%), whereas the updated and earlier results for LTVs are closer (75% versus 73%). Even without a rigorous statistical test, it is evident that the difference in the estimates for cars is not likely due to chance or limited data because the confidence intervals for the two estimates (51% to 57% for the updated, 38% to 50% for the 1999 result) do not even overlap. It raises the question whether the increase in the observed effectiveness is "real" (belts actually becoming more effective) or due to some artifact in the data and/or the analyses.[40]

One potential explanation for escalating effectiveness is the increasing number of States adapting rear seat belt laws, possibly resulting in inaccurate reporting of belt use by survivors, similar to what happened in the 1980s with front seat belts (see Section 1.3). There is, however, little escalation **within** the current database. The results for the current data, MY 1990-to-2015 cars in CY 1990-to-2014 FARS are quite steady. When the cars are subdivided into two model-year cohorts, MY 1990 through 2000 and MY 2001 through 2015, the observed fatality reduction for 3-point belts (using, for simplicity, the basic double-pair comparison analysis, without adjustment for occupant age and gender) is 58 percent in the earlier cars and 56 percent in the later-model cars. Effectiveness has changed little by model year (at least since MY 1990). When the FARS cases are instead subdivided into four calendar-year cohorts, CY 1990 through 1999, CY 2000 through 2004, CY 2005 through 2009, and CY 2010 through 2014, observed fatality reduction likewise does not show a trend: 54 percent, 57 percent, 60 percent and 55 percent.

There is a discrepancy, however, internal to the data and analyses of the 1999 report. Here is Table 2-1 on p. 19 of the 1999 report. It is similar to Table 2 in Section 1.3 of the current report, except that it presents double-comparison analyses with five rather than two control groups: (1) unrestrained drivers and RF passengers at seats not equipped with frontal air bags; (2) 3-point belted, no air bags; (3) automatic 2-point belted, no air bag; (4) unrestrained, seat equipped with air bag; and (5) 3-point belted, with air bag. (Only the last two control groups are used in Table 2 of the current report because the database is limited to vehicles with frontal air bags and without automatic 2-point belts.)

[40] Belt pretensioners and load limiters had been phased into the front seats of all new cars and LTVs by MY 2008, but as of 2016 are standard for rear seats only on a few luxury models; Kahane, C. J. (2013, November). *Effectiveness of pretensioners and load limiters for enhancing fatality reduction by seat belts* (Report No. DOT HS 811 835, pp. 1-3, 37-50). Washington, DC: National Highway Traffic Safety Administration. Available at crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811835

Table 2-1 From Morgan (1999)[41]: Fatalities by Belt Use and Seating Position
(Cars with 3-point or lap-only ObdR belts,
cars with a driver/RF occupants and ObdR passengers,
FARS 1988 to mid-1997)

Back Seat Restraint Use	Back Seat Fatalities	Front Seat Restraint Use	Front Seat Fatalities	Risk Factor	Fatality Reduction
Unrestrained	3,028	3-point belt	2,098	1.443	
Lap belted	1,135		1,079	1.052	27%
Lap/shoulder belted	807		880	0.917	36%
Unrestrained	4,953	unrestrained	7,248	0.683	
Lap belted	161		471	0.342	50%
Lap/shoulder belted	119		344	0.346	49%
Unrestrained	1,016	2-point automatic belt	818	1.242	
Lap belted	89		133	0.669	46%
Lap/shoulder belted	403		603	0.668	46%
Unrestrained	650	air bag alone	820	0.793	
Lap belted	0		1		
Lap/shoulder belted	49		148	0.331	58%
Unrestrained	670	air bag plus 3-point belt	371	1.806	
Lap belted	3		2		
Lap/shoulder belted	431		490	0.880	51%

The data in the last two sections of the preceding table more or less overlap the database of the current report: cars with frontal air bags in crashes mostly in CY 1990 or later. These last two double-pair comparisons for lap/shoulder belted ObdR passengers yield effectiveness estimates of 58 percent and 51 percent, respectively. Their weighted average is 52 percent, which is quite close to the 54-percent effectiveness estimated above from the entire database of the current report. Instead, it is the first three double-pair comparisons, based on earlier cars not yet equipped with frontal air bags (and not included in the current report's database) that generate lower effectiveness estimates for ObdR 3-point belts, especially the 36-percent estimate in the first section of Table 2-1, where the control group is 3-point belted front-seat occupants of vehicles not equipped with frontal air bags. It is unknown why the effectiveness estimate for ObdR belts was so low in those cars. Suffice it to say that those cars are now well over 20 years old and have mostly been retired.

[41] Morgan, 1999, p. 19.

Effectiveness by passenger age group: The 1999 report found 3-point belts at the ObdR seats of passenger cars generally less effective for people 55 and older (28% fatality reduction) than for passengers 15 to 54 years old (53% fatality reduction for males, 45% for females) or children 5 to 14 years old (52% fatality reduction).[42] These trends continue. Double-pair comparison analyses of belt effectiveness were performed, by passenger age group, with the current report's database. These updated estimates of fatality reduction with 3-point belts for ObdR passengers are 34 percent for people 55 and older, 62 percent for passengers 15 to 54 years old, and 55 percent for children 5 to 14 years old. All of the reductions are statistically significant. As Zhou, Rouhana, and Melvin explain, the effect of aging is more severe in belt loading than in blunt impact force: belt loading is a more static, less dynamic load than blunt impact, and thus has a less linear response. Also, belt force is concentrated on bone, rather than soft tissue. Bone deteriorates more rapidly with age than soft tissue. As a result, belt effectiveness has historically been somewhat lower for older occupants.[43]

1.7 Summary

Three-point belts significantly reduce fatality risk for center rear seat passengers of both cars and LTVs. So does the lap belt alone; however, the still limited data may be sufficient for a tentative conclusion that, in cars, 3-point belts are more effective than lap belts alone.[44] As in previous studies, 3-point belts continue to significantly reduce fatality risk for outboard rear seat passengers of cars and LTVs. The effectiveness estimates and their 95-percent confidence bounds are shown in Table 4:

[42] Morgan, 1999, p. 48.
[43] Zhou, Q., Rouhana, S. W., & Melvin, J. W. (1996). Age effects on thoracic injury tolerance, *40th Stapp Car Crash Conference Proceedings*, Paper No. 962421 (Publication No. P-305). Warrendale, PA: Society of Automotive Engineers.
[44] Effectiveness is borderline-significantly higher (i.e., at the 1-sided .05 level) for 3-point belts than for lap belt only in passenger cars in a logistic regression model that does not control for occupant age and gender.

Table 4: Fatality Reduction (%) by Seat Belts for Rear Seat Passengers
(MY 1990-to-2014 cars and LTVs in CY 1990-to-2014 FARS)

	Estimated Fatality Reduction (%)	95% Confidence Bounds
Passenger cars		
Center rear seat		
3-point belt	58	41 to 69
Lap belt only	48	33 to 59
Outboard rear seat		
3-point belt	54	51 to 57
LTVs		
Center rear seat		
3-point belt	75	63 to 84
Lap belt only	73	66 to 78
Outboard rear seat		
3-point belt	75	73 to 77

2. Comparison of occupants' relative fatality risk at the various seating positions in a vehicle

2.1 Relative risk – 30 years ago – and more recently

In his classic analysis of 1975-to-1985 FARS data, Evans found that unrestrained rear seat occupants of passenger cars had substantially lower fatality risk than the unrestrained drivers and right front (RF) seat passengers in the same vehicles; center rear (CR) seat passengers had even lower risk than outboard rear (ObdR) seat passengers:

Relative Fatality Risk by Seating Position for Unrestrained Occupants
FARS 1975-to-1985, Passenger Cars (Evans)[45]

Driver	1.000
Right front seat	1.006
Outboard rear seat	.738
Left rear seat	.734
Right rear seat	.742
Center rear seat	.626

[45] Evans, 1991, pp. 47-50.

In computing the fatality risk ratios, Evans limited the analysis to driver-passenger pairs, riding in the same vehicle, where both the driver and the passenger were unrestrained. That still left most of the data, because in 1975-to-1985 FARS, almost entirely before seat belt laws, fewer than 5 percent of driver and RF passenger fatalities and fewer than 3 percent of rear seat passenger fatalities were belted. He also limited to passenger cars, but in 1975 to 1985, before minivans, SUVs, and CUVs were popular, about 80 percent of the front seat occupants and over 90 percent of the rear seat occupants were in cars. Realizing that demographics vary by seating position, Evans controlled for occupant age and gender by limiting the analysis to driver-passenger pairs who were of the same gender and within 3 years of each other's age; he also limited the analysis to occupants 16 and older.

This report will update risk ratios with current FARS data. However, because most people buckle up nowadays, the analysis will primarily address the risk ratios of belted occupants, not unrestrained occupants. The goal is to find out if the large advantages of the rear seating positions for unrestrained occupants of yesteryear's vehicles are still present for restrained occupants in today's vehicles.

In CY 1975 to 1985, most of the cars on the road met only the early FMVSS or none at all – e.g., frontal air bags barely existed. Large advantages for unrestrained occupants in the rear seats, especially in the center rear seat, are not so startling in these bygone vehicles. The distribution of crashes intrinsically favors the rear seat passenger: there are a lot more high-speed frontal impacts than rear impacts – and in a frontal, the front seat occupants, being closer to the impact area and intrusion, are more vulnerable than the rear seat passengers. Furthermore, an occupant sitting adjacent to the struck side of a vehicle (near-side occupant) is usually more vulnerable than occupants sitting some distance away from that side.

But changes in vehicle design since the 1970s may have narrowed or possibly even reversed the differences between seats. Some occupant protection technologies, especially frontal air bags, energy-absorbing steering assemblies, belt pretensioners, and load limiters have been furnished exclusively or primarily in the front seats. Repeated structural improvements to the fronts and sides of vehicles, as evidenced by steadily better performance on crash tests, will likely have the largest effect for people sitting closest to the front or the side of the vehicle, respectively: they are likely to benefit front-seat occupants more than rear-seat, outboard occupants more than center-seat.

Belt use may also narrow the differences between seating positions. Unrestrained occupants, immediately after impact, contact the vehicle's interior components that surround them and are brought to an abrupt stop. These components vary considerably, depending on the seating position. In a frontal impact, for example, the driver and RF passengers contact the relatively rigid steering assembly, windshield header, and/or instrument panel (as well as possibly the more giving laminated-glass windshield), whereas rear seat passengers contact the relatively benign backs of the front seats. Belt use, however, can mitigate or sometimes even prevent occupants' contacts with nearby components. A large portion of the occupant's energy is absorbed through the belt system – and the forces exerted by the belt upon the occupant are fairly similar at the various seating positions within the vehicle, because they do not depend so much on what components are located nearby.[46]

FIGURE 3: VEHICULAR FATALITY-RISK INDEX BY CALENDAR YEAR (1955 = 100)
BASED ON PERCENT OF POTENTIAL FATALITIES SAVED BY VEHICLE SAFETY TECHNOLOGIES

Of course, even if relative differences between seating positions have diminished, it is important to note that in **absolute** terms, passenger cars and LTVs have both become much safer at all seating positions. Figure 3, based on a 2015 NHTSA report, shows that the overall, absolute decrease in the occupant fatality risk from CY 1955-1960 to CY 2012, due to increased belt use, air bags, ESC, and the other FMVSS, was 56 percent.[47] This rising tide of safety benefited everyone: absolute risk decreased substantially at all seating positions, but not necessarily by exactly equal amounts. If safety improvements help front seat occupants even more than they help rear seat passengers, the **relative** gap between the rear and front seats can diminish even while absolute safety improves for both.

A 2005 NHTSA report by Kuppa, Saunders, and Fessahaie signaled that the rear seats were no longer the safest place for occupants of all ages. Whereas their double-pair comparison analyses of 1993-to-2003 FARS data still showed that children and other occupants younger than 50 benefited from sitting in rear seats in frontal crashes, restrained adult occupants older than 50 were significantly better off in the front seats than the rear seats. NHTSA has performed frontal crash tests for FMVSS compliance since 1972 and for NCAP since 1978 with restrained dummies in the front seat. Kuppa, Saunders, and Fessahaie frontally crash-tested five MY 2004 vehicles with restrained adult dummies in both the rear and front seats. The injury measures of the dummies in rear seats in these frontal crash tests were generally higher than those of the dummies of the same size in the driver and front passenger seat. The seat backs of integrated rear seats experienced excessive forward rotation in frontal crash tests, thereby causing the dummy's head to hit the console or front seat back, resulting in high head and neck injury measures.[48] These findings are consistent with NHTSA evaluations of seat belt effectiveness, which showed relatively lower effectiveness for rear seat passengers 55 and older, whereas late-model front seat

[46] Example of a possible exception: In a side impact, the loading of the shoulder belt on the neck could depend on which side the belt is anchored (same or opposite of the impact side) and whether the occupant will also contact the side interior surface of the vehicle.
[47] Kahane, 2015, p. xxvii.
[48] Kuppa, S., Saunders, J., & Fessahaie, O. (2005, June). Rear seat occupant protection in frontal crashes. *Proceedings of the Nineteenth International Technical Conference on the Enhanced Safety of Vehicles* (Paper No. 05-0212). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/pdf/esv/esv19/05-0212-O.pdf

belts with pretensioners and load limiters maintained their high effectiveness levels for older occupants.[49]

In 2015 Durbin et al. confirmed that the safety advantage of the rear seats had shrunk and, furthermore, this might still be an ongoing process, with the latest-model vehicles possibly safer overall in the front seat than the rear seat. They analyzed CY 2007-to-2012 FARS and NASS-CDS data for crash involvements of MY 2000 and later cars and LTVs. They estimated national fatality rates per 100 occupants involved in tow-away crashes by using FARS counts as the numerator and weighted NASS-CDS counts as the denominator. After adjusting the rates for occupant age and gender, the overall fatality rate for rear seat passengers was not lower than for front-seat occupants. Children 8 and younger continued to have lower fatality rates if they sat in the rear seat than in the front seat, but for people older than that, this was not the case. Furthermore, in the vehicles of MY 2007 and later, the adjusted fatality risk for rear seat passengers was a statistically significant 46 percent higher than for front seat occupants.[50]

2.2 Analysis goal and database

The objective of the analyses is to compare the fatality risk, for occupants at least 5 years old, at any two seating positions in a passenger car or LTV. Later on, the goal will be to compare the intrinsic fatality risk – i.e., the relative risk of two occupants of the same age and gender, but sitting in different seats. But the initial task is just to gather a list of **occupant pairs** – two people riding in the same crash-involved vehicle, sitting at different seating positions – and to compute the fatality risk ratio for all the pairs in which person no. 1 sat at position A and person no. 2 sat at position B.[51]

Four seating positions will be considered: drivers, right front seat passengers, outboard rear seat passengers, and center rear seat passengers. Sometimes the ObdR passengers will be subdivided into left-side and right-side. The center front seat, present in ever fewer vehicles, will not be included in the analyses.

The database, extracted from CY 1990 through 2014 FARS, is quite similar to the one used for the belt effectiveness analyses of Chapter 1 of this report. The principal difference is that the vehicle records will include information about the RF passenger in addition to data elements for the driver, the ObdR passengers, and the CR passengers. As in Chapter 1, all analyses will be

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[49] Morgan, 1999, p. 48; Kahane, 2013, pp. 218-223.

[50] Durbin, D. R., Jermakian, J. S., Kallan, M. J., McCartt, A. T., Arbogast, K. B., Zonfrillo, M. R., & Myers, R. K. (2015). Rear seat safety: Variation in protection by occupant, crash and vehicle characteristics. *Accident Analysis and Prevention*, *80*, pp. 185-192. When all the data in the second section of their Table 3 is combined, the risk ratio for rear-seat to front-seat occupants is 1.11; excluding children younger than 4, it is 1.30.

[51] An analysis could also be performed with a database that is a census or probability sample of crashes of all severities and outcomes, such as a State crash file, or a merge of FARS (fatal crashes) with NASS-GES (other crashes): an analysis of the relative fatality risk would be P(fatality | occupant in seating position 1) / P(fatality | occupant in seating position 2), controlling for gender, age, belt use, etc. However, the advantages of making the analysis internal to FARS and focusing on occupant pairs within the same vehicle include: (1) Being in the same vehicle is a sort of automatic control for crash severity, whereas files such as GES or State data have little information to indicate how severe the crash was; (2) Nearly complete vehicle identification (VINs) in FARS, more so than in GES or State files; and (3) FARS cases may have more complete and accurate information on vehicle occupancy and belt use than non-fatal cases in GES or State files.

limited to vehicles equipped with frontal air bags at the driver's seat and 3-point belts at the ObdR seats. Because driver air bags did not appear in large numbers until MY 1990, the analyses are limited to MY 1990 through 2015 vehicles in CY 1990 through 2014 FARS data.

Records of MY 1990-to-2015 cars and LTVs are extracted from FARS data for CY 1990 to 2014 under the following conditions and retaining the following data elements:

- The make, model, and MY must be decodable from the first 12 characters of the VIN, using the VIN-decode programs which have been developed by NHTSA's Evaluation Division through MY 2013 (exception: all MY 2014 and 2015 vehicles will be included if BODY_TYP indicates they are cars or LTVs, because we know these vehicles have 3-point belts at the CR seats; BODY_TYP will also be the basis for classifying them as cars or LTVs);
- The vehicle was occupied by a driver and at least one passenger 5 years or older who occupied an RF, ObdR, or CR seat (for example: 1 driver and 1 RF passenger; 1 driver and 1 ObdR passenger; 1 driver, 1 RF, and 2 ObdR passengers, etc.);
- At least one occupant of the vehicle was a fatality and at least one of the fatalities was a driver or a RF, ObdR, or CR passenger 5 years or older;
- The availability of a frontal air bag for the driver and the RF seat and a 3-point belt (or a lap belt only) at the CR seat is likewise derived from the VIN (or from the VIN-decoded make-model, or from the model year);
- The vehicle record will include data elements pertaining to the driver; the RF passenger if there is one; the passengers, if any, sitting in the 21, 22, and 23 seating positions (second row left, center, and right); and, for LTVs, the passengers sitting in the 31, 32, and 33 seating positions (third row left, center, and right), subject to the following conditions:[52]
    - The occupant's age and gender are known in FARS;
    - Occupants must be at least 5 years old;
    - Occupants' restraint use must be known. Child passengers riding in child safety seats or booster seats are excluded. In other words, REST_USE has to be 0 (in CY 1986 to 2009 only), 1, 2, 3, 7 (in CY 2010 to 2014 only), 8 (restraint used type not specified – but only for occupants 10 or older, so as to exclude any younger occupant who might have been in a safety seat or booster seat) or 13; 0 or 7 mean unbelted, the other codes mean belted;
    - At a seat equipped with 3-point belts, we will count any belted occupant as 3-point belted, regardless of whether REST_USE is 1, 2, 3, 8, or 13; likewise, if a CR seat is equipped with lap belts only (according to the VIN), we will count any belted occupant as lap-belted, regardless of what REST_USE says;
- The driver's belt must be the 3-point type; vehicles with automatic 2-point belts for the driver are excluded;
- Information on the RF passenger will be included only if the RF seat was equipped with a frontal air bag; if the RF passenger is 10 or younger, it has to be an advanced air bag (with suppression or low-risk deployment for young passengers); and
- If FARS says 2 or more people occupied the same seating position, only the first of these people is included in the analysis.

[52] Passengers in the fourth or higher rows of seats of full-size vans are not included in the analyses.

A single vehicle record may contribute multiple occupant pairs to various analyses. For example, a car occupied by a driver, one RF, two ObdR, and one CR may contribute: (1) a driver-RF pair to the driver-versus-RF analysis, if at least one of those two occupants was a fatality; (2) up to two driver-ObdR pairs, provided that each pair in the analysis must include at least one fatality; (3) a driver-CR pair; (4) up to two RF-ObdR pairs; (5) a RF-CR pair; and (6) up to two ObdR-CR pairs.[53]

2.3 Basic fatality risk ratios

The initial analysis gathers all the pairs for a specific combination of seating positions – e.g., all the driver-RF pairs – tallies the number of fatalities at each of the two seating positions, and computes the actual fatality risk ratio for one seating position relative to the other. Table 5 computes these ratios for the RF, ObdR, and CR seating positions relative to the driver. Table 5 does not mimic Evans' analysis of 1975-to-1985 FARS: it is not limited to unrestrained occupants, nor is it limited to occupant pairs of the same gender and within 3 years in age. It includes any pair of occupants of the same vehicle, regardless of their belt use, age, or gender.

Table 5: Actual Fatality Risk Ratios for Passengers Relative to Drivers
By Passenger Seating Position and Vehicle Type
(FARS 1990 to 2014; all passenger-driver pairs, including dissimilar belt use)

Passenger Seating Position	Passenger Fatalities	Driver Fatalities	Passenger/Driver Risk Ratio	Passenger Belt Use	Driver Belt Use
			Passenger Cars		
Right front	28,332	26,311	1.077	62%	63%
Outboard rear	10,623	9,064	1.172	35%	60%
Center rear[54]	422	323	1.307	20%	64%
			LTVs		
Right front	11,736	11,909	.985	58%	61%
Outboard rear	6,400	5,650	1.133	33%	63%
Center rear[55]	300	215	1.395	20%	67%

For example, there are 45,808 passenger cars whose occupants included a driver and an RF passenger 5 years or older (and possibly other passengers), where at least one of these two

[53] Just as in (1) and (2), pairs from (3), (4), (5), and/or (6) are included in the analysis only if at least one occupant in the pair was a fatality.
[54] Limited to passenger cars whose CR seats are equipped with 3-point belts.
[55] Limited to LTVs whose CR seats are equipped with 3-point belts.

occupants and possibly both were fatalities. In these cars, there were 28,332 RF passenger fatalities and 26,311 driver fatalities, a fatality risk ratio of 1.077.

Table 5 shows that risk ratios are unfavorable for ObdR passengers relative to drivers (1.172 in cars, 1.133 in LTVs) and even more so for CR passengers relative to drivers (1.307 and 1.395, respectively). But Table 5 also reveals why that is so. Unlike the CY 1975-to-1985 timeframe analyzed by Evans, when hardly anyone buckled up, belt use is quite high for drivers, even those involved in fatal crashes: at least 60% in every row of Table 5. Belt use of rear-seat passengers, until quite recently, lagged way behind drivers. In the 1990-to-2014 FARS database, it was only 33 to 35 percent for the ObdR passengers of cars and LTVs and a mere 20% for the CR passengers.

The first step toward a level playing field for comparing risk at various seating positions is to limit the data to occupant pairs with identical belt use: to compare belted passengers to belted drivers and, separately, unrestrained passengers to unrestrained drivers, as in Table 6 and in all the remaining analyses of this chapter. Furthermore, Table 6 has separate belted-versus-belted comparisons for the CR seat in vehicles equipped with lap belts only at that seat and for vehicles with 3-point belts at all seating positions. From here on, we will be comparing the risk at **different** seating positions, but with **identical** belt use. Some of these differences will be small. But these results are distinct from the findings of Chapter 1, which show that a belted occupant has much lower risk than an unbelted occupant at the **same** seating position.

Table 6: Actual Fatality Risk Ratios for Passengers Relative to Drivers – by Passenger Seating Position, Vehicle Type, and Belt Use (FARS 1990 to 2014; limited to passenger-driver pairs with identical belt use)

Passenger Seating Position	Passenger Fatalities	Driver Fatalities	Passenger/Driver Risk Ratio	Average Age: Passenger	Average Age: Driver	Percent Female: Passenger	Percent Female: Driver
Passenger Cars – Driver and Passenger Both Belted							
Right front	15,837	14,632	1.082	47	47	60	38
Outboard rear	4,023	4,245	.948	31	39	54	42
Center rear (lap only)	158	201	.786	21	37	56	48
Center rear (3-point)	109	149	.732	21	37	61	51
LTVs – Driver and Passenger Both Belted							
Right front	5,869	6,001	.978	47	48	59	36
Outboard rear	2,325	3,054	.761	30	42	56	40
Center rear (lap only)	189	285	.663	25	41	53	44
Center rear (3-point)	59	89	.663	26	41	61	41
Passenger Cars – Driver and Passenger Both Unrestrained							
Right front	8,218	8,262	.995	30	30	40	26
Outboard rear	3,821	4,637	.824	23	27	36	27
Center rear	532	710	.749	20	26	45	30
LTVs – Driver and Passenger Both Unrestrained							
Right front	3,359	3,869	.868	32	34	41	26
Outboard rear	1,961	2,968	.661	25	31	41	28
Center rear	459	782	.587	23	31	46	30

In sharp contrast to Table 5, the risk ratio is always less than 1 for rear seat passengers relative to drivers, sometimes much less than 1. The only passengers with higher aggregate risk than the drivers of their vehicles (1.082) are the belted RF passengers of cars. Nevertheless, the demographic data in the four right columns of Table 6 demonstrate that the comparisons are still not on a level playing field. For all groups of rear seat passengers, the age of the passenger is, on the average, substantially less than the age of the driver of the same vehicle. For example, the belted ObdR passengers of cars averaged 31 years old, but their drivers, 39 years. Being younger is usually a bias that would substantially favor the rear seat passengers (exception: occupants younger than 18). On the other hand, all groups of rear seat passengers are more likely to be females than their drivers – e.g., 56 percent of belted ObdR passengers of cars are female, but only 40 percent of their drivers. At most ages, females are at somewhat more risk than males, so this is a bias that favors the drivers. The demographics are different for the RF seat. The RF passengers are the same age, on the average, as their drivers, but are more often females – e.g., for belted RF passengers of cars, age averages 47 for both the passengers and their drivers, but 60 percent of the passengers are female, versus only 38 percent of the drivers. Thus, the statistics in Table 6 tend to be biased in favor of the rear seat passengers, but against the RF passengers.

Another potential flaw introduced with Table 6 is that it relies on the belt use reported in FARS. As discussed in Section 1.3, NHTSA believes some fraction of actually unrestrained drivers and right front passengers who survive crashes say that they were belted – whereas belt use of front seat fatality cases is more accurately reported, as is the belt use of all rear seat passengers, both survivors and fatalities. This could affect the risk ratios for rear seat passengers in Table 6. For example, if FARS says the driver and ObdR passenger were both belted and only the ObdR passenger died, that case would be counted as an ObdR passenger fatality in the "both belted" section of Table 6. But if that surviving driver was actually unrestrained, that is no longer a driver-passenger pair with identical belt use, and it should be omitted completely from Table 6, thereby reducing the risk ratio for belted ObdR passengers to belted drivers.

It is unknown which **individual** drivers and RF passengers incorrectly reported their belt use. NHTSA, however, has empirically derived a universal exaggeration factor (UEF) to adjust downwards the belt effectiveness estimates for the front seat based on double-pair comparison analyses of FARS data after 1985 and make them comparable to the unbiased estimates from earlier data: $E = 100 - [1.369 \times (100 - E^*)]$, where E^* is the effectiveness estimate observed in the analysis and E is the true effectiveness.[56]

[56] Kahane, 2000, pp. 2-3 and 10-19.

Table 7: Actual Fatality Risk Ratios for Passengers Relative to Drivers – by Passenger Seating Position, Vehicle Type, and Belt Use
(FARS 1990 to 2014; passenger-driver pairs with identical belt use; with correction of belt use reporting by surviving drivers)

Passenger Seating Position	Passenger Fatalities	Driver Fatalities	Passenger/Driver Risk Ratio	Average Age		Percent Female	
				Passenger	Driver	Passenger	Driver
Passenger Cars – Driver and Passenger Both Belted							
Right front	15,837	14,632	1.082	47	47	60	38
Outboard rear	3,904	4,245	.920	31	40	54	42
Center rear (lap only)	152	201	.756	20	37	56	49
Center rear (3-point)	107	149	.718	21	37	60	50
LTVs – Driver and Passenger Both Belted							
Right front	5,869	6,001	.978	47	48	59	36
Outboard rear	2,238	3,054	.733	30	42	56	41
Center rear (lap only)	181	285	.635	25	41	54	44
Center rear (3-point)	57	89	.640	26	41	60	42
Passenger Cars – Driver and Passenger Both Unrestrained							
Right front	8,218	8,262	.995	30	30	40	26
Outboard rear	3,984	4,637	.859	24	27	36	27
Center rear	555	710	.782	21	26	46	30
LTVs – Driver and Passenger Both Unrestrained							
Right front	3,359	3,869	.868	32	34	41	26
Outboard rear	2,109	2,968	.711	25	31	41	28
Center rear	498	782	.637	24	32	46	31

In the 1990-to-2014 FARS data used for the analyses of this report, a reclassification of approximately 4 percent of the reportedly belted surviving drivers and RF passengers, randomly selected, to unrestrained diminishes the double-pair comparison estimates of belt effectiveness by the amount postulated by the UEF. Thus, in the rear-seat to driver comparisons in Table 7 and subsequently, a randomly selected 4 percent of surviving reportedly belted drivers has been reclassified as unbelted prior to running any part of the analysis. Likewise, in the rear-seat to RF comparisons in Table 8, a randomly selected 4 percent of surviving reportedly belted RF passengers has been reclassified as unbelted prior to running any part of the analysis.[57]

Reclassification is unnecessary for the RF-to-driver risk analyses, because belt use is incorrectly reported at both positions, the effects canceling each other. (It was also unnecessary in the effectiveness analyses of Chapter 1 of the report. They compare belted rear seat passengers to unbelted rear seat passengers, not to front seat occupants. Inaccurate reporting for the front seat merely moves cases from one control group to another, not necessarily biasing results in a particular direction.[58])

Reclassifying the database to compensate for inaccurate belt use reporting has a visible, predictable influence on the results. Typically, the risk ratios for belted rear seat occupants relative to drivers are about .03 units lower with the reclassified data (Table 7) than the original data (Table 6). For example, the risk ratio for belted ObdR passengers in cars relative to their drivers is .948 in Table 6 and .920 in Table 7. Conversely, risk ratios increase by about .03 to .05 units for unrestrained passengers – e.g., the "too good to be true" .587 risk ratio for unrestrained CR passengers of LTVs in Table 6 rises to .637 in Table 7. In other words, adjusting for the UEF is not as influential here as in double-pair comparison analyses of belt effectiveness in the front seat (where it scales back a 62% effectiveness estimate to 48%, for example[59]) but it is not negligible: .03 units adjustment is comparable to the standard errors that will be computed in the next section for the risk ratios for ObdR passengers. As discussed above, the risk ratios for RF passengers remain unchanged from Table 6 to Table 7. Likewise unchanged from Table 6, every group of RF passengers has a higher percentage of females than the drivers of their vehicles; every group of rear seat passengers is younger, on the average, and has a higher percentage of females than the drivers of their vehicles.

2.4 Adjustment for age and gender with logistic regression

NHTSA's 2013 evaluation of the injury vulnerability of older occupants and women develops logistic regression models that estimate the comparative fatality risk of two occupants sitting in different seating positions but in the same vehicle – as a function of their age and gender. For

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[57] Four alternative random selections of the 4 percent of surviving reportedly belted drivers resulted in slightly different values of the actual (Table 7) and adjusted (Tables 8a, 8b, and 8c) ObdR:driver risk ratios, e.g., within a range of ±0.004 for belted occupants of cars and ±0.006 for belted occupants of LTVs (95% confidence ranges for the risk ratio, based on the t distribution with 4 df). This is not an important source of uncertainty, given that Tables 8a and 8b show that other sources of error amount to ±0.062 for cars and ±0.055 for LTVs.
[58] Moving surviving drivers from the belted control group to the unbelted control group would have increased the effectiveness estimate for CR seat belts when belted drivers are the control group; it would have decreased the CR belt effectiveness estimate when unbelted drivers are the control group; the increase and decrease might cancel one another when the weighted average effectiveness is computed.
[59] Kahane, 2000, p. 14.

example, given a driver and RF passenger of the same crash-involved vehicle, and given that at least one and possibly both were fatalities, the model estimates the probability that the driver was a fatality as a function of the driver's and passenger's age and gender; likewise the probability that the RF passenger was a fatality.[60] That evaluation focused on the effect of aging one year on fatality risk or the difference in fatality risk of a male and female of the same age in the same type of crash; it did not compare the risk that the same person would have had in different seating positions. Nevertheless, similar regression models are well suited for adjusting any of the passenger-to-driver fatality risk ratios in Table 7 for the demographic differences of the driver and passenger populations – and estimating what the risk ratio would have been if the passengers had the same age and gender distribution as the drivers. Or, more generally, any occupant-in-seating-position1—occupant-in-seating-position2 risk ratios – e.g., where seating position 1 is the RF seat and seating position 2 is the CR seat, etc. The three steps in the analysis are:

- Create a single reference population – representative of passengers who ride in late-model vehicles – of occupant pairs in which the univariate distribution of age and gender for occupant1 is identical to the univariate distribution of age and gender for occupant2 – i.e., the demographics are, on the average, the same for both seating positions.
- Take any group of actual position1-position2 occupant pairs in our 1990-to-2014 FARS database – e.g., the pairs in the second row of Table 7, belted drivers and belted ObdR passengers of passenger cars – and use the data to calibrate a logistic regression model that estimates the occupant-in-position1 and the occupant-in-position2 fatality risk for **any** hypothetical occupant pair as a function of the occupant1's and occupant2's age and gender.
- Use the model's regression coefficients to compute a fatality risk for occupant1 and for occupant2, for each of the pairs in the reference population. Sum up these risks to obtain the overall average risk for seating position 1, the overall average risk for seating position 2, and the adjusted fatality risk ratio for seating position 2 relative to seating position 1.

Since this report is primarily a study of passengers' fatality risk, the **reference population** should reflect the distribution of passengers (rather than drivers) in relatively late-model vehicles – namely, the vehicles equipped at the RF seat with certified-advanced compliant (CAC) frontal air bags, but without on-off switches.[61] CAC air bags phased in from MY 2003 through 2007. With their suppression or low-risk deployment features, they have largely eliminated the risks for child passengers associated with earlier air bags. The starting point for our reference population is a subset of our CY 1990-to-2014 FARS database: the actual population of RF-rear seat passenger pairs in vehicles equipped with CAC air bags; the pairs should, furthermore, have known and identical belt use and at least one of the pair should be a fatality. Then, in addition, a duplicate pair will be added to the reference population, but exchanging the age and gender for the two seating positions. For example, if the FARS database has a vehicle with a 24-year-old male in the RF seat and a 20-year-old female in the left rear seat, the reference population will have one pair with a 24-year-old male at seating position 1 and a 20-year-old female at seating position 2 – and another pair with a 20-year-old female at seating position 1 and a 24-year-old male at seating position 2.

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[60] Kahane, 2013, pp. 9-83.

[61] The presence or absence of on-off switches for the air bag at the RF seat was irrelevant in the analyses of Chapter 1, because they did not include any RF passenger cases.

Because it always includes a pair and its reverse, the reference population will have the same univariate distribution of age and the same percentage of females at positions 1 and 2. The reference population consists of 3,008 pairs in passenger cars and 3,214 pairs in LTVs (note that both numbers are divisible by 2, because 2 pairs are created in the reference population from each eligible pair in the original database). This same reference population will be used in **every** analysis, regardless of what two seating positions are compared in that analysis. In that way, the risk ratio for CR passengers to drivers, say, is directly comparable to the risk ratio of RF passengers to drivers.

The data points in our **logistic regressions** can be any group of actual position1-position2 occupant pairs in the 1990-to-2014 FARS database – e.g., the pairs in the second row of Table 7, belted drivers and belted ObdR passengers of passenger cars. As stated above, in each pair, at least one and possibly both people were fatalities. Two dependent variables are defined for each data point: FATAL1 = 1 if the occupant at position 1 was a fatality, = 2 if a survivor; FATAL2 = 1 if the occupant at position 2 was a fatality, = 2 if a survivor. Because there are two dependent variables, there will be two regressions.

In NHTSA's 2013 evaluation, there were 8 independent variables pertaining to the occupants' age and gender, including linear terms, quadratic age terms, and age x gender interaction terms.[62] That would be inappropriate here. The purpose of the 2013 research was to explore the effects of age and gender; specifically, to see how those effects change with age. Here, all we need are relatively simple first-order factors to adjust the results for demographic variations by seating position: we are not interested in the effects of age and gender *per se*. The basic regression in the 2013 report was estimated from 154,467 data points; here, many of the regressions will involve far fewer cases and we must be careful not to over-fit the data with too many parameters. The 2013 research was limited to occupants 21 and older: in that range, risk always increases with age; the only question is how much. Here, the database includes passengers as young as 5: risk decreases with age through childhood and adolescence before it increases in adulthood. Thus, the effects of age and gender are more complicated here than in the 2013 research, with less data to estimate them. Furthermore, the effects of age and gender on fatality risk in childhood and adolescence cannot be estimated directly from the data by regression for some seating positions – e.g., there are few drivers younger than 16.

What would help here is a single variable pertaining to the occupant's age and another single variable pertaining to gender that incorporate the nonlinear relationships of age and gender to fatality risk – and whose coefficients can be estimated from the data even at seating positions where there are few adolescents or children.

NHTSA's 2013 report found that fatality risk, given the same physical insult, is fairly constant for occupants 18 to 21 years old; increases by a fairly constant percentage with each year that a person ages, about 3 percent per year, starting when they are 21 until they are approximately 35 years old; and from then on at a gradually accelerating rate.[63] Nevertheless, the after-35 acceleration is not excessive. For simplicity, a constant percentage increase may be assumed from 21 onwards. Exploratory analyses of a subset of our CY 1990-to-2014 database, consisting

[62] *Ibid*., pp. 17-27.
[63] *Ibid*., pp. x-xi, 13-15.

of driver-ObdR pairs, where the ObdR passenger was 18 or younger, indicate that the passenger's risk was fairly constant from about 15 to 18 but increased for each year that the passenger was **under** 15 by more or less the **same** amount that the driver's risk increased for each year **over** 21: in both cases, the regression coefficient's magnitude was close to 0.035. For the purposes of this report, the effect of age may be approximated by a piecewise log-linear function – i.e., risk decreasing at a constant percentage per year until a person is 15, then constant until 21, and then increasing by that same percentage per year from 21 onwards.[64] This can be incorporated into a single independent variable:

- AGE_FACTOR = 15 – AGE if the occupant is younger than 15; = 0 if 15 to 21 years old; = AGE – 21 if older than 21

This variable needs to be defined for both occupant1 and occupant2 in the pair, so it will actually furnish two independent variables, AGE_FACTOR1 and AGE_FACTOR2.

NHTSA's 2013 report also found that fatality risk, given the same physical insult, has historically been about 25 percent higher for a female than for a male of the same age (less in late-model vehicles) when occupants are 18 to 35 years old; after 35, the advantage for males diminishes gradually and steadily with each passing year; eventually, somewhere between 65 and 100, depending on the seating position, turning to an advantage for females. Two analyses of our CY 1990-to-2014 database explored the relationship between gender and fatality risk for people younger than 18: (1) comparison of the driver and RF passenger of the same vehicle, when they are exactly the same age and have the same belt use but one is male and the other female; and (2) pairs of ObdR passengers in the same vehicle, when they are nearly the same age and have the same belt use, but one is male and the other female.[65] These analyses suggest (although firm conclusions are impossible, given the limited data) that risk is about 25 percent higher for 15-to-17 year old females than for males of the same age, just as it is for 18-to-35 year old females. Younger than 14, the advantage for males diminishes, with little difference between males and females 5 to 7 years old. For the purposes of this report, the risk increase for females relative to males of the same age may be approximated by a piecewise linear function – i.e., rising linearly from zero effect for 5-year-olds to the full effect at 15, then constant up to 35, then diminishing linearly to zero at 85 and negative beyond.[66] This, too, can be incorporated into a single independent variable:

- FEM_FACTOR = 0 for males; = 1 for females 15 to 35 years old; = 1-.1*(15-AGE) for females 5 to 14 years old; = 1-.02*(AGE-35) for females older than 35

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[64] Evans, 1991, Figure 2-3 on p. 27, the graph labeled "car right-front passenger" illustrates how risk decreases by a fairly constant proportion each year from early childhood to the later teens, remains constant for a few years, and then increases by about the same constant proportion each year from the early twenties onward into late middle age – confirming the utility our piecewise log-linear function as a first-order approximation.

[65] The driver-RF comparisons were limited to people 16 and older. The ObdR-ObdR pairs had to belong to the same 3-year age cohort, namely 5-to-7, 8-to-10, 11-to-13, 14-to-16, etc.

[66] Evans, 1991, Figure 2-2 on p. 25 illustrates how females' and males' risk is about the same in early childhood; females' risk relative to males increases by an approximately constant proportional rate into the mid-teens, remains at this peak until the mid-30s, then decreases by about the same constant proportion up to at least the late 70s – confirming the utility our piecewise log-linear function as a first-order approximation.

This variable also needs to be defined for both occupant1 and occupant2 in the pair, furnishing two independent variables, FEM_FACTOR1 and FEM_FACTOR2.

With these independent and dependent variables, it is possible to compare any two seating positions in the vehicle. Here, for example, is a regression on the 7,186 occupant pairs consisting of a belted ObdR passenger in a car (occupant 1) and the belted driver of the same car (occupant2), at least one and possibly both a fatality, the passenger at least 5 years old. The second line of Table 7 shows that these 7,186 pairs included 3,904 passenger fatalities and 4,245 driver fatalities: an unadjusted risk ratio of .920. Table 7 also notes that the average age of the passengers was 31, the drivers 40; 54 percent of the passengers and 42 percent of the drivers were females. Here are the coefficients estimated by the logistic regression in which the dependent variable is whether or not the ObdR passenger was fatally injured:

Cars, Belted ObdR with belted driver: ObdR fatality risk
Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	0.1214	0.0473	6.5772	0.0103
AGE_FACTOR1	1	0.0502	0.00191	690.8291	<.0001
AGE_FACTOR2	1	-0.0345	0.00186	342.9983	<.0001
FEM_FACTOR1	1	0.1337	0.0622	4.6306	0.0314
FEM_FACTOR2	1	-0.1832	0.0593	9.5481	0.0020

And here are the coefficients when the dependent variable is whether or not the driver was fatally injured:

Cars, Belted ObdR with belted driver: Driver fatality risk
Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	0.5004	0.0486	105.8547	<.0001
AGE_FACTOR1	1	-0.0517	0.00189	746.9512	<.0001
AGE_FACTOR2	1	0.0375	0.00200	351.2611	<.0001
FEM_FACTOR1	1	-0.2145	0.0646	11.0098	0.0009
FEM_FACTOR2	1	0.1484	0.0609	5.9406	0.0148

In both regressions, **every** independent variable has a significant effect ($\chi^2 \geq 3.84$) in the expected direction. In the first regression, AGE_FACTOR1 has coefficient +.0502 (with $\chi^2 = 690.83$) – i.e., the likelihood that the ObdR passenger was a fatality increases with each year that the passenger is older than 21 or younger than 15. The significant <u>negative</u> (-.0345) coefficient for AGE_FACTOR2 ($\chi^2 = 343.00$) says that each year the driver's age exceeds 21 decreases the odds that, in this particular database, the ObdR passenger will be a fatality – i.e., the drivers' risk increases with age; in this database where either the ObdR passenger or the driver (but only occasionally both) is a fatality, the driver's fatality in this crash means that the

ObdR passenger most likely survived. FEM_FACTOR1 has coefficient +.1337 (χ^2 = 4.63) – i.e., risk is higher if the ObdR passenger is a female, especially so for passengers 15 to 35 years old. FEM_FACTOR2 has a negative coefficient -.1832 (χ^2 = 9.55) – i.e., risk is higher for the driver if the driver is a female, and, in this database, that reduces the likelihood that the ObdR passenger was a fatality. In the second regression, which estimates the driver's fatality risk, the regression coefficients each have the opposite sign and similar magnitude of what they were in the first regression.

Logistic regression estimates a linear relationship between the log-odds that the dependent variable equals 1 and the independent variables. The first regression model predicts the log-odds of an ObdR passenger fatality to be:

$$Z1 = .1214 + .0502\ AGE\_FACTOR1 - .0345\ AGE\_FACTOR2 + .1337\ FEM\_FACTOR1 - .1832\ FEM\_FACTOR2$$

Whereas the log-odds of a driver fatality are:

$$Z2 = .5004 - .0517\ AGE\_FACTOR1 + .0375\ AGE\_FACTOR2 - .2145\ FEM\_FACTOR1 + .1484\ FEM\_FACTOR2$$

Based on the regression formulas, given a [real or imaginary] ObdR-driver pair in which the ObdR passenger's characteristics are AGE_FACTOR1 and FEM_FACTOR1 and the driver's characteristics are AGE_FACTOR2 and FEM_FACTOR2, the probability of an ObdR passenger fatality is:

$$E\_FATAL1 = \exp(Z1)/(1+\exp(Z1))$$

and the probability of a driver fatality is:

$$E\_FATAL2 = \exp(Z2)/(1+\exp(Z2))$$

For example, one of the pairs in our reference population consists of occupant1, a 48-year-old female and occupant2, an 18-year-old male. With a 48-year-old female ObdR passenger and an 18-year-old male driver, the two preceding equations estimate the passenger's fatality risk is .829 and the driver's fatality risk is .258. The next pair in the reference population reverses the demographics: an 18-year-old male passenger with a 48-year-old female driver. Now the regression equations estimate .280 fatality risk for the passenger and .835 for the driver. If we sum the fatality probabilities for just these two pairs in the reference population, the regressions predict .829 + .280 = 1.109 passenger fatalities and .258 + .835 = 1.093 driver fatalities: almost the same, but with a small advantage for the driver.[67]

If we sum the fatality probabilities for all of the 3,008 pairs in the reference population for passenger cars (which, as discussed above, includes 1,504 actual occupant pairs in recent FARS data plus the 1,504 hypothetical pairs in which the demographics are reversed), they add up to

[67] That is, if p_r = P(fatality | the "real" passenger), p_s = P(fatality | the "switched" passenger), q_r = 1 – p_r, q_s = 1 – p_s, and X = the number of fatalities among the "real" and "switched" passengers, then E(X) = p_r q_s + p_s q_r + 2p_r p_s = p_r + p_s.

1,722 ObdR passenger fatalities and 1,694 driver fatalities: a risk ratio of 1.017 for ObdR fatalities relative to drivers. In this reference population, the average age of occupant1 is 33.69, and likewise for occupant2; 48.4 percent of the occupant1 cases are females and likewise for occupant2. (As explained above, because for any pair in the reference population, the pair with the reverse demographics is also included, occupant1 and occupant2 will have the same univariate age and gender distributions.) Unlike the actual FARS cases in Table 7, where the ObdR passengers were, on the average, younger and more often female than the drivers, the reference population has no age or gender bias. The risk ratio, which was .920 for the actual FARS cases, has increased to 1.017 after the adjustment for age and gender. In other words, belted ObdR passengers of cars in the actual data had lower fatality risk than their belted drivers primarily because they were younger. If they instead had the same age and gender distribution as the drivers, they would have had slightly (1.7%) higher fatality risk.

Confidence bounds[68] for the adjusted risk ratios are generated by a jackknife technique.[69] This procedure is suitable because:

- The estimator is complex (it is a quotient of two statistics, each a sum, over a reference population, of other statistics generated by regression equations);
- The individual observations are not fully independent, but are clustered (e.g., if one vehicle has 2 ObdR passengers, it may furnish 2 ObdR-driver pairs to the analysis); and
- The database is limited: it might be unwise to split the data into small, mutually exclusive subsets and perform separate analyses for each subset, because there might not be enough cases in each subset for successful regression analyses.

The 7,186 FARS ObdR-driver pairs used to compute the unadjusted risk ratio in Table 7 and then used again to run the two logistic regressions are subdivided into 10 systematic random subsamples of approximately equal size, based on the last two digits of the case number, ST_CASE – e.g., one of these subsamples might consist of all FARS cases with ST_CASE ending in 09, 20, 39, 52, 53, 71, 78, 79, 84, or 95. Ten pairs of regressions are performed, each using the 9/10 of the FARS data that remain after one of the subsamples is removed – one regression with ObdR fatality as the dependent variable and the other with driver fatality as the dependent variable. The subsample is then replaced before the next subsample is removed (thus, the name, "jackknife procedure"). The 10 pairs of regressions yield 10 pairs of estimates of the regression coefficients – the intercept and the coefficients for AGE_FACTOR1, AGE_FACTOR2, FEM_FACTOR1, and FEM_FACTOR2, one set for each dependent variable. These coefficients are each slightly different from the original coefficient based on the full FARS data. The 10 sets of alternative coefficients are used to create 10 alternative pairs of regression equations, which in turn are all applied to the same reference population to obtain 10 alternative estimates of the adjusted risk ratio.

[68] FARS is a census of fatalities, not a simple random sample. Nevertheless, in NHTSA evaluations and analyses, standard statistical tests are often applied to FARS data with the implicit rationale that the United States is a "sample" of a hypothetical population of thousands of countries, each essentially similar to the United States, with the same types of vehicles and drivers, and each with its own fatal crash experience. The confidence bounds we are trying to estimate is the range of likely results if the adjusted risk ratios were to be computed by the same method in each of those countries, using each country's FARS-like database.
[69] See Kahane, 2013, pp. 33-35 for a similar application of the jackknife technique.

The computation of confidence bounds involves the logarithms of the adjusted risk ratios. If the log of the adjusted risk ratio for the entire FARS database of 7,186 ObdR-driver pairs is x and this changes to x + h when all FARS cases are used **except** those with ST_CASE ending in 09, 20, 39, 52, 53, 71, 78, 79, 84, or 95, a "pseudo-estimate" x – 9h is generated for the subsample including **only** the FARS cases with ST_CASE ending in 09, 20, 39, 52, 53, 71, 78, 79, 84, or 95 (because x would be the weighted average of x – 9h for 1/10 of the data and x + h for 9/10 of the data). The standard error of these 10 pseudo-estimates estimates the standard deviation of the log of the adjusted risk ratio for the full database. For confidence bounds and statistical tests, that risk ratio can be treated as a t-distribution with 9 degrees of freedom (df).

However, the variance estimate obtained by running through the procedure just once could be too high or too low by chance, depending on what cases happened to get into the 10 subsamples. A second iteration of the same procedure, but with FARS split up into subsamples in a different way, might generate a lower or higher estimate. Numerous iterations, each with a different splitting of FARS into subsamples, will generate a range of estimates of the standard error, and the median of these estimates will be used. Specifically, the last two digits of ST_CASE were used to subdivide FARS into 100 groups (numbered 0 to 99). The numbers 0 to 99 were randomly re-ordered by a SAS random-number generator and listed in the new order. The FARS cases whose last two ST_CASE digits were among the first 10 on the new list became subsample 1, the next 10 became subsample 2, and so on. After these 10 subsamples were created, the numbers 0 to 99 were randomly reordered anew and another set of 10 subsamples was created. In all, the procedure was repeated 11 times and it created 11 sets of 10 subsamples each.

In our example of belted ObdR passengers relative to belted drivers of passenger cars, the adjusted risk ratio is 1.0166 and its logarithm is .0165. The 10 pseudo-estimates in the first of the 11 iterations range from -.105 to +.127. The standard error of these 10 pseudo-estimates is .0293.

The remaining 10 iterations of the same procedure yield standard errors ranging from .0192 to .0385. The median of these 11 estimates of the standard error is .0267.

Because .0165/.0267 = 0.62 is less than 2.262, the 97.5th percentile of a t-distribution with 9 df, the log of adjusted risk ratio is not significantly different from zero, based on a two-sided 95-percent test – i.e., the risk ratio itself, 1.017 is not significantly different from 1; we cannot reject the null hypothesis that the ObdR seating position and the driver's seating position have equal risk for people of the same age and gender. The 95-percent confidence bounds for the log of the adjusted risk ratio are

$$.0165 \pm 2.262 \times .0267 = -.0439 \text{ to } +.0769$$

In other words, the 95-percent confidence bounds for the adjusted risk ratio are

$$\exp(.0165 \pm 2.262 \times .0267) = 0.957 \text{ to } 1.080$$

2.5 Results

Tables 8a, 8b, and 8c on the next three pages present the main results of this chapter: estimates of the adjusted fatality risk ratios for each seating position relative to any of the other seating positions. These include adjusted risk ratios for all the passenger-to-driver comparisons listed in Table 7 and, in addition, the various possible passenger-to-passenger comparisons.

Table 8a compares the risk of **belted** occupants at various seating positions of **passenger cars**. The first two rows, for example, also appeared in Table 7: RF relative to driver and ObdR relative to driver. In the CY 1990-to-2014 FARS data, in crash involvements where a belted RF passenger and a belted driver rode in the same car, there were a total of 15,837 RF and 14,632 driver fatalities, an actual risk ratio of 1.082. The RF passengers and drivers both averaged 47 years old, but a higher percentage of the passengers were females (60% versus 38%), who tend to have higher fatality risk than males, given the same physical insult. After the analysis adjusts for age and gender, the risk ratio drops to .998 (95% confidence bounds: .971 to 1.030). Conversely, the actual risk ratio for ObdR passengers relative to drivers was .920, but the ObdR passengers have a demographic advantage: they are, on the average, 9 years younger than the drivers (31 versus 40). After adjustment for age and gender, the risk ratio increases to 1.017 (confidence bounds: .957 to 1.080). In other words, fatality risk is almost identical at the driver's, RF, and ObdR seating positions after controlling for occupants' age and gender: 1.000, 0.998, and 1.017, respectively. Risk is also almost identical, relative to the driver, at the left rear (1.016) and right rear (1.014) seats.

Most important, Table 8a does not show a statistically significant difference between **any** pair of seating positions, for belted occupants of passenger cars – i.e., all of the lower confidence bounds are smaller than 1.000 and all of the upper bounds are larger than 1.000. We cannot reject the null hypothesis that, averaging over the entire occupant population, the various seating positions of a car are about equally safe. (This does not preclude the possibility that, for certain subgroups of the population – e.g., children – some seating positions are safer than others.) It is true that the adjusted risk ratio for CR passengers with 3-point belts relative to drivers, .838, is lower than the other ratios in Table 8a. But this estimate is based on far less data than some of the others (107 CR passenger fatalities versus 3,904 ObdR and 15,837 RF passenger fatalities in the comparisons with drivers) and it has wider confidence bounds (.628 to 1.119). Furthermore, the comparisons of the CR with the RF or ObdR passengers (later on in Table 8a) do not show a large advantage for the CR seat.

In theory, if the adjusted risk ratios had been measured with perfect accuracy, the adjusted risk ratio for seating position x relative to z should be the product of the x:y and y:z ratios. The statistics in the preceding tables, however, are estimates based on limited data: x:z need not equal (x:y)(y:z) because of sampling error in each estimate. For example, in Table 8a, ObdR:driver is 1.017, which does not exactly equal (ObdR:RF)(RF:driver) = 1.048 x .998 = 1.046; nevertheless, 1.046 is within the .957-to-1.080 confidence bounds for the ObdR:driver ratio.

Table 8a: Passenger Cars, Belted Occupants: Fatality Risk Ratios Adjusted for Age and Gender, by Seating Position-Pairs
(FARS 1990 to 2014; with correction of belt use reporting by surviving drivers & RF)

Seating Position		Actual Fatalities		Actual Risk Ratio	Average Age		Percent Female		Adjusted Risk Ratio	95% Conf Bds	
Occupant 1	Occupant 2	Occ 1	Occ 2		Occ 1	Occ 2	Occ 1	Occ 2		Lower	Upper
Right front	Driver	15,837	14,632	1.082	47	47	60	38	.998	.971 to	1.030
Outboard rear	Driver	3,904	4,245	.920	31	40	54	42	1.017	.957 to	1.080
Left rear	Driver	1,678	1,841	.911	30	40	54	44	1.016	.945 to	1.094
Right rear	Driver	2,226	2,404	.926	32	40	55	40	1.014	.949 to	1.084
Center rear (lap)	Driver	152	201	.756	20	37	56	49	.895	.717 to	1.119
Center rear (3-pt)	Driver	107	149	.718	21	37	60	50	.838	.628 to	1.119
Outboard rear	Right front	2,937	3,148	.933	34	41	55	55	1.048	.990 to	1.110
Center rear (lap)	Right front	98	126	.778	21	38	56	61	1.166	.908 to	1.496
Center rear (3-pt)	Right front	84	93	.903	24	39	61	52	1.169	.825 to	1.656
Center rear (lap)	Outboard rear	160	163	.982	23	28	63	59	1.015	.804 to	1.281
Center rear (3-pt)	Outboard rear	113	130	.869	24	29	66	56	.924	.700 to	1.219

NOTE: **None** of the adjusted risk ratios are significantly different from 1.000.

Table 8b: LTVs, Belted Occupants: Fatality Risk Ratios Adjusted for Age and Gender, by Seating Position-Pairs
(FARS 1990 to 2014; with correction of belt use reporting by surviving drivers & RF)
(Adjusted risk ratios significantly different from 1.000 are shown in **bold print**)

Seating Position		Actual Fatalities		Actual Risk	Average Age		Percent Female		Adjusted Risk	95% Conf Bds	
Occupant 1	Occupant 2	Occ 1	Occ 2	Ratio	Occ 1	Occ 2	Occ 1	Occ 2	Ratio	Lower	Upper
Right front	**Driver**	**5,869**	**6,001**	**.978**	**47**	**48**	**59**	**36**	**.936**	**.905 to**	**.968**
Outboard rear	**Driver**	**2,238**	**3,054**	**.733**	**30**	**42**	**56**	**41**	**.886**	**.834 to**	**.943**
Left rear	Driver	1,088	1,359	.801	29	42	56	41	.980	.906 to	1.060
Right rear	**Driver**	**1,150**	**1,695**	**.678**	**30**	**42**	**56**	**40**	**.813**	**.746 to**	**.887**
Center rear (lap)	Driver	181	285	.635	25	41	54	44	.832	.651 to	1.065
Center rear (3-pt)	Driver	57	89	.640	26	41	60	42	.918	.585 to	1.440
Outboard rear	Right front	1,539	2,010	.766	33	44	57	59	.939	.851 to	1.035
Center rear (lap)	Right front	105	177	.593	25	41	54	58	.824	.616 to	1.102
Center rear (3-pt)	Right front	47	78	.603	28	45	66	61	.856	.563 to	1.303
Center rear (lap)	**Outboard rear**	**153**	**204**	**.750**	**26**	**29**	**50**	**53**	**.758**	**.602 to**	**.956**
Center rear (3-pt)	Outboard rear	61	74	.824	26	33	65	62	.931	.628 to	1.381

Table 8c: Cars and LTVs, Unrestrained Occupants: Fatality Risk Ratios Adjusted for Age and Gender, by Seating Position-Pairs (FARS 1990 to 2014; with correction of belt use reporting by surviving drivers & RF) (Adjusted risk ratios significantly different from 1.000 are shown in **bold print**)

Seating Position		Actual Fatalities		Actual Risk	Average Age		Percent Female		Adjusted Risk	95% Conf Bds	
Occupant 1	Occupant 2	Occ 1	Occ 2	Ratio	Occ 1	Occ 2	Occ 1	Occ 2	Ratio	Lower	Upper
				Passenger Cars – Both Occupants Unrestrained							
Right front	Driver	8,218	8,262	.995	30	30	40	26	1.000	.971 to	1.030
Outboard rear	Driver	3,984	4,637	.859	24	27	36	27	.947	.868 to	1.034
Left rear	Driver	1,798	2,127	.845	23	27	36	27	.949	.869 to	1.036
Right rear	Driver	2,186	2,510	.871	24	27	37	26	.946	.857 to	1.044
Center rear	Driver	555	710	.782	21	26	46	30	.880	.767 to	1.010
Outboard rear	Right front	3,061	3,440	.890	24	27	37	39	.945	.864 to	1.034
Center rear	Right front	456	511	.892	21	25	45	40	.994	.880 to	1.124
Center rear	**Outboard rear**	**1,108**	**1,235**	**.897**	**21**	**24**	**54**	**40**	**.883**	**.800 to**	**.976**
				LTVs – Both Occupants Unrestrained							
Right front	**Driver**	**3,359**	**3,869**	**.868**	**32**	**34**	**41**	**26**	**.887**	**.840 to**	**.937**
Outboard rear	**Driver**	**2,109**	**2,968**	**.711**	**25**	**31**	**41**	**28**	**.841**	**.741 to**	**.955**
Left rear	**Driver**	**954**	**1,425**	**.669**	**24**	**32**	**42**	**30**	**.835**	**.731 to**	**.953**
Right rear	**Driver**	**1,155**	**1,543**	**.749**	**25**	**31**	**40**	**26**	**.849**	**.736 to**	**.981**
Center rear	**Driver**	**498**	**782**	**.637**	**24**	**32**	**46**	**31**	**.785**	**.646 to**	**.954**
Outboard rear	Right front	1,649	1,954	.844	26	32	41	43	.972	.868 to	1.088
Center rear	Right front	373	490	.761	24	31	49	43	.899	.761 to	1.061
Center rear	**Outboard rear**	**968**	**1,316**	**.736**	**23**	**26**	**54**	**44**	**.734**	**.643 to**	**.838**

Table 8b presents the same list of comparisons as Table 8a, but for belted occupants of **LTVs**. Unlike passenger cars, there are significant differences between seating positions: between the right and left sides and between the front and rear seats. The adjusted risk ratio for RF passengers relative to drivers is .936, significantly lower than 1.000 (confidence bounds: .905 to .968). ObdR passengers have significantly lower risk than drivers, .886; nevertheless, when the ObdR passengers are subdivided, left and right, almost the entire risk reduction is for the right rear seat (.813 relative to the driver) whereas the left rear seat passenger has almost the same risk of the driver of that LTV (.980), after controlling for age and gender. It is not obvious why the seating positions on the right side of LTVs (but not cars) are safer than those on the left side of the same row. The next section will explore the issue and consider various hypotheses.

Although none of the individual belted CR:belted driver risk ratios in Tables 8a and 8b is **significantly** less than 1.000, all four point estimates are less than 1.000 (.895 for cars with CR lap belt only, .838 for cars with 3-point belt, .832 for LTVs/lap belt, and .918 for LTVs/3-point). The pattern suggests that overall belted CR passengers may be at somewhat lower risk than belted drivers of the same age and gender.

Table 8c compares the risk of two **unrestrained** occupants of the same vehicle. In passenger cars, the adjusted risk ratio for the RF passenger relative to the driver is exactly 1.000. The estimates for the adjusted risk ratios for each of the rear seating positions, relative to the driver, are all lower than 1, ranging from .880 for the CR to .949 for the left rear seats, but none of these are significantly lower than 1. The large safety advantage for the rear seat that Evans found in cars of 30 to 50 years ago (.738 for ObdR and .626 for CR relative to drivers) no longer exists today, even for unrestrained rear seat passengers relative to unrestrained drivers.[70]

In LTVs, every passenger seating position has significantly lower risk than the driver's seat, after controlling for occupants' age and gender. Adjusted risk ratios span from .785 for the CR seat to .841 for the ObdR seats to .887 for the RF seat. But even here, the benefits of the rear seat are less than what they were at the time of Evans' analysis. In Table 8c, for both passenger cars and LTVs, when both passengers were unrestrained, the center rear seat was safer than an outboard rear seat. For unrestrained passengers of LTVs (unlike belted passengers), there is little difference between the left rear (.835) and right rear (.849) seats.

2.6 A closer look at the right versus the left seats

Tables 8a and 8b showed that seating positions on the right side of LTVs, but not passenger cars, are safer for belted occupants than those on the left side of the same row. Detailed analyses of risk ratios by type of crash and/or type of LTV might help explain the results.

Different factors might be at work in the front and the rear seats. The overall effects in the front seat can be explained reasonably well by simply estimating risk ratios separately for each of four crash types: frontal impacts, side impacts (left or right), first-event rollovers, and other crashes (mostly rear impacts). The crash types are defined from the FARS variables IMPACT1, IMPACT2, MDAREAS, HARM_EV, and MAN_COLL as in NHTSA's 2015 evaluation of lives

[70] Evans, 1991, pp. 47-50.

saved by vehicle safety technologies.[71] (Less than 2 percent of the cases had insufficient information to define the crash type; they were excluded from these analyses.)

Table 9 compares the actual and adjusted risk ratios by crash type for belted RF passengers relative to belted drivers of cars and LTVs. Within each crash type, the adjusted risk ratios are remarkably similar for cars and LTVs. In frontals and rollovers, the RF passenger is a bit safer than the driver in both cars and LTVs; in side and rear impacts, the RF passenger has somewhat higher risk.

Table 9: Fatality Risk Ratios for Belted RF Passengers Relative to Belted Drivers, By Crash Type (FARS 1990 to 2014)

Crash Type	Percent of Driver Fatalities[72]	RF:Driver Fatality Risk Ratio Actual	Adjusted for Age/Gender
		Passenger Cars	
All crashes	100	1.082	.998
Frontal impact	42	1.065	.937
Side impact	46	1.173	1.132
First-event rollover	7	.832	.831
Rear/other	5	1.179	1.085
		LTVs	
All crashes	100	.978	.936
Frontal impact	48	.944	.905
Side impact	26	1.101	1.099
First-event rollover	22	.914	.915
Rear/other	5	1.115	1.140

These are plausible findings: among frontal impacts, head-on offset collisions of two vehicles approaching one another on a two-lane road are an especially severe type and, usually, the offset damage would be concentrated in front of the drivers. Left turns across approaching traffic result in especially severe side impacts and, usually, the impact will be near the RF passenger area of the turning vehicle.

[71] Kahane, 2015, pp. 350, 355, and 358.
[72] Among the driver-RF pairs included in this analysis.

However, the overall results are different for cars (.998) and LTVs (.936) simply because their distributions of crash types are different. Almost half of the belted fatalities in passenger cars take place in side impacts, where the RF passenger is at greater risk than the driver. LTVs, with their higher and stronger side structures, are relatively less vulnerable in side impacts, but more prone to rollover. A higher percentage of their fatalities are in frontals and rollovers, where the RF passenger is at less risk than the driver: thus, the overall RF:driver risk ratio is significantly less than 1.000, even though, within each individual crash type, the ratios are about the same as in cars.

The preceding factor – different crash distributions of cars and LTVs – would similarly affect the risk ratios of rear seat passengers. But in Table 8b, the difference between the right rear and left rear seats was even larger than the difference between the RF and driver seats. Perhaps there are additional factors at work for rear seat passengers. Table 10 compares the left rear:driver and right rear:driver risk ratios by crash type for belted occupants of cars and LTVs.

In passenger cars, the results are actually not so different from the front seat: the right rear passenger is slightly safer than the left rear passenger in frontal impacts (.825 versus .860), but slightly less safe in side impacts (1.029 versus .975), averaging out to nearly equal overall risk (1.014 versus 1.016). The only noteworthy difference from Table 9 is that rear seat passengers, both left- and right-side, are at much higher risk than drivers in rear impacts (3.765 and 3.161, respectively), as might be expected, because there is not much structure between the back of the car and the rear seats. But rear impacts account for only 4 percent of the driver fatalities and, even at these elevated risk levels, they still account for just a limited percentage of the rear seat passenger fatalities.

But in LTVs, the right rear passenger has a lower risk index than the left rear passenger in **all four** types of crashes. The advantage for the right side is especially large in frontal impacts and rollovers, consistent with Table 9, but appears even in side impacts (1.046 versus 1.120) and rear impacts (2.420 versus 2.697).

Table 10: Fatality Risk Ratios for Belted Left Rear and Right Rear Seat Passengers, Relative to Belted Drivers, by Crash Type (FARS 1990 to 2014)

Crash Type	Percent of Driver Fatalities[73]	Risk Ratios: Left Rear:Driver Actual	Left Rear:Driver Adjusted	Right Rear:Driver Actual	Right Rear:Driver Adjusted
Passenger Cars					
All crashes	100	.911	1.016	.926	1.014
Frontal impact	43	.806	.860	.793	.825
Side impact	44	.843	.975	.911	1.029
First-event rollover	8	.639	.669	.611	.669
Rear/other	4	3.458	3.765	3.028	3.161
LTVs					
All crashes	100	.801	.980	.678	.813
Frontal impact	46	.708	.847	.574	.672
Side impact	24	.937	1.120	.871	1.046
First-event rollover	26	.664	.832	.529	.622
Rear/other	4	2.020	2.697	1.754	2.420

A simple explanation would have been that LTVs have relatively few right-side impact crashes, but this is not the case: the ratio of right-side to left-side impacts, in FARS, is about the same in cars and LTVs. Likewise, the ratio of frontal impacts that have damage off-center to the right (IMPACT2 = 1) to off-center left (IMPACT2 = 11) is also about the same in cars and LTVs.

Another possible factor, at least in some vans and SUVs that have three or more rows of seats, is that the “right-side” seat in the second row is not directly adjacent to the door, but separated from it by an aisle. Furthermore, in some of those vehicles the aisle continues through the third row – e.g., if there are more than three rows (full-size vans) or if the third row has narrower seats, with space on the right side (some minivans and SUVs). Extra space on the right could mitigate some of the risk for belted right rear seat passengers relative to the left rear seat. By contrast, pickup trucks with 4-door cabs and SUVs with two rows of seats would tend to have the right rear and left rear seats about equidistant from the right and left doors, respectively.

[73] Among the driver-ObdR pairs included in this analysis.

Table 11 compares the left rear:driver and right rear:driver risk ratios for belted occupants of cars and four different configurations of LTVs: pickup trucks, SUVs with 2 rows, second row of vans or SUVs with 3 or more rows, and third row of vans or SUVs with 3 or more rows.

Table 11: Fatality Risk Ratios for Belted Left Rear and Right Rear Seat Passengers, Relative to Belted Drivers, by Vehicle Type/Seating Configuration (FARS 1990 to 2014)

		Risk Ratios			
Vehicle Type/ Seating Configuration	Percent of LTV Driver Fatalities[74]	Left Rear: Driver		Right Rear: Driver	
		Actual	Adjusted	Actual	Adjusted
Passenger car		.911	1.016	.926	1.014
Pickup truck (4-door)	16	.715	.905	.538	.718
2-row SUV	41	.757	.912	.662	.758
2nd row of 3+-row LTV	35	.857	1.064	.744	.895
3rd row of 3+-row LTV	8	.839	1.226	.769	1.194

In Table 11, the right rear passenger has a lower risk index than the left rear passenger in **all four** LTV seating configurations. The advantage for the right side over the left side of the rear seat is approximately the same in pickup trucks (no aisle), 2-row SUVs (no aisle) and the second row of LTVs with three or more rows of seats (usually has an aisle). The presence of an aisle or space on the right side does not appear to be a decisive factor in making the right rear seat safer than the left rear seat.

In other words, these analyses do not identify an additional factor that makes the right rear seats of LTVs safer than the left rear seats. Perhaps there isn't any. The crash distribution of LTVs (relatively few fatal side impacts, relatively many frontals and rollovers) already favors the right-side occupant in both the front and the rear seats; it may just be a coincidence, with our limited database, that the observed margin of safety for the right rear seat over the left rear seat is even higher than for the RF versus the driver seat.

Here is one more detailed analysis that compares rear to front seat occupants, rather than right side to left side. Table 12 presents adjusted risk ratios by of belted ObdR passengers relative to belted drivers by detailed vehicle type **and** crash type.

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[74] Among the driver-ObdR pairs included in this analysis.

Table 12: Fatality Risk Ratios for Belted ObdR Passengers Relative to Belted Drivers, By Vehicle Type/Seating Configuration and Crash Type (FARS 1990 to 2014)

Vehicle Type	Crash Type	Adjusted Risk Ratio
Passenger car	Frontal impact	.840
	Side impact	1.009
	First-event rollover	.665
	Rear/other	3.403
Pickup truck (4 doors)	Frontal impact	.715
	Side impact	.994
	First-event rollover	.625
	Rear/other	2.233
2-row SUV	Frontal impact	.832
	Side impact	.906
	First-event rollover	.577
	Rear/other	2.756
2nd row of 3+-row LTV	Frontal impact	.727
	Side impact	1.360
	First-event rollover	1.032
	Rear/other	2.286
3rd row of 3+-row LTV	Frontal impact	.634
	Side impact	1.477
	First-event rollover	1.102
	Rear/other	6.744

Table 12 shows that fatality risk in frontal impacts is lower for belted ObdR passengers than for belted drivers in every vehicle type, by about the same amount. The safety technologies introduced at the front seating positions, such as frontal air bags, belt pretensioners, and load limiters do not fully compensate for the great advantage that rear seat passengers have of being far away from the impact and far away from any intrusion. Indeed, the third-row occupant has even lower risk relative to the driver in frontal impacts (.634) than any of the second-row occupants. Nevertheless, the technologies introduced at the front seating positions appear to have at least partly offset the rear seat's intrinsic advantage. In 1975-to-1985 FARS data, the

ObdR:driver risk ratio in passenger cars was 0.62 in frontal impacts.[75] Table 12 shows it has deteriorated to 0.84 in our database.

In side impacts, risk is more or less the same for front- and rear-seat occupants, although there is some variation among the vehicle types. In rollovers, the rear seat is safer than the front seat in cars, pickup trucks, and SUVs with two rows of seats, but apparently not in LTVs with multiple rows of rear seats. Perhaps this is because the rear window is a relatively small ejection portal in vehicles with a single row of rear seats, but a larger one in a vehicle with multiple rows. In rear impacts, ObdR passengers of cars and of the third row of LTVs have the highest risk relative to drivers. The lowest relative risk is in pickup trucks and in the second row of LTVs with 3 or more rows: in both cases, there is space and protective structure (a truck bed or a third row of seats) behind the second-row occupant.

2.7 Trends of the ObdR:driver risk ratio in the latest vehicles

This section and the next one examine subsets of the database to address issues raised in the two recent analyses of fatality risk for rear seat passengers cited in Section 2.1.

Durbin et al., as discussed in Section 2.1, reported that the safety advantage of the rear seats over the front seat, for belted occupants, had vanished and, in fact, steadily turned into a disadvantage during the MY 2000-to-2013 timeframe. Qualitatively, this is not an implausible finding, because several technologies were introduced that benefited front seat occupants. The big push to equip front seat belts with pretensioners came in the model years shortly after 2000, whereas pretensioners in the rear seats have been limited to relatively few luxury vehicles as late as MY 2016. The performance of vehicle structures improved significantly in frontal impacts, as evidenced, for example, by the Insurance Institute for Highway Safety's offset-frontal test: in MY 2000, only 24 percent of new vehicles achieved a "good" overall rating, but by MY 2007, 86 percent of new vehicles were rated good. The improvement might especially benefit front seat occupants, who sit closer to the frontal impact sites than rear seat passengers. Side (torso) air bags were initially supplied at the front seats; usually later, if at all, at the rear seats.[76]

Quantitatively, however, Durbin's group found a large deterioration of the rear seat relative to the front seat: a risk ratio of 0.79 for belted rear seat passengers relative to RF passengers in MY 2000 to 2002, deteriorating to 1.10 in MY 2003 to 2006, and rising to 1.46 (significantly higher than 1.00) in MY 2007 to 2013.[77] These alarming numbers call for a second look – using the methods of this chapter, which are based directly on FARS data, rather than their complex method using FARS counts as a numerator and weighted NASS-CDS counts as a denominator. Additionally, the analysis here: (1) includes 2 more years of data (CY 2013 and 2014 FARS, which were not yet available for Durbin et al.); (2) compares ObdR passengers to drivers rather

[75] Evans (1991), Figure 3-6 on p. 50, average of the left rear and right rear in 12:00 impacts.
[76] Kahane (2013, November), pp. 1-3, 37-50; Bean, J.D., Kahane, C. J., Mynatt, M., Rudd, R.W., Rush, C.J., & Wiacek, C. (2009, September). *Fatalities in frontal crashes despite seat belts and air bags*. (Report No. DOT HS 811 202, pp. 6-8). Washington, DC: National Highway Traffic Safety Administration. Available at crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811102.
[77] Durbin et al., 2015, p. 189.

than RF passengers, to increase the number of occupant pairs available for the analysis;[78] and (3) corrects the belt use of the surviving drivers (as discussed in Section 2.3).

Table 13 shows the analysis results for belted ObdR relative to belted drivers for the full MY 1990-to-2015 database and for the subsets of MY 1990-to-2002, MY 2003-to-2006, and MY 2007-to-2015 vehicles. The first section is for passenger cars, the second for LTVs. The first lines in these sections (all MY 1990 to 2015) are copied from the "Outboard rear versus driver" lines of Tables 8a and 8b, respectively. The third section of Table 13 combines the data for cars and LTVs, as did the analysis by Durbin and colleagues.

Table 13: Trends in Fatality Risk Ratios for Belted ObdR Passengers Relative to Belted Drivers (FARS 1990 to 2014; with correction of belt use reporting by surviving drivers)

Model Years	Actual Fatalities: Obd R	Actual Fatalities: Drivers	Actual Risk Ratio	Adjusted Risk Ratio	95% Conf. Bounds: Lower	95% Conf. Bounds: Upper
Passenger Cars						
All MY	3,904	4,245	.920	1.017	.957 to	1.080
1990-2002	2,810	3,200	.878	.975	.908 to	1.046
2003-2006	672	664	1.012	1.119	.983 to	1.273
2007-2015	422	381	1.108	1.198	.989 to	1.453
LTVs						
All MY	2,238	3,054	.733	.886	.834 to	.943
1990-2002	1,383	2,013	.687	.854	.780 to	.934
2003-2006	608	756	.804	.946	.818 to	1.094
2007-2015	247	285	.867	.940	.726 to	1.216
Passenger Cars and LTVs Combined						
All MY	6,142	7,299	.841	.970	.922 to	1.020
1990-2002	4,193	5,213	.804	.938	.887 to	.991
2003-2006	1,280	1,420	.901	1.031	.934 to	1.138
2007-2015	669	666	1.005	1.100	.966 to	1.252

[78] The risk ratio for RF passengers relative to drivers changed little during the 1990-to-2015 timeframe.

Table 13 confirms a directional trend of improving safety for front seat occupants that is not matched by commensurate improvements for rear seat passengers. In passenger cars, the adjusted ObdR:driver risk ratio is .975 for MY 1990 to 2002, 1.119 for MY 2003 to 2006, and 1.198 for MY 2007 to 2015. In LTVs, the risk ratios are .854, .946, and .940, respectively. For cars and LTVs combined, the trend is .938, 1.031, and 1.100.

On the other hand, these trends hardly duplicate the alarming quantitative increase reported by Durbin et al. (from 0.79 in MY 2000 to 2002 to 1.46 in MY 2007 to 2013). In fact, the risk ratio for MY 2007 and onwards in Table 13 is only 1.100 for cars and LTVs combined, and it is not significantly greater than 1.000. None of the adjusted risk ratios in Table 13 is significantly larger than 1.000.

2.8 ObdR:RF risk ratios by passenger age group

Kuppa et al., as discussed in Section 2.1, found a safety advantage of the rear seats over the front seat, for belted passengers less than 50 years old during the CY 1993-to-2003 timeframe, but this advantage turned to a clear disadvantage for people over 50. Again, qualitatively, this is not an implausible finding, because analyses have repeatedly shown that the fatality-reducing effectiveness of belts in the rear seat drops significantly for older passengers, whereas the effectiveness of current belts in current front seats (where the belts are equipped with pretensioners and load limiters and, in addition, there are frontal air bags at that seating position) remains fairly steady across occupant age groups.[79]

Quantitatively, however, Kuppa, Saunders, and Fessahaie found rather alarming risk ratios in CY 1993-to-2003 FARS data: 1.446 for belted rear seat passengers 50 to 74 years old relative to belted RF passengers of that age in vehicles equipped with dual frontal air bags, deteriorating to a ratio of 2.320 for passengers 75 and older (both ratios are significantly higher than 1.00).[80] These analyses can be updated with our CY 1990-to-2014 database, which includes a much larger number of vehicles equipped with dual frontal air bags, including more recent vehicles. The analysis here also: (1) directly compares ObdR and RF passengers in the same vehicle, versus their more complex approach of separately computing rear passenger:driver and RF:driver ratios and then taking a ratio of ratios; and (2) corrects the belt use of the surviving RF passengers (as discussed in Section 2.3).

The logistic regression models used elsewhere in this chapter are not particularly helpful for comparing relative risk by occupant age groups. Instead, an approach similar to the one used by Evans in 1991 will work here:[81] limiting the analysis to ObdR:RF pairs of passengers who are more or less the same age. (As in all the analyses of this chapter, both are passengers of the same vehicle, both need to be at least 5 years old, and at least one or possibly both were a fatality.) This decreases the usable data, but has the advantage that the working database will have similar univariate distributions of age for the ObdR and the RF passengers. It becomes unnecessary to adjust for age differences. Likewise any age group of ObdR passengers within this working database will be paired with RF passengers of about the same age distribution. However, to

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[79] Morgan, 1999, p. 48; Kahane, 2013, pp. 218-223; see also Section 1.6 of this report.
[80] Kuppa, Saunders, & Fessahaie, 2005, Figure 1 and Appendix C.
[81] Evans, 1991, pp. 47-50.

enlarge the working database, ObdR:RF pairs will be included if their ages are within 5 years (whereas Evans limited to ±3 years). Also, at least initially, unlike Evans, we will not require the pairs to be of the same gender – because the univariate gender distributions are fairly similar for belted ObdR and RF passengers (see the "outboard rear – right front" rows of Tables 8a and 8b), whereas Evans compared passengers to drivers, where the percentage of females is substantially lower. Every vehicle in the analysis must be equipped with a frontal air bag at the RF seat and, if the RF occupant is less than 10 years old, it must be a CAC air bag, as in all the other analyses of this chapter.

The working database, passenger cars and LTVs combined, comprises 3,467 ObdR:RF pairs within 5 years of one another's age. Among them, there were 2,003 ObdR passenger fatalities and 2,046 RF passenger fatalities, an actual risk ratio of .979. That is almost identical to the .970 adjusted risk ratio, using the logistic regression approach, for the entire CY 1990-to-2014 database (9th row of Table 13) – evidence that the two analytic methods produce similar results. In the working database, the RF passengers average 31.90 years old and the ObdR passengers, 31.55 years: almost the same age distribution. The ObdR passengers are more often female than the RF (50% versus 44%), but this is a negligible bias, as the relationship of gender with fatality risk is far less than the effect of age.

Table 14a presents initial estimates of risk ratios when the working database is subdivided into three groups, based on the age of the ObdR passengers. (The RF passengers in these ObdR:RF pairs are within 5 years of the ObdR passenger in their vehicle; thus, for example, if the ObdR passengers are 50 or older, the RF passengers in those pairs would be at least 45 years old.)

Table 14a: Passenger Cars and LTVs Combined – Initial Fatality Risk Ratios
For Belted ObdR Passengers Relative to Belted RF Passengers of Similar Age
(FARS 1990 to 2014; with correction of belt use reporting by surviving drivers)

ObdR Age	Actual Fatalities		Actual Risk Ratio	Average Age		Percent Female	
	Obd R	RF		ObdR	RF	ObdR	RF
5 to 15	337	321	1.050	12.8	14.6	49	49
16 to 49	1,171	1,284	.912	22.2	22.3	41	39
50 and older	495	441	1.122	70.9	70.9	76	53

In the second row in Table 14a, belted ObdR passengers 16 to 49 years old, the ObdR and RF passengers in the pairs match up almost perfectly on average age (22.2 versus 22.3) and quite close on percent female (41 versus 39). This population of pairs is "self-controlling" on age and gender and the actual risk ratio, .912, requires no further adjustment. In this age group, over the range of MY 1990-to-2015 cars and LTVs combined, the ObdR seat is about 9 percent safer than the RF seat for belted passengers.

The matching is not quite as satisfactory in the other two rows. The young ObdR and RF passengers have exactly the same gender distribution (49% females). But the RF passengers are, on the average, almost 2 years older (14.6 versus 12.8) – because most pre-teen passengers sit in the rear seats and, in addition, the analysis has excluded RF passengers 10 or younger if the seat is not equipped with a CAC air bag. Closer age-matching for the young passengers is accomplished by: (1) Requiring that the RF be at most 3 years older (but can still be up to 5 years younger) than the ObdR; (2) If the ObdR is 15 years old, the RF may not be older than 17.

The older passengers match up well on age (the average is 70.9 for both ObdR and RF), but a substantially higher percentage of the ObdR passengers are female (76% versus 53%). The disparity is avoided by excluding a randomly selected 45 percent of the pairs in which the RF passenger is male and the ObdR passenger is female.

The upper section of Table 14b presents refined estimates of the risk ratios after limiting the working database to provide better age or gender matching for the young and old occupant groups. The lower section focuses on more recent cars and LTVs, MY 2003 and later.

The ObdR and RF passengers match up well on age and gender throughout Table 14b. For the young passengers, the average ages are within a year (13.1 versus 14.1 for MY 1990 to 2015, 12.5 versus 13.4 for MY 2003 to 2015) – reasonably close without dropping too many cases. For the older passengers, the percentage of females is now about the same at both seating positions.

Table 14b: Passenger Cars and LTVs Combined – Refined Fatality Risk Ratios For Belted ObdR Passengers Relative to Belted RF Passengers of Similar Age (FARS 1990 to 2014; with correction of belt use reporting by surviving drivers)

ObdR Age	Actual Fatalities Obd R	Actual Fatalities RF	Actual Risk Ratio	Average Age ObdR	Average Age RF	Percent Female ObdR	Percent Female RF
			MY 1990 to 2015				
5 to 15	253	243	1.041	13.1	14.1	51	49
16 to 49	1,171	1,284	.912	22.2	22.3	41	39
50 and older	407	351	1.160	71.0	70.9	70	66
			MY 2003 to 2015				
5 to 15	67	67	1.000	12.5	13.4	45	47
16 to 49	431	414	1.041	23.0	23.0	43	37
50 and older	169	140	1.207	71.1	70.8	68	66

For young passengers (but excluding any RF passengers 10 or younger unless the RF seat was equipped with a CAC air bag), the risk ratio is 1.041 over the entire MY 1990-to-2015 range and exactly 1.000 for MY 2003 to 2015. The 1.041 ratio is not significantly different from 1. It is based on 253 ObdR and 243 RF fatality cases: 253 out of 496 is within the acceptance range of a binomial distribution with p = .5. In other words, with CAC air bags and with a population of young passengers that is primarily late pre-teen or early teen – as evidenced by average ages in the 5-to-15 age groups in Tables 14a and 14b such as 13.1, 14.1, 12.5, and 13.4; only 24 percent of these young passengers are 12 years old and younger, whereas 76 percent are 13 to 15 years old – this data does not support any new conclusion that the ObdR seat is safer than the RF seat or vice versa. As part of the agency's ongoing evaluation program, future analyses will address updated restraint system effectiveness and the relative risk of the various seating positions for child passengers younger than 13. NHTSA continues to recommend that child passengers 12 years old and younger ride in the rear seats, protected by an age-appropriate restraint system.

For passengers 16 to 49 years old, the data shows little difference between the ObdR and RF seating positions. The risk ratio, consistent with the analyses of Section 2.7, has changed from .912 favoring the ObdR for the whole working database to 1.041 in the MY 2003 and later cars and LTVs. However, the 1.041 is not significantly greater than 1.000.

For belted passengers older than 50, a group that averages 71 years old in our working database, the analysis shows somewhat higher risk for the ObdR seating position than the RF: the ratio is 1.160 for the entire database and 1.207 for MY 2003 and later. The 1.160 is significantly greater than 1.000, but the 1.207, based on considerably less data, is not. In other words, there may be some added risk when older passengers sit in the ObdR rather than the RF seat, but hardly to the alarming extent estimated by the earlier analysis of CY 1993-to-2003 FARS data (risk ratios of 1.446 for passengers 50 to 74 years old and 2.320 for passengers 75 and older).

2.9 Summary

Statistical analyses of the FARS 1990-to-2014 database estimate "adjusted fatality risk ratios" that measure the relative risk, in all crash modes combined, for belted occupants of the same age and gender at two different seating positions. If the risk for a belted driver is indexed to 1.000, the adjusted risk ratios for belted passengers at the various seating positions are shown in Table 15:

Table 15: Fatality Risk Ratios for Belted Occupants, by Seating Position
(FARS 1990 to 2014; adjusted for occupant age and gender)

Seating Position	Adjusted Fatality Risk Ratio	95% Confidence Bounds
	PASSENGER CARS	
Driver	indexed to 1.000	
Right front	.998	.971 to 1.080
Outboard rear	1.017	.957 to 1.080
Left rear	1.016	.945 to 1.094
Right rear	1.014	.949 to 1.084
Center rear (3-point belted)	.838	.628 to 1.119
	LTVs	
Driver	indexed to 1.000	
Right front	.936	.905 to .968
Outboard rear	.886	.834 to .943
Left rear	.980	.906 to 1.060
Right rear	.813	.746 to .887
Center rear (3-point belted)	.918	.585 to 1.440

In passenger cars, the adjusted risk index does not differ significantly from 1.000 at any of the various seating positions. At the center rear seat, the point estimate is somewhat lower (.838), but due to the limited data at that seating position, it is not significantly lower than 1.000. Belted occupants of LTVs have significantly lower fatality risk, relative to the driver, at the right front seat (.936), the outboard rear seats (.886) and, especially, the right rear seat (.813).

The distribution of crash types in LTVs is different from cars, in a manner that could favor both the right-side and the rear-seat LTV occupants (and, thus, doubly favor the right rear seat passenger). Side impacts – where right-side occupants may be at higher risk because of the exceptional severity of left-turn-across-traffic collisions – account for a lower proportion of fatalities in LTVs than in cars, because LTVs often have higher and stronger side structures than cars. Frontal impacts are relatively more prevalent in LTVs. Front-seat occupants are at higher risk in frontal impacts because they sit closer to the impact point and their section of the occupant compartment can be compromised due to intrusion; left-side occupants may also be at higher risk because of the severity of head-on, offset collisions of two vehicles approaching one another, where the damage tends to be concentrated towards the left front.

Appendix

Initial Model Year for 3-Point Belts in the Center Rear Seat, MY 1994-2007

There were no 3-point belts in center rear seats in the United States before MY 1994. All cars and LTVs with center rear seats were equipped with 3-point belts in MY 2008 and later. The following table lists the first year that a make-model was equipped with 3-point belts (and continued to be equipped with them in all subsequent years). Any make-models not listed here either: (1) had been discontinued by 2008 and never had 3-point belts, (2) did not receive 3-point belts until 2008, (3) were not sold until 2008 or later, or (4) do not have a center rear seat. The numbers preceding the make-model names are the make-model codes generated by the VIN-decode programs that have been developed by NHTSA's Evaluation Division through MY 2013.

Sources: www.safercar.gov and www.cars.com.

Make-Model Code and Name		First MY With 3-Point CR Belts
2001 Jeep Compass		always had 3-point belts
2312-2313 Jeep Grand Cherokee		2005
2316-2317 Jeep Commander		2005
2320-2323 Jeep Wrangler		2007
2342-2343 Jeep Liberty		always
2352-2353 Jeep Patriot		always
3307 Hummer H3		always
3313-3317 Hummer H2		2006
6… Chrysler passenger cars		2001
6052 Chrysler PT Cruiser		always
6054 Chrysler Pacifica		2007
6312-6317 Chrysler Aspen		always
6400-6409 Chrysler Town & Country		2006
7… Dodge passenger cars		2001
7021 Dodge Magnum		always
7204-7205 Dodge Dakota	crew cab	2005
7214-7215 Dodge Ram Pk 1500	crew cab	2002
7224, etc. Dodge Ram Pk 2500	crew cab	2003
7234, etc. Dodge Ram Pk 3500	crew cab	2003
7312-7313 Dodge Durango		2004
7342-7343 Dodge Nitro		always
7400-7409 Dodge Caravan		2006
9020 Plymouth Neon		2001

Make-Model Code and Name		First MY With 3-Point CR Belts
10… Eagle		never
11… Sprinter		2003
12016 Ford Crown Victoria		2003
12017 Ford Taurus	sedan	1997
	others	2005
12021 Ford 500		always
12022 Ford Freestyle		always
12024 Ford Edge		always
12035 Ford Contour		1998
12037 Ford Focus		always
12… All other Ford passenger cars		2006
12212-12215 Ford F-150 Pk	ext & crew cab	2004
12300-12308 Ford Explorer (incl Sport-Trac)		2003
12312-12317 Ford Expedition		2003
12342-12347 Ford Escape		2005
12402 Ford Wind/Freestar		2004
13001 Lincoln Town Car		1998
13005 Lincoln Continental		1996
13… All other Lincoln		2003
14016 Mercury Grand Marquis		2003
14017 Mercury Sable	sedan	1997
	others	2005
14020 Mercury Montego		always
14037 Mercury Mystique		1998
14039 Mercury Marauder		always
14302-14308 Mercury Mountaineer		2003
14342-14347 Mercury Mariner		2005
14402 Mercury Monterey		always
14… All other Mercury		2006
18002 Buick LeSabre		2000
18022 Buick LaCrosse		always
18302-18303 Buick Rainier		always
18356-18357 Buick Rendezvous		always
18454-18547 Buick Teraza		always
18… All other Buick		2006
19003 Cadillac DeVille		2000
19014 Cadillac Seville		1998
19017 Cadillac Catera		1998
19… All other Cadillac		2003

Make-Model Code and Name		First MY With 3-Point CR Belts
20002 Chevrolet Impala		2000
20016 Chevrolet Cavalier		2003
20022 Chevrolet Cobalt		always
20023 Chevrolet HHR		always
20032 Chevrolet Prizm		1998
20036 Chevrolet Monte Carlo		2002
20037 Malibu/Classic CG 18068		never
20037 Malibu CG 18078		2004
20037 Malibu/Maxx CG 18079		2004
20039 Chevrolet Aveo		always
20… All other Chevrolet passenger cars		2006
20204-20205 Chev Colorado crew cab		2004
20210-20235 Chev Silverado	crew cab	2004
	ext cab	2007 if the new design
20300-20303 Chevrolet Blazer		never
20302-20307 Chevrolet Trailblazer		always
20312-20313 Chevrolet Tahoe		2003
20322-20327 Chevrolet Suburban		2003
20338-20339 Chevrolet Equinox		always
20342-20347 Chev Avalanche		2003
20410-20436 Chevrolet G Van		2004
20452-57 Chevrolet Venture		never
20452-57 Chevrolet Uplander		always
21022 Olds Aurora		2001
21302-21303 Olds Bravada		2002
22002 Pontiac Bonneville		2001
22016 Pontiac Sunfire		2003
22020 Pontiac Grand Prix		2004
22032 Pontiac Vibe		always
22… All other Pontiac passenger cars		2006
22338-22339 Pontiac Torrent		always
22352-22353 Pontiac Aztek		always
22452-57 Pontiac Montana (not SV6)		never
22452-57 Pontiac Montana SV6		always
23008 GMC Acadia		always
23204-23205 GMC Canyon crew cab		2004
23210-23235 GMC Sierra	crew cab	2004
	ext cab	2007 if the new design
23300-23303 GMC Jimmy		never
23302-23307 GMC Envoy		always
23312-23319 GMC Yukon		2003
23322-23229 GMC Yukon XL		2003
23410-23436 GMC Savana		2004

Make-Model Code and Name		First MY With 3-Point CR Belts
24005 Saturn L		2001
24362-24366 Saturn Vue		always
24… All other Saturn		2003
30040 VW Jetta	cg 30010 only	1999
	all	2000
30042 VW Golf/GTI		2000
30046 VW Passat		1999
30048 VW Phaeton		always
30313 VW Touareg		always
30… All other VW		2006
32030 Audi A6/S6		2002
32040 Audi S4/S6		2002
32042 Audi A6	4-door sedan	1998
	others	1999
32043 Audi A4	station wagon	1998
	others	2002
32044 Audi A8		2000
32046 Audi S8		2002
32047 Audi Allroad		always
32… All other Audi		2003
33035 Mini-Cooper		no center rear seat
34034 BMW 300	station wagon	2001
	all others	2003
34035 BMW 500		1997
34037 BMW 700		2002
34303 BMW X3		always
34313 BMW X5		2004
34… All other BMW		2005
35039 Nissan Maxima		1999
35043 Nissan Sentra		2000
35047 Nissan Altima		2000
35049 Nissan Murano		always
35204-35205 Nissan Frontier	crew cab	2005
35212-35215 Nissan Titan		always
35300-35303 Nissan Pathfinder		2005
35312-35313 Nissan Armada		always
35322-35323 Nissan Xterra		2005
35452 Nissan Quest		2001
35… All other Nissan		2006

Make-Model Code and Name		First MY With 3-Point CR Belts
37031 Honda Civic		2001
37032 Honda Accord		1998
37039 Honda Fit		always
37205 Honda Ridgeline		always
37302-37303 Honda CR-V		2002
37322-37323 Honda Pilot		2003
37402 Honda Odyssey		1999
38204-38205 Isuzu crew cab pickups		2004
38302-38307 Isuzu Ascender		always
39032 Jaguar XJ		1997
39034 Jaguar S Type		always
39… All other Jaguar		2003
41035 Mazda Protégé		1999
41037 Mazda 626		1998
41… All other Mazda passenger cars		2003
41053 Mazda CX-7		always
41312-41313 Mazda CX-9		always
41342-41347 Mazda Tribute		2005
42043 Mercedes S		2000
42048 Mercedes E		1999
42302-42307 Mercedes ML		2000
42… All other Mercedes		2001
45313 Porsche Cayenne		2004
47031 Saab 900		1994
47… All other Saab		1999
48034 Subaru Legacy		2000
48… All other Subaru		2001
49032 Toyota Corolla		1998
49040 Toyota Camry		1997
49043 Toyota Avalon		1996
49044 Toyota Camry Solara	coupe	1999
	convertible	no center rear seat
49045 Toyota Echo		always
49046 Toyota Prius		always
49… All other Toyota cars (except convertibles)		2003
49204-49205 Toyota Tacoma Pk	crew cab	2005
49212-49215 Toyota Tundra Pk	ext & crew cab	2004
49302-49303 Toyota 4Runner		2003

Make-Model Code and Name	First MY With 3-Point CR Belts
49313 Toyota Land Cruiser	1998
49322-49326 Toyota RAV4	2001
49342-49347 Toyota Highlander	always
49352-49353 Toyota Sequoia	always
49362-49363 Toyota FJ Cruiser	always
49402-49303 Toyota Sienna Van	2004
51… Volvo	1994
52034 Mitsubishi Galant	2000
52040 Mitsubishi Diamante	1997
52046 Mitsubishi Lancer	always
52047 Mitsubishi Outlander	always
52312-13 Mitsubishi Endeavor	always
52333 Mitsubishi Montero	2003
52336-37 Mitsubishi Montero Sport	2002
52… All other Mitsubishi	2005
53033 Suzuki Aerio	2003
53… All other Suzuki passenger cars	2004
53336-53337 Suzuki Grand Vitara	2006
53338-58339 Suzuki XL-7	2004
54035 Acura TL	1999
54036 Acura RL	1998
54039 Acura TSX	always
54323 Acura MDX	always
54… All other Acura	2006
55033 Hyundai Sonata	1999
55035 Hyundai Elantra	2002
55036 Hyundai Accent	2003
55038 Hyundai XG300	2002
55… All other Hyundai	2005
58032 Infiniti Q45	1999
58033 Infiniti G20	1999
58034 Infiniti J30	1999
58035 Infiniti I30	1999
58036 Infiniti I35	always
58037 Infiniti G35	always
58038 Infiniti M45	always
58039 Infiniti FX35	always
58… All other Infiniti	2004
59031 Lexus ES	1997

Make-Model Code and Name		First MY With 3-Point CR Belts
59032 Lexus LS		1997
59034 Lexus GS		1998
59313 Lexus LX		1998
59… All other Lexus		2001
62307 Land Rover Discovery		1999
62… All other Land Rover		2002
63033 Kia Spectra	cg 63008 only	2004
	all	2005
63034 Kia Optima		2002
63035 Kia Amanti		always
63302-63303 Kia Sportage		2005
63312-63313 Kia Sorento		always
63… All other Kia		2006
64032 Daewoo Nubira	sedan	2000
64… All other Daewoo		never
67… Scion		always

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