Special issue: crash compatibility

STATUS REPORT

INSURANCE INSTITUTE FOR HIGHWAY SAFETY

Vol. 33, No. 1, February 14, 1998

Crash compatibility

How vehicle type, weight affect outcomes

A Geo Metro crests a hill on a winding rural road and meets an oncoming Dodge Ram pickup traveling in the wrong lane. Neither driver swerves, and the two vehicles collide head on.

It's easy to guess the small car will fare worse in this encounter. After all, the pickup is more than twice as heavy. All else being equal, people in large and/or heavy vehicles are less likely to be injured than those in small and/or light ones. This is true in both single- and multiple-vehicle crashes. In two-vehicle crashes like this fictitious one, both vehicles' weights — especially if they're very different — strongly influence crash outcome. Heavy vehicles protect their occupants in two-vehicle crashes but make things worse for people in lighter vehicles.

Weight by itself isn't the only, or even necessarily the major, factor influencing crash outcome. Other design characteristics are involved.

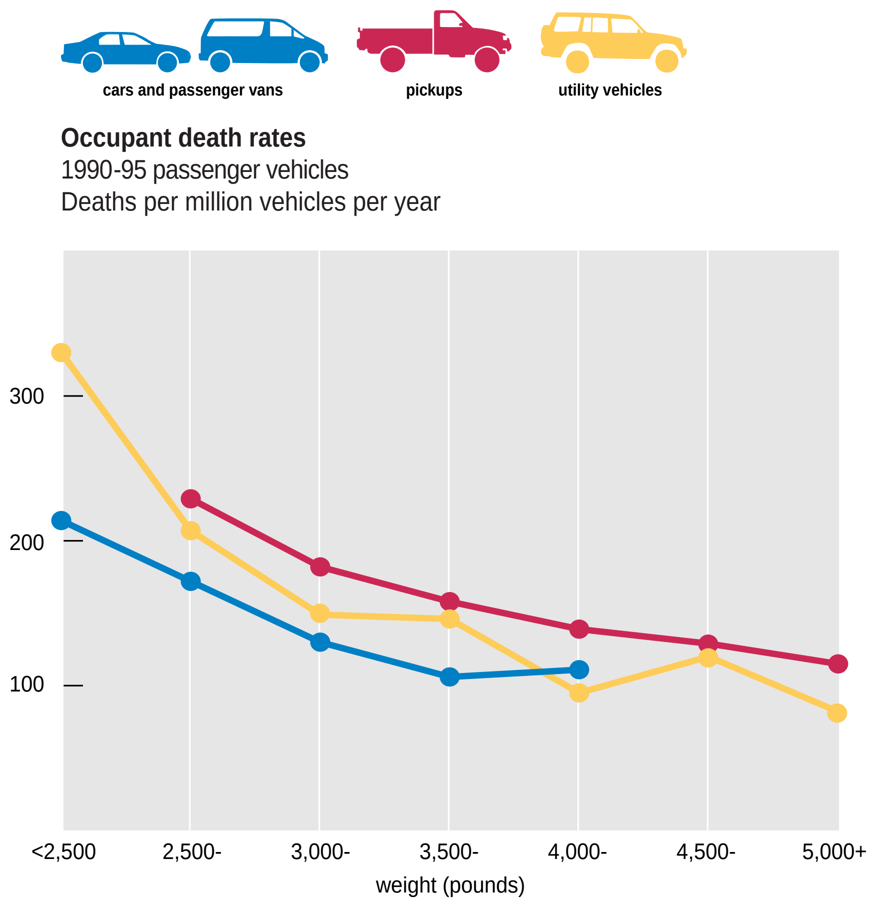


Figure 1

These include vehicle stiffness and geometric design. The more these differ between vehicles, the more incompatible they are in terms of crashworthiness.

Incompatibilities among passenger vehicles aren't new. Small cars and large pickups were popular in the 1970s and '80s, too. But the rapid growth in utility vehicle sales in recent years has raised new concerns about this issue, which some call "vehicle aggressivity."

The Institute has taken a comprehensive look at passenger vehicle occupant death rates in relation to vehicle type, weight, and crash configuration, exploring the extent to which incompatibility contributes to the overall problem of deaths in crashes. This analysis looks at occupant deaths in 1990-95 model passenger vehicles during calendar years 1991-96.

Also examined are occupant deaths in the *other* vehicles in two-vehicle crashes — that is, vehicles in collisions with the passenger vehicles studied. Crashes that resulted in pedestrian, bicyclist, or motorcyclist deaths are included as well to assess the complete fatality picture for the 1990-95 models.

Results are presented separately for cars (including passenger vans, often called minivans), pickups, and utility vehicles and by weight within each of these vehicle types. Death rates were computed from counts of deaths in various crash configurations involving 1990-95 models and their registration counts. Rates are deaths involving a particular vehicle type and weight class per million of that type/weight combination registered per year. Crash data are from the federal Fatality Analysis Reporting System. Vehicle registration numbers are from R.L. Polk.

The results reflect differences beyond vehicle factors, such as use patterns and where and how vehicles are driven. Pickups, for example, are more likely to be in rural areas where fatal crashes are more prevalent. Nevertheless, these analyses show important relations between passenger vehicle characteristics, fatal crashes, and vehicle incompatibility in crashes.

Occupant death rates: As vehicle size or weight decreases, the number of occupants killed in crashes increases. The lightest passenger cars, pickups, and utility vehicles, which also are the smallest, typically have the highest death rates, and the heaviest and largest have the lowest. Although weight and size are closely related, they can affect occupant safety differently, especially in two-vehicle crashes. For this analysis, the Institute focused on

vehicle weight because weight differences are major contributors to two-vehicle crash incompatibility.

Relationships between passenger vehicle weight and occupant death rates are well documented, but differences among various passenger vehicle types aren't so well known. In each weight class, pickups have the highest occupant death rates, and cars have the lowest. The lightest utility vehicles (there are no pickups in this weight class) have by far the highest death rates. There are 330 deaths per million vehicles per year among utility vehicles weighing less than 2,500 pounds. This compares with 214 deaths per million per year for cars in the same weight class.

Single-vehicle crashes: It's often claimed that lighter vehicles have higher death rates primarily because they're at a disadvantage in collisions with heavier vehicles. Wrong. Even when light vehicles are in crashes not involving other vehicles, they have higher occupant death rates than heavy ones. Within each weight class, pickups and utility vehicles have much higher single-vehicle crash death rates than cars. Utility vehicles weighing

Occupant death rates
1990-95 passenger vehicles
Deaths per million vehicles per year

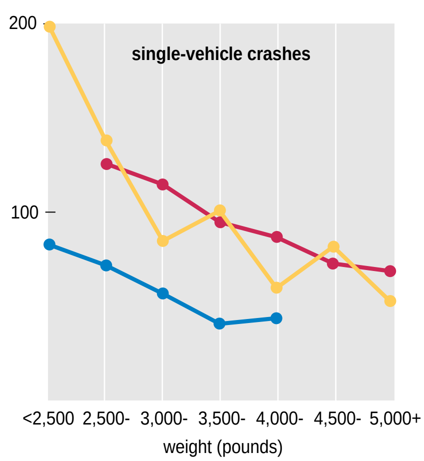


Figure 2

Pickups and utility vehicles have high property damage liability losses

Pickups and utility vehicles have below average insurance claims losses under collision coverage but higher than average property damage liability losses. This is a main finding of a new Highway Loss Data Institute (HLDI) study of automobile insurance claims payments for 1995-97 model passenger vehicles.

Collision coverage reimburses for damage to the insured person's vehicle, usually when the driver is assumed to be at fault. Property damage liability coverage insures against the physical damage the insured person's vehicle does to another vehicle or to other property in a collision when the insured driver or vehicle is deemed at fault.

The HLDI study found distinct differences between the loss patterns of pickups and utility vehicles and those of cars and passenger vans.

Pickups and utility vehicles, especially the largest utility vehicles, have lower than average collision coverage losses but higher than average property damage liability losses. Among cars, however, collision losses range from 20 percent above average for small cars to 26 percent below average for large cars. Cars' property damage losses are all about or below average. Passenger vans have below average property damage liability losses, too.

The average property damage liability loss payment for all passenger vehicles is $81, which in relative terms equals 100 and represents the average loss result of all vehicles. So the result of 132 for large utility vehicles is nearly one-third higher than average.

For collision coverage, the average loss payment per insured vehicle year for all vehicles is $224 — 100 in relative terms for all vehicles in this category. With a relative collision loss of 60, large utility vehicles have the lowest overall collision losses — 40 percent below average.

Collision and property damage liability insurance losses by vehicle type and size class, 1995-97 models, average loss payment per insured vehicle year

Vehicle Type and Size		Collision $	Collision relative	Property Damage Liability $	Property Damage Liability relative
Cars	small	$268	120	$79	98
	midsize	$250	112	$73	90
	large	$206	92	$62	77
Passenger vans		$165	74	$64	79
Pickups	small	$200	89	$101	125
	standard	$168	75	$95	117
Utility vehicles	small	$211	94	$94	116
	midsize	$212	95	$98	121
	large	$135	60	$107	132
All passenger vehicles		$224	100	$81	100

less than 2,500 pounds have a death rate more than twice the rate for passenger cars in the same weight class.

Single-vehicle crashes account for 41 percent of all deaths in passenger cars, but they account for 65 percent of all deaths in utility vehicles. In pickups, single-vehicle crashes account for about 59 percent of all occupant deaths. Much of the high occupant death rates in single-vehicle crashes — for utility vehicles in particular but also for pickups — is due to the greater likelihood of these vehicles being in rollover crashes. Nearly 80 percent of occupant deaths in single-vehicle crashes of utility vehicles involve rollovers. This compares with 48 percent for cars and 62 percent for pickups.

Two-vehicle crashes: In two-vehicle crashes, relationships between vehicle weight and death rates still are strong, but differences among vehicle types in each weight class are less pronounced. Cars and pickups have similar occupant death rates, but utility vehicles have somewhat lower two-vehicle death rates in each weight class. The two-vehicle occupant death rate for utility vehicles weighing 2,500-3,000 pounds is 54 compared with rates of 83 for people in cars and 89 in pickups.

Other vehicle types in crashes: How frequently are different vehicle types involved as the *other* vehicle in two-vehicle crashes with occupant deaths in 1990-95 passenger vehicles (figures 3, 4)?

Just under 50 percent of the occupant deaths in cars in two-vehicle crashes involve another car. This percentage ranges from 48 percent for the lightest cars with occupant deaths to 40 percent for the heaviest ones. Pickups are 20-21 percent

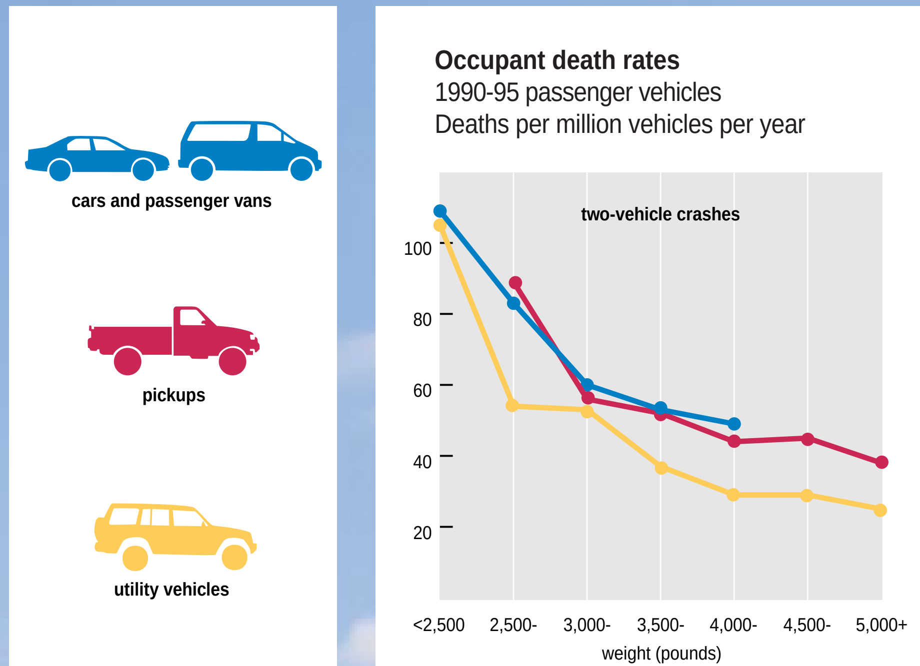


Figure 3

and utility vehicles 7-8 percent of the other vehicles, regardless of the weight class of the cars with the occupant deaths.

Medium and heavy trucks frequently are the other vehicles involved in crashes when people in cars die. Trucks are the other vehicles in 17 percent of deaths in the lightest cars and 26 percent of deaths in the heaviest ones.

Overall, cars are less likely to be the other vehicles in two-vehicle crashes when people die in pickups or utility vehicles. Cars are the other vehicles in 31 percent of deaths in pickups, 40 percent of deaths in utility vehicles, and 45 percent of deaths in cars in two-vehicle crashes.

Medium and heavy trucks are the other vehicles in 32 percent of deaths in pickups and 26 percent of deaths in utility vehicles in two-vehicle crashes. For all types of passenger vehicles, 20-32 percent of occupant deaths in two-vehicle crashes involve medium and heavy trucks. This reflects the huge weight mismatches in such crashes. Even the heaviest pickups and utility vehicles are light compared with large trucks. Despite this, large trucks can be modified to be more compatible in crashes with passenger vehicles (see page 8).

Other-vehicle occupant deaths: The risk posed by other vehicles to 1990-95 passenger vehicle occupants in collisions involving two-vehicles tells only part of the compatibility story. What is the risk to the occupants of *other* vehicles that collide with 1990-95 passenger vehicles?

Not surprisingly, the heaviest passenger vehicles have the *(cont'd on p. 6)*

Mix of other vehicles in two-vehicle crashes

1990-95 passenger vehicles

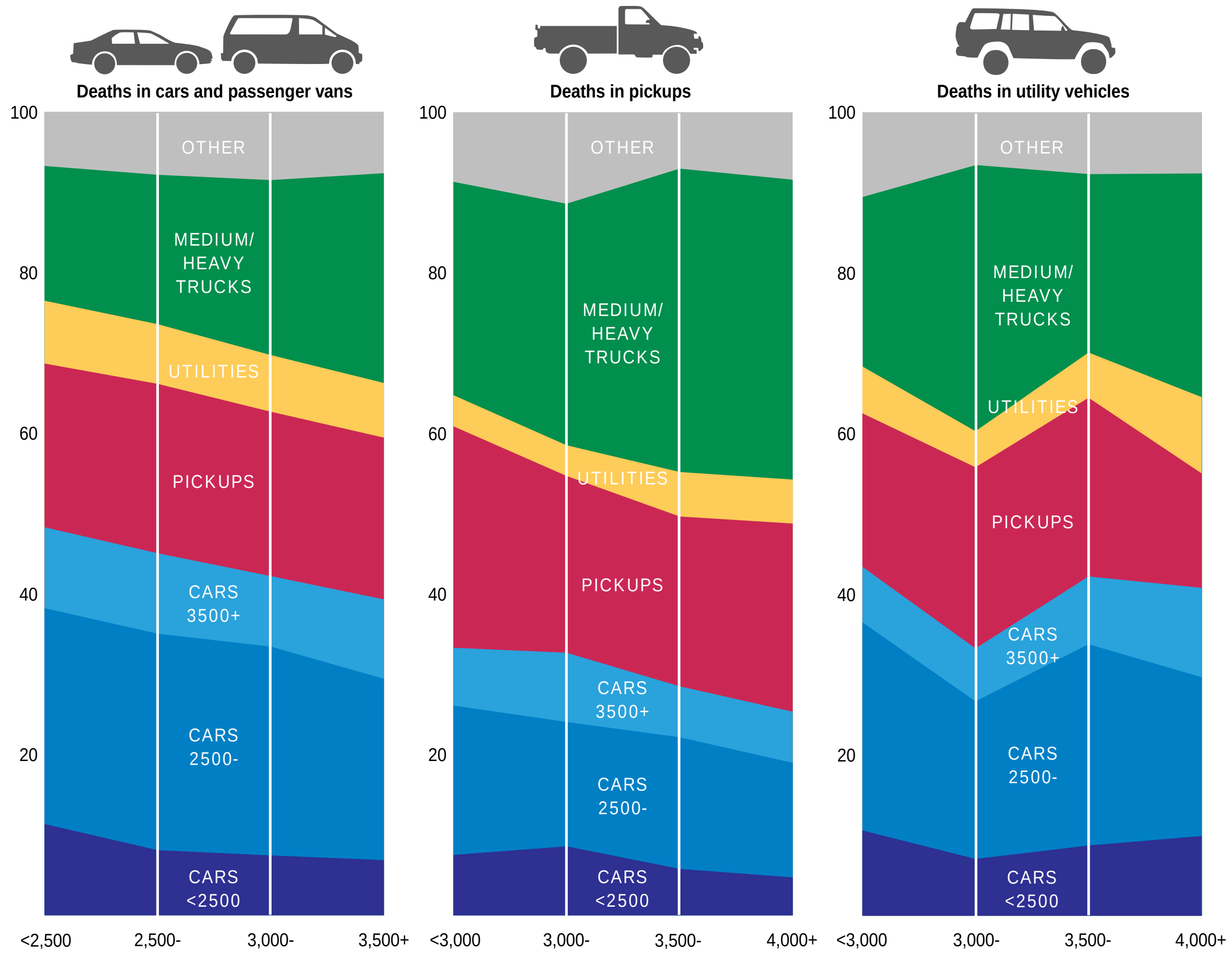


Figure 4

Heavy utility vehicle registrations rise as heavy car popularity falls

The U.S. passenger vehicle fleet is substantially different today than it was 20 years ago when heavy cars dominated the road and utility vehicles were nearly nonexistent.

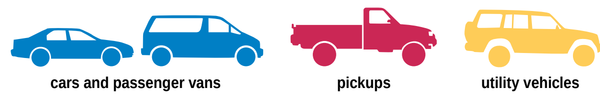
Among all new passenger vehicle registrations, the proportion of cars declined from 84 percent in the 1975 model year to 64 percent of the 1995 models, with passenger vans accounting for another 8 percent. The mix of cars by weight also has changed dramatically. Forty-three percent of the 1975 model passenger vehicles registered were cars weighing more than 3,500 pounds. In contrast, this proportion had dropped to 9 percent by the 1995 model year.

Pickup registrations remained a relatively stable 14-16 percent of new passenger vehicle registrations during the same 20-year period, but in recent years utility vehicle registrations have jumped. In the 1980 model year, utility vehicles were only 1 percent of passenger vehicle registrations. By the 1995 model year they accounted for 12 percent.

Counts for 1996 and ’97 models aren’t available yet, but new vehicle sales reports for these years show even more utility vehicles on the road. About 11 percent of new passenger vehicles sold in 1996 were utility vehicles. Last year, these vehicles accounted for about 16 percent of new passenger vehicle sales. Pickups accounted for about 18 percent of new passenger vehicles sold in 1996 and for about 19 percent of new passenger vehicle sales in 1997.

Percent of passenger vehicle registrations by vehicle type, weight, and model year

Vehicle Type	Weight (pounds)	Model Year 1975	1980	1985	1990	1995
Cars	<2,500	13	38	29	17	16
	2,500-	28	41	38	47	39
	3,500+	43	6	9	8	9
Passenger vans		0	0	2	7	8
	Total	**84**	**85**	**78**	**79**	**72**
Pickups	<3,500	1	8	12	7	5
	3,500-	9	4	2	5	5
	4,000+	4	2	2	4	6
	Total	**14**	**14**	**16**	**16**	**16**
Utility vehicles	<3,500	0	0	4	3	2
	3,500-	1	0	0	1	5
	4,000+	1	1	2	1	5
	Total	**2**	**1**	**6**	**5**	**12**



Occupant death rates in other vehicles in two-vehicle crashes
1990-95 passenger vehicles
Deaths per million vehicles per year

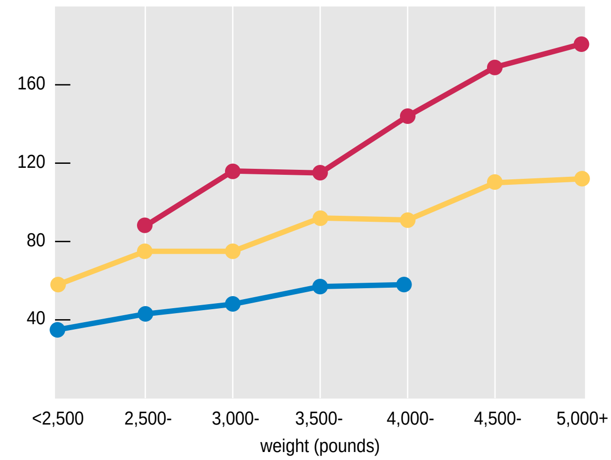


Figure 5

(cont’d from p. 4) highest rates of occupant deaths in the *other* vehicles with which they collide (figure 5). But again there are big differences among vehicle types. In every weight class, pickups have the highest other-vehicle death rate, and passenger cars have the lowest. Even the heaviest cars have lower other-vehicle death rates than the lightest pickups or utility vehicles. Heavy pickups have by far the highest rates in other vehicles.

Pedestrian/bicyclist/motorcyclist deaths: Most people who die in crashes are in passenger vehicles. But pedestrians, bicyclists, and motorcyclists are especially vulnerable in crashes with passenger vehicles. Death rates for this group are somewhat higher in collisions with pickups or utility vehicles than cars.

Pedestrian/bicyclist/motorcyclist death rates
1990-95 passenger vehicles
Deaths per million vehicles per year

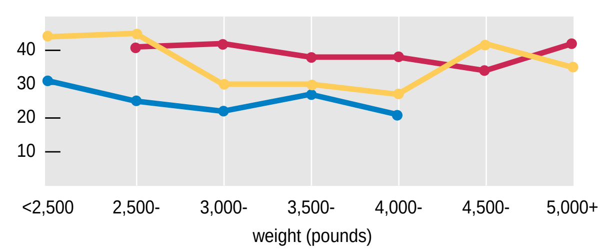


Figure 6

Overall death rates: Combining occupant death rates in passenger vehicles with other-vehicle occupant death rates and pedestrian/bicyclist/motorcyclist rates provides an assessment of the overall societal risk for different vehicle types and weight classes (figure 7). Within each comparable weight class, pickups have the highest overall death rates, and passenger cars have the lowest. For utility vehicles and passenger cars, there are relationships between their overall death rates and vehicle weight. The lightest of these vehicles have the highest overall death rates. This is especially so for utility vehicles. Overall death rates for pickups, however, are almost independent of weight.

"The fatal crash experience of different types of passenger vehicles helps put the compatibility issue in perspective," says Institute President Brian O'Neill. "In two-vehicle crashes involving cars, more deaths occur in the cars than in the other vehicles. Only when heavier cars are involved are there slightly more deaths in the other vehicles. But in two-vehicle crashes with pickups or utility vehicles there are many more deaths in the other vehicles."

Compatibility among vehicles: How does the risk of death vary for people in recent model cars that collide with other cars, pickups, or utility vehicles?

To answer, occupant deaths in two-vehicle crashes in 1991-96 where both vehicles were 1990-95 models were tabulated for each vehicle type/weight class combination. The ratio of deaths is the relative risk. In order to have sufficient numbers for the various crash pairs, weight classes were combined, so results are presented for only three classes within each vehicle type.

Table 1 shows the relative risk based on nearly 2,000 occupant deaths in car-to-car crashes. For collisions between cars in the same weight classes, by definition the relative risk is 1-to-1. The first column of the all-crashes results shows as the weight of the other car increases, the relative risk for people in cars weighing less than 2,500 pounds worsens from 2.4-to-1 to 3.1-to-1.

There were about 850 occupant deaths in front-to-front crashes between two cars, and the relative risk patterns in relation to car weight show more than twice the risk of death for people in cars weighing less than 2,500 pounds.

Slightly more than 800 car occupants were killed in cars struck in the side by another car. In this crash configuration, the relative risk for collisions between cars in the same weight group is no longer 1-to-1. The overall risk for people in the side-struck cars relative to those in the front-striking cars is 6.4. For people in the lightest cars struck in the side, the relative risk of death is 10.8 compared with 3.5 for the heaviest cars.

In collisions between cars and pickups or cars and utility vehicles, people in cars always have the highest relative death risk. However, fewer people in cars died in these crashes than in car-to-car crashes. About 450 people riding in *(cont'd on p. 10)*

Occupant and other road user death rates
1990-95 passenger vehicles
Deaths per million vehicles per year

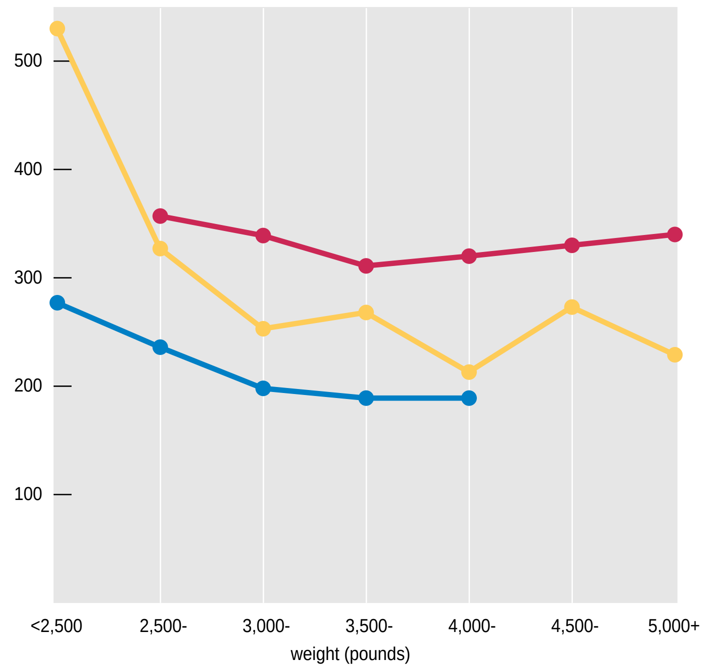


Figure 7

Table 1

Two-car fatal crashes
Relative risk of occupant death by car weight and crash type
1990-95 cars

Crash Type	Car Weight	Car Weight (pounds) <2500	2500-	3500+	
All	<2,500	1.0			
	2,500-	2.4	1.0		
	3,500+	3.1	2.1	1.0	
Front to front	<2,500	1.0			
	2,500-	2.7	1.0		
	3,500+	2.4	1.8	1.0	
Front to side	Front-striking car		Side-struck car		**All**
	<2,500	6.7	2.6	—	**3.1**
	2,500-	12.4	6.1	2.6	**6.2**
	3,500+	—	—	—	**19.5**
	All	**10.8**	**6.0**	**3.5**	**6.4**

Note: A dash indicates insufficient numbers to compute reliable relative risks.

The sides of cars have strong sill areas below the doors. If a utility vehicle or pickup were to hit the side of a small car, the main impact would be to the door, which isn't as strong as the sill area. This would increase the risk of serious injury to people inside the car.

Roles of weight, stiffness, and geometry in crash compatibility

Peruse promotional pamphlets of new vehicles and you'll see words like crash crumple zones and safety cages. What are these and why are they important?

Crumple or crush zones are the front- and rear-ends of cars that should absorb crash energy. Safety cages are the occupant compartments that should remain intact in a crash so the people inside can be protected by restraint systems — safety belts plus airbags.

For optimum crash protection, the structural elements of crush zones should bend and crumple, absorbing crash energy and allowing restrained occupants to decelerate with an intact occupant compartment. This shortening of the crush zone provides the distance needed to decelerate restrained occupants, allowing them to experience lower forces than if they had stopped abruptly.

In two-vehicle crashes, both vehicles' characteristics influence the outcome. In a serious head-on crash with two vehicles traveling at the same speed, the heavier one will drive the lighter one backwards. This means people in the lighter vehicle typically would experience greater forces — and probably more severe injuries — than if their vehicle hit a rigid barrier at the same speed. This vehicle, in effect, experiences a more severe crash than the heavier one, which is why vehicle weight differences contribute to incompatibilities.

Crush zone stiffness and length: These influence compatibility, too. If the heavier vehicle also is stiffer, then the lighter car crushes more in addition to being knocked backward. However, if the heavier vehicle has a long crush zone as soft as the lighter car's, both cars crush equally. With sufficient crush space, the crash energy can be absorbed by both vehicles' crush zones so people in the lighter vehicle experience diminished injury-causing crash forces.

Geometry: Another design feature influencing compatibility is crush zone geometry, especially the heights of the main energy-absorbing elements. If a heavier vehicle's crush zone energy-absorbing structures — for example, the engine support cradle — are higher than a lighter vehicle's corresponding structures, both vehicles' crush zones wouldn't absorb crash energy. One would override the other, diminishing effective energy absorption.

Similar considerations apply when the front of a vehicle hits the side of another vehicle. Then there's virtually no crush space for the side-struck vehicle. Plus, the crush zones of the striking vehicle are stiffer than the door of the side-struck vehicle. The geometric mismatch problem can be severe, too, if the main energy-absorbing elements of striking vehicles impact at the middle of the doors. This is likely with many utility vehicles and pickups, compared with the relatively strong sill area below the doors, more likely with passenger cars.

The influences of weight, geometry, and stiffness on crash compatibility can be illustrated for hypothetical crashes between pairs of vehicles. For example, in a head-on crash between a small light car and large heavy one, theory suggests in order to maximize effective crush distance, the lighter car should be the stiffer of the two.

It's not clear that optimizing for this single mismatch by making light cars stiffer is appropriate for all real-world crashes. So a head-on collision between two small light cars with stiff crush zones is likely to be worse than one between the same cars with softer crush zones.

In practice, passenger vehicle characteristics that lead to different weights, stiffnesses, and geometric designs among vehicles are rarely dictated or even strongly influenced by crash compatibility concerns. Heavy utility vehicles and pickups typically have front-end energy absorbing structures that are much stiffer and higher than the equivalent components on cars. And heavy cars have crush zones that typically are stiffer than those on lighter cars even though these directly contribute to crash incompatibility.

Reducing crash incompatibility: Despite this, crash incompatibility can be reduced. For example, there are numerous studies regarding the major incompatibility between heavy trucks and passenger vehicles. Occupants of passenger cars are six times as likely to die when they collide with a large truck compared with another car. One way to improve car occupants' odds of surviving crashes with heavy trucks is to modify trucks' structures to make them more compatible with passenger vehicles in crashes.

The mass differences between trucks and cars cannot be changed, but front underrun protection devices have been proposed to prevent truck front ends from overriding passenger vehicles. One prototype design is a truck bumper of honeycomb aluminum mounted on a strong support frame. This structure would prevent a car from underriding a truck front, as well as transfer some of the energy of impact to the truck chassis. In crash tests, such designs have proved effective, indicating that despite large weight mismatches, changes to front-end geometry and stiffness can improve compatibility.

The range of vehicles on U.S. roads has different weights, structural stiffnesses, and crush zone geometries. These can make vehicles incompatible in crashes. Changes can be made to vehicles, particularly heavy trucks, to reduce crash incompatibility and lower occupant injury risk.

(cont'd from p. 7) cars died in crashes with utility vehicles. Slightly more than 1,000 people in cars died in collisions with pickups compared with nearly 2,000 who died in car-to-car crashes.

All crashes: For all crashes between cars and pickups or cars and utility vehicles, the overall relative risk for people in cars is about 4-to-1. Figures 8 and 9 show the relative death risks for people in cars in crashes with pickups or utility vehicles by vehicle weight. The highest relative risks involve people in the lightest cars in collisions with the heaviest pickups or utility vehicles. In the most adverse combinations, people in cars have more than 10 times the relative death risk in all collisions compared with people in pickups or utility vehicles. This compares with the most adverse relative risk for all car-to-car crashes of about 3-to-1.

Front-to-front crashes: Figures 10 and 11 show the relative risk of death for the 521 people killed in passenger cars in front-to-front crashes with pickups or utility vehicles. For this subset of all crashes, the death counts for many of the individual vehicle type and weight class pairs were insufficient to compute relative risks. Shown only are results for each car weight class colliding with all pickups or utility vehicles and for each pickup or utility vehicle weight class colliding with all cars.

The overall relative death risk for occupants of passenger cars is about 3-to-1 in front-to-front collisions with pickups and about 4-to-1 for corresponding collisions with utility vehicles. As before, the relative death risk for people in passenger cars is highest in the lightest cars and in collisions with the heaviest pickups or the heaviest utility vehicles.

Side-impact crashes: The relative risk for the nearly 800 people killed in cars struck in the side by pickups or utility vehicles is particularly high. It's more than 25 times higher than in the striking vehicles compared with about 6 times higher for people killed in cars struck in the side by other cars. In fact, because the death risk is so low in pickups and utility vehicles — out of 822 deaths in these collisions, 793 were in the side-struck cars — pickup and utility vehicle results were combined to get sufficient numbers to compute relative risks.

Figure 12 shows results for these front-to-side collisions. The overall relative risk for people in cars is 27-to-1. For people in cars weighing less than 2,500 pounds, the risk jumps to 47-to-1. For all occupants of cars regardless of vehicle weight, the risk is 48-to-1 when cars are struck by the heaviest pickups or utility vehicles.

Car and pickup fatal crashes
Relative risk of car occupant death
by vehicle weight
1990-95 cars and pickups

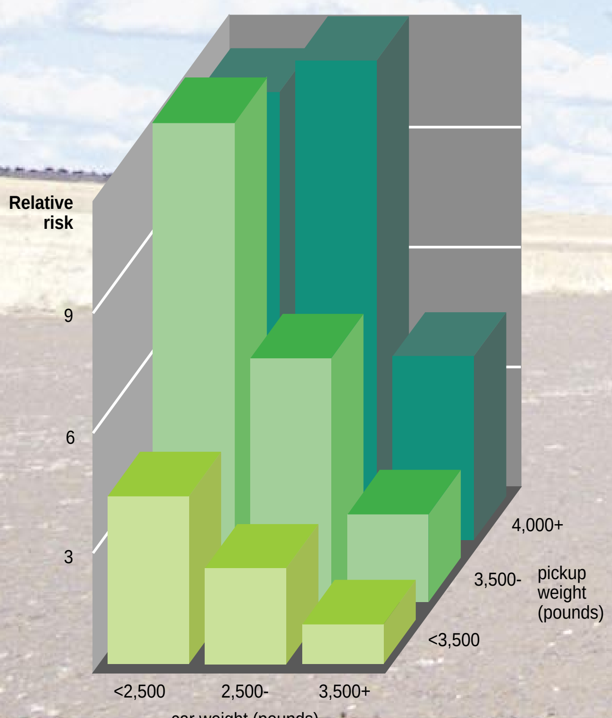


Figure 8

Car and utility vehicle fatal crashes
Relative risk of car occupant death
by vehicle weight
1990-95 cars and utility vehicles

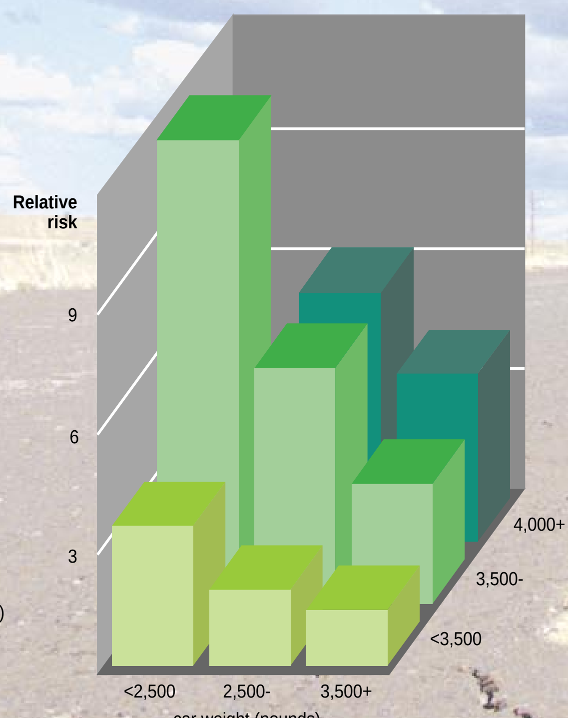


Figure 9

Note: There were insufficient numbers to compute the relative risk for utility vehicles weighing 4,000+ pounds in crashes with cars weighing <2,500 pounds.

Cars and pickups in front-to-front crashes
Relative risk of car occupant death by vehicle weight
1990-95 cars and pickups

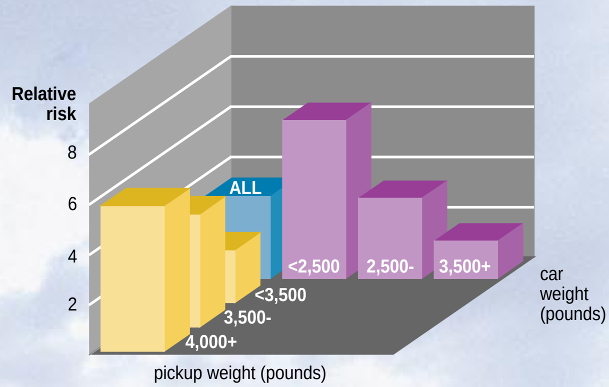


Figure 10

Cars and utility vehicles in front-to-front crashes
Relative risk of car occupant death by vehicle weight
1990-95 cars and utility vehicles

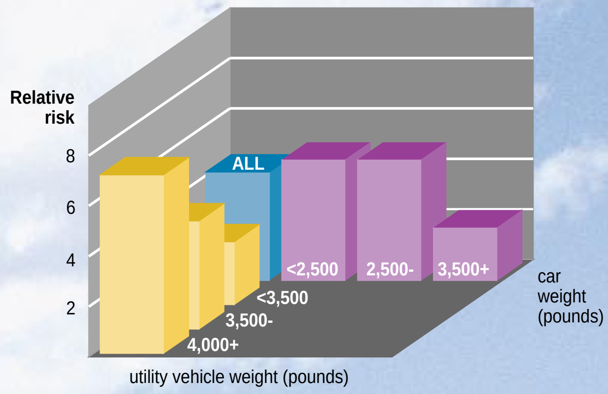


Figure 11

Cars struck in the side by pickups or utility vehicles
Relative risk of car occupant death by vehicle weight
1990-95 passenger vehicles

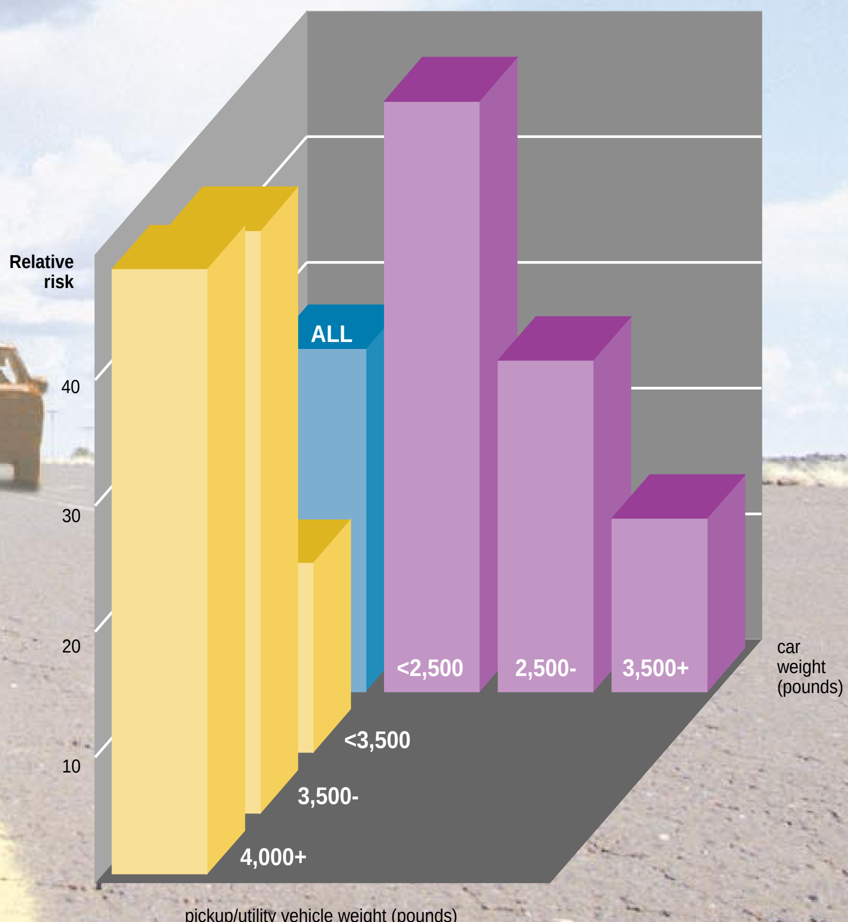


Figure 12

Brian O'Neill, Institute president, on the crash compatibility issue

The relative risk results highlight the particular problems for people in cars or passenger vans colliding with pickups or utility vehicles, especially when the cars are struck in their sides. Addressing front-to-side crash compatibility should be a priority, even though improvements to vehicles' side and front designs won't be easy to accomplish without altering the geometry of vehicles.

These analyses show the major concerns that have been raised about crash incompatibility between light and heavy cars are overstated for the U.S. vehicle fleet.

Automakers should design their cars so occupants are as safe as possible, without worrying about incompatibility among cars in crashes. The principal focus for incompatibility improvements needs to be on pickups and utility vehicles and the sides of passenger cars.

STATUS REPORT

INSURANCE INSTITUTE FOR HIGHWAY SAFETY

1005 N. Glebe Rd., Arlington, VA 22201 703/247-1500 Fax 247-1588 Internet: www.highwaysafety.org

Vol. 33, No. 1, February 14, 1998

This special issue focuses on crash compatibility. Other special issues have focused on the following subjects:

Editor: Kim Stewart
Art Director: Joyce Thompson

Contents may be republished with attribution.
This publication is printed on recycled paper.

ISSN 0018-988X