

PROTECTING CARS FROM UTILITY VEHICLES

Clues from Real-World Data and Crash Tests

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Passenger vehicles in the United States range from small, lightweight cars to large, heavy pickup trucks and utility vehicles. When vehicles at the extremes of this spectrum crash into each other, the injury data raise issues of incompatibility—that is, of inequitable risk of injury and death for the vehicles' occupants. Heavier vehicles cause more deaths in the other vehicles with which they collide than do lighter vehicles, per million vehicles registered.

Vehicle type is also significant. Utility vehicles and especially pickups cause more deaths in other vehicles with which they collide than do cars, even after accounting for vehicle weight. The risk from utility vehicles and pickups to other vehicles' occupants is particularly great in side impacts. These findings confirm the importance of identifying ways to mitigate the problems of incompatibility in crashes.

Reducing Aggressivity

Much attention has focused on reducing the aggressive characteristics—or aggressivity—of pickups and utility vehicles. According to an experimental crash test program, the principal aggressive characteristics of these vehicles are the front-end geometry and the greater mass. Front-end stiffness, though potentially important, has proved less significant; minor changes in the front-end geometry may mitigate the effects of vehicle stiffness.

The test results support new vehicle designs that include stiff cross members located low in the front-end structure of vehicles with higher ride heights. In a collision, this design improves interactions with the impact-absorbing structure of the other vehicle.

However, review of real-world crash injury data suggests that vehicle aggressivity should not distract safety professionals from efforts to improve the protection of vehicle occupants. Vehicle-to-vehicle

crashes of pickups or utility vehicles with cars account for a minority of all crash fatalities in cars.

Single-vehicle crashes are the largest causes of death and serious injuries in all vehicle crashes. Improvements in vehicle protection—or crashworthiness—can reduce the risk of injuries in single-vehicle crashes as well as mitigate injuries in crashes with larger and heavier vehicles. For example, side impact airbags with head protection can shield against head injuries in collisions with trees and poles as well as with front ends of pickups and utility vehicles. Evidence from crashes and experiments support these conclusions.

Changing Priorities

Vehicle design can affect not only the protection of the vehicle's occupants but also the extent to which the vehicle can cause injuries to occupants of other vehicles or to other road users. Protection of the occupants is often referred to as a vehicle's self-protection; the risk posed to other road users is referred to as crash incompatibility.

Issues of crash incompatibility have received less attention than issues of self-protection. Vehicle regulations in the United States and Europe have resulted in padded interiors, safety belts, airbags, and structural designs that protect the occupants. In comparison, regulations for designs that limit risk to pedestrians or to occupants of other vehicles or that reduce property damage are not as varied or extensive.

This may now be changing. In the United States, an increase in the sales of sport utility vehicles (SUVs) has increased the diversity of the U.S. fleet, even though the proportion of small, lightweight vehicles is declining (Table 1). In 1999, 18 percent of new passenger vehicle registrations in the United States were SUVs, and two-thirds of these weighed

TABLE 1 Passenger Vehicle Registrations by Vehicle Type, Weight, and Model Year (Percent)

Vehicle type	Weight (kg)	1975	1985	1995	1999
Cars	<1,135	12%	28%	15%	9%
	1,135-1,590+	27	37	39	39
	1,590+	41	8	9	6
Passenger vans		0	2	8	8
	Total	81	76	71	61
Pickups	<1,590	1	12	4	4
	1,590-1,815+	9	2	5	3
	1,815+	3	2	6	12
	Total	13	16	16	18
Sport utility vehicles	<1,590	1	4	2	3
	1,590-1,815+	1	0	5	5
	1,815+	1	1	5	10
	Total	2	5	11	18

more than 1,815 kg (4,000 lb.). At the other end of the spectrum, 9 percent of new 1999 registrations were light or small cars weighing less than 1,135 kg (2,500 lb.).

The weight, size, and geometric disparities between SUVs and many smaller cars have led to extensive media attention to the aggressivity of SUVs—particularly of larger SUVs. The design of SUVs derives from pickup trucks, which have had a significant market share for a long time; therefore incompatibilities similar to those between SUVs and cars have been around for the past 25 years. What is new is the dramatically increased presence of the heavier SUVs and pickups on the road—in 1975, pickups and SUVs weighing more than

1,815 kg accounted for 4 percent of new passenger vehicles; in 1999, this jumped to 22 percent.

Two-Vehicle Crashes

In two-vehicle crashes, differences in vehicle weight affect the outcomes of occupant injuries. Heavier vehicles have fewer occupant deaths than do lighter vehicles, per registered vehicle (Figure 1), but the vehicles with which heavier vehicles collide have a higher rate of occupant deaths (Figure 2).¹ These effects result from the physical law of conservation of momentum—in a collision, the occupant compartment of the lighter vehicle will experience greater deceleration.

However, Figure 2 also confirms that factors other than differences in weight contribute to crash incompatibility. For each weight category, there are more fatalities in cars and passenger vans that collide with SUVs (per registered SUV) than in cars and passenger vans that collide with other cars (per registered car); the same is true for all weights of cars and passenger vans that collide with pickups.

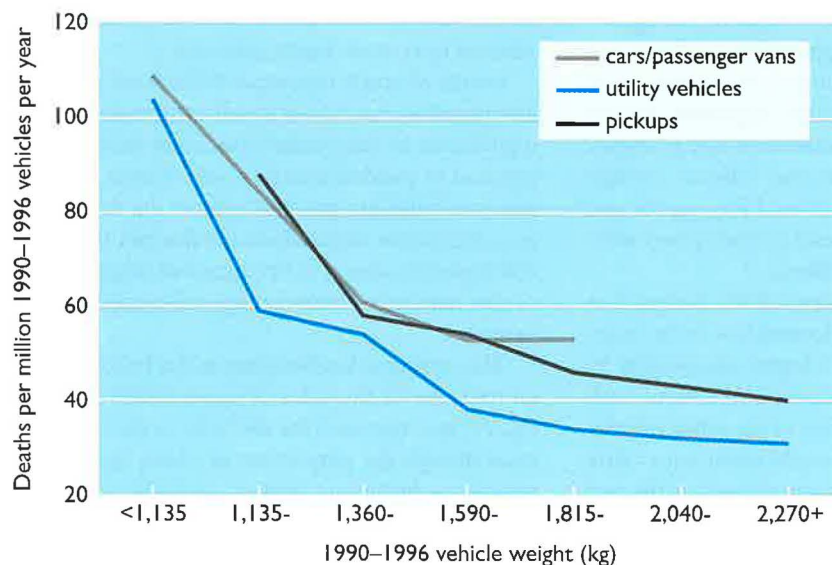
The difference in fatality risk to other vehicles' occupants is particularly great in side impacts. Figures 3 and 4 show fatality rates in the other vehicles in two-vehicle front-to-front collisions and in two-vehicle front-to-side collisions, respectively. The risk that an SUV weighing 1,815 to 2,039 kg will cause the death of a car occupant in a front-to-front collision is 10 to 20 percent greater than the risk if a car of the same weight collided with another car in a similar crash. However, SUVs are twice as likely as cars to cause the death of a car occupant in a front-to-side impact. For pickups, the risk is even greater than for SUVs.

The results show that, in two-vehicle crashes, SUVs and pickups pose greater risks to occupants of cars than do other cars, even after adjusting for weight differences, and the risks from SUVs and pickups are highest when the cars are struck in the side. Clearly, vehicle characteristics other than mass contribute to crash incompatibility.

Crash Tests

Past research has shown that vehicle geometry (1) and stiffness (2) can influence crash incompatibility. However, real-world crash data do not reveal the distinct and relative influences of vehicle weight, geometry, and stiffness on occupant injury risks in two-

FIGURE 1 Occupant death rates in 1990–1996 model passenger vehicles in two-vehicle crashes.



¹Based on fatality data for 1990–1996 model vehicles, from the Fatality Analysis Reporting System for 1991 to 1997, and on the number of vehicle registration-years for 1990–1996 vehicles during 1991 to 1997, obtained from R. L. Polk.

vehicle crashes, because SUVs and pickups generally are stiffer, ride higher, and are heavier than cars.

To sort out these factors, the Insurance Institute for Highway Safety conducted a series of six 90-degree front-to-side crash tests with both vehicles in motion. In each test, the side-struck vehicle was a Mercury Grand Marquis moving at 24 km/h with a BioSID—a biofidelic (i.e., true-to-life) side-impact dummy—in the driver position. The striking vehicles, a Lincoln Town Car and five Ford F-150 pickups, were moving at 48 km/h.

The baseline pickup—a normal F-150 4×2—had a stiffer front end than the Lincoln Town Car but weighed about the same. The lower front structural elements (i.e., the front frame members) of the normal F-150 were about the same height as the Town Car's. The four other F-150 pickups varied in weight, front-end stiffness, and ride height (Table 2).

Surprising Results

Nolan et al. had reported that increased mass, increased stiffness, and increased ride height each increased the extent of damage to the side-struck car (3). However, the actual injury risk measured by the driver dummy in the tests was not as predictable (Table 3). Increased vehicle height increased the likelihood of the head contacting the striking vehicle (Figure 5) and also increased several indicators of chest injury measured in the dummy: thoracic trauma index (TTI), thoracic deflection, and thoracic viscous criterion. Increased mass further increased the risk of a head strike but affected only the TTI measure of thoracic injury.

Most surprising was the unclear effect of vehicle stiffness. Although the dummy injury measures were lower in the vehicle struck by the car than by the stiffer pickup of a similar weight, the stiffest vehicle (the 4×4 version of the pickup) did not record the highest injury ratings. Thoracic injury risk was lower in this test than when the target car was struck by a 4×2 pickup of similar weight and height but less stiffness.

Areas for Adjustment

Apparently the degree to which some areas of a vehicle's front end are stiffer than others—and where the stiffer areas are located—can affect incompatibility in side impacts. The 4×4 pickup had a pair of tow hooks that made contact with the side of the car at a low level (Figure 6). This stiff but low engagement with the car produced an intrusion profile that accelerated the dummy's pelvis earlier than its thorax. Other researchers also have reported the benefits of a "vertical" intrusion profile (4).

Therefore the location and homogeneity of stiffness may be more important than overall stiffness

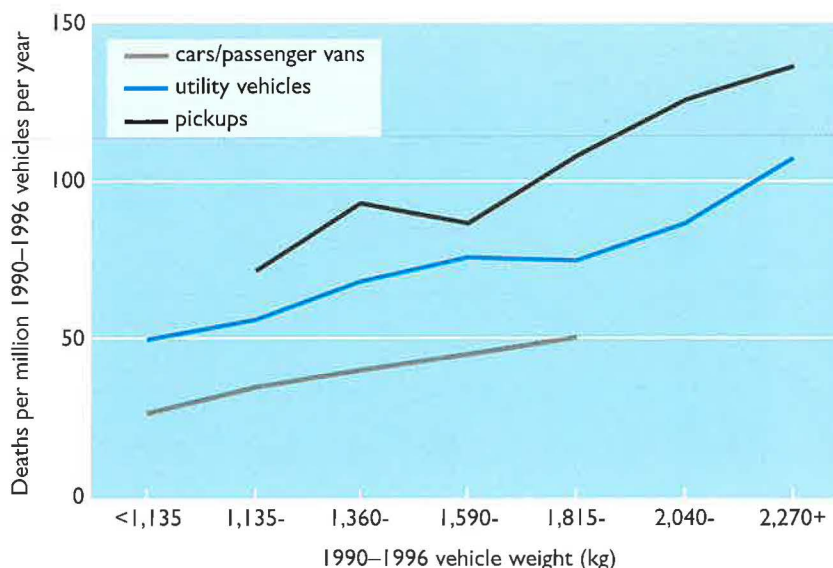


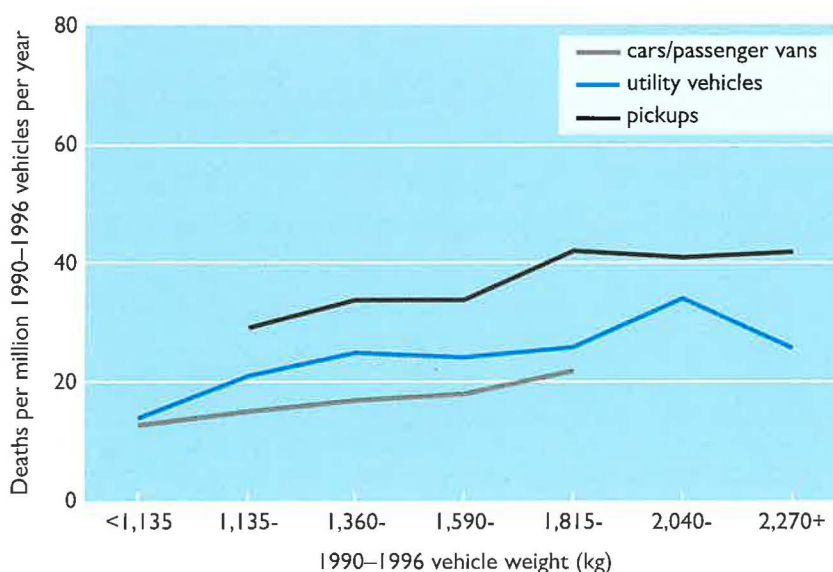
FIGURE 2 Occupant death rates for cars and passenger vans in two-vehicle crashes with 1990-1996 model passenger vehicles, by type of striking vehicle.

in improving vehicle compatibility. The findings suggest that the incompatible features of front ends in side impacts may be mitigated by designs that spread the load of the striking vehicle both horizontally and vertically.

Results of the crash tests also confirm that the higher hood heights of pickups and SUVs are another major factor in incompatibility; the higher hoods are more likely to strike an occupant's head in side impacts with cars. Data from the U.S. Department of Transportation's National Automotive Sampling System for 1992 to 1997 show that the likelihood of serious or more life-threatening² head

²Abbreviated Injury Scale (AIS) 3+. The AIS rates injuries in terms of threat to life, from 0 or no threat to 6, not survivable. An injury of AIS 3 is considered serious.

FIGURE 3 Occupant death rates for cars in front-to-front crashes with 1990-1996 model year passenger vehicles, by type of striking vehicle.



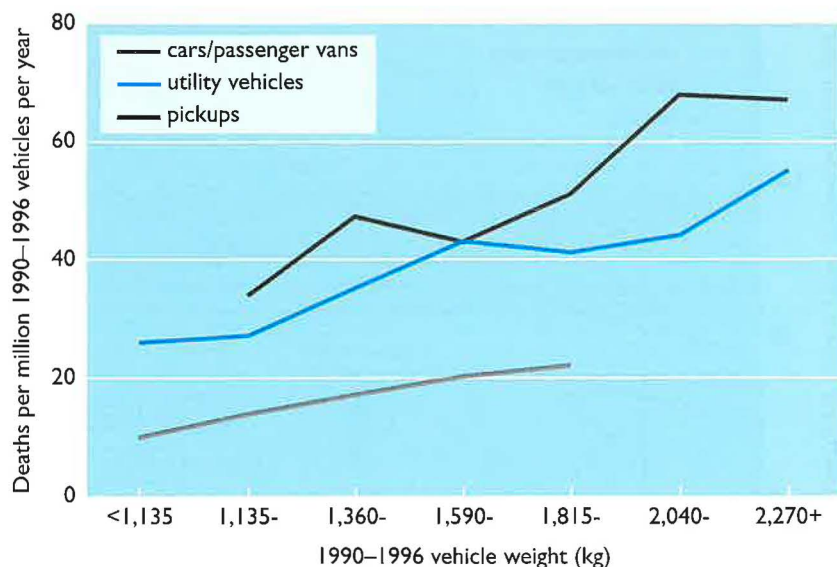


FIGURE 4 Occupant death rates for cars struck in the side by front ends of 1990–1996 model passenger vehicles, by type of striking vehicle.

TABLE 2 Test Matrix To Assess the Effects of Mass, Ride Height, and Stiffness

Height	Stiffness	Mass	
		Low (~2,080 kg)	High (~2,400 kg)
Low	Low	Lincoln Town Car	No test
Low	High	Normal F-150 4x2	Heavy F-150 4x2
High	High	Raised F-150 4x2	Raised-heavy F-150 4x2
High	Highest	No test	F-150 4x4

TABLE 3 Mercury Grand Marquis BioSID Injury Measures

Type	Striking vehicle			Head injury criterion	Thoracic trauma index	Thoracic deflection (mm)	Thoracic viscous criterion (m/s)	Pelvis acceleration (g)
	Height	Stiffness	Mass					
Town Car	Low	Low	Low	75	50	41	0.40	48
F-150	Low	High	Low	182	68	37	0.40	105
F-150	High	High	Low	227	86	60	1.51	105
F-150	Low	High	High	249	101	32	0.37	103
F-150	High	High	High	no data	111	62	1.54	114
F-150	High	Highest	High	717	87	48	0.44	109
Injury reference values				1000	85	42	1.00	130



FIGURE 5 The Ford F-150 pickups, with higher hoods than the Lincoln Town Car, increased chance of head injury to occupants of the Mercury Grand Marquis in side impact tests.

or face injuries increases sharply for occupants in side-struck cars (not including passenger vans) when the striking vehicle is a utility vehicle or pickup instead of another car (Figure 7).

Potential Countermeasures

The test results show that higher ride height contributes to increased thoracic injury risk and increased likelihood of head contact with the striking vehicle's hood. The frame rail heights of a group of SUVs and pickups vary considerably, but all are significantly higher than the stronger parts of cars' side structures (Figure 8).

One countermeasure—already implemented for some SUVs—is the addition of a strong beam across



FIGURE 6 Stiff tow hooks below bumper of the Ford F-150 4x4 pickup probably reduced risk of chest injury in the Mercury Grand Marquis by accelerating the struck driver's pelvis earlier than the chest. Paint transferred to leading edge of hood shows where the dummy's head contacted hood during test.

the front end, mounted below the frame rails. Ford has added this feature to its largest SUV and has indicated plans to add similar beams to its other large SUV models. The Ford Expedition's Blocker-Beam™ however, still is higher than car rocker panels (Figure 8). The beam's effectiveness as a countermeasure for incompatibility in front-to-front or front-to-side crashes is not yet known.

In every crash test involving a striking pickup, there was a threat to the struck driver's head. Countermeasures to reduce the risk of a car occupant's head being struck by the hood of a pickup or SUV in front-to-side crashes would be desirable, but practical modifications to the front ends of SUVs and pickups are not likely.

Meaningful reductions in head injury risk in such crashes probably would involve adding side airbags that deploy between the head and any intrusion of a striking vehicle. The airbags also would benefit car occupants in single-vehicle side impacts that risk head injury from external objects.

Reducing Vulnerability

Crash incompatibility does not only involve the aggressive features of one vehicle but also the vulnerability or crashworthiness of the other vehicle. Crash incompatibility can be reduced either by changing an aggressive characteristic (e.g., mass or stiffness) or by improving crashworthiness (e.g., adding a head airbag for side impacts or increasing the mass of the lightest vehicles). Improving crashworthiness is likely to be more beneficial because it addresses injury risks in single-vehicle as well as two-vehicle crashes.

Real-world crash data illustrate this. As shown in Figure 9, crashes involving two passenger vehicles are not the cause of most occupant deaths. According to data from the U.S. Department of Transportation's Fatality Analysis Reporting System, about 15 percent of occupant deaths in 1990–1996 model cars during calendar years 1991 to 1997 occurred in crashes with SUVs or pickups. Another 21 percent occurred in crashes with other cars; most of these involved cars without great differences in mass. Occupant deaths in light cars (less than 1,135 kg) follow a similar pattern—15 percent of the deaths occurred in crashes with pickups and SUVs and 23 percent in crashes with other cars. Single-vehicle crashes are the leading cause of car occupant deaths, even in the lightest cars.

Two-vehicle crashes are more significant when considering nonfatal injuries. In Germany, more than half of nonfatal car occupant injuries occur in two-vehicle crashes (5). The same is true in the United States—two-vehicle crashes account for

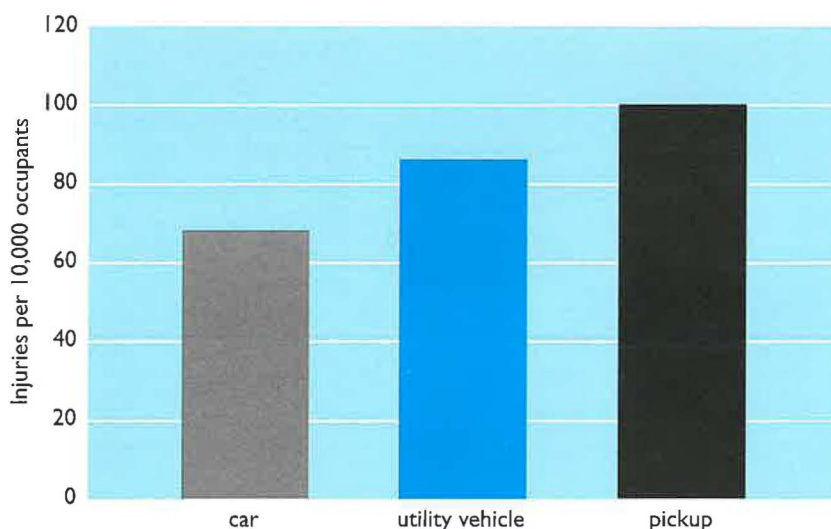
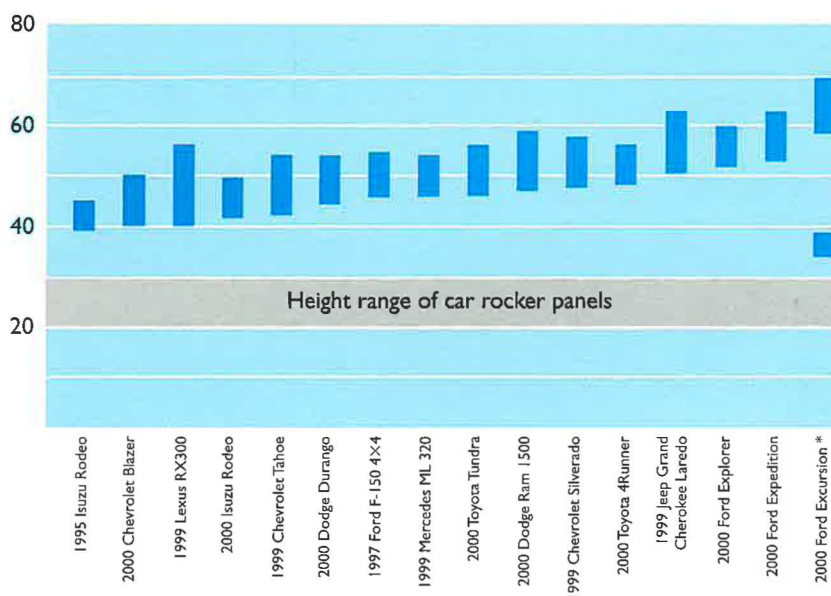


FIGURE 7 Occupant head or face injuries (AIS 3+) in side-struck cars in two-vehicle crashes, by type of striking vehicle.

almost 60 percent of moderate and more serious nonfatal car occupant injuries (National Automotive Sampling System data, 1991–1997; Figure 10). However, as with fatalities, collisions with other cars—not with SUVs or pickups—accounted for most of these nonfatal injuries (38 percent). Only 13 percent of the injuries to car occupants occurred in collisions with SUVs or pickups.

Car-to-car crashes account for almost half of all injuries (47 percent) to occupants in light cars. The small size and light weight of the vehicles increase the vulnerability of occupants in collisions with any other object, even other light vehicles. The influence of weight is evident—in comparison, only 28 percent of injuries in heavy cars (1,590–1,814 kg) occur in collisions with other cars.

FIGURE 8 Height (cm) of frame rails for SUVs and pickups compared with height of car rocker panels.



*Lower black section is BlockerBeam™; upper black section is frame rail.

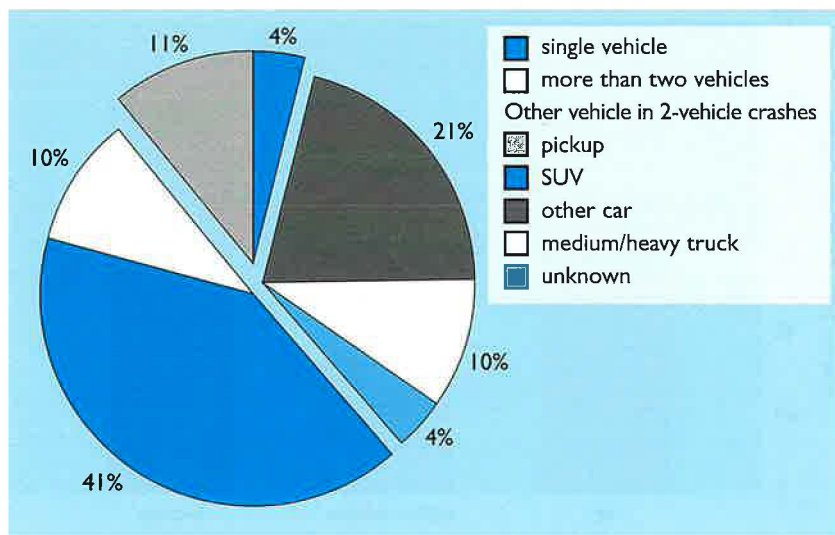


FIGURE 9 Distribution of car occupant deaths by crash type, 1990–1996 model cars.

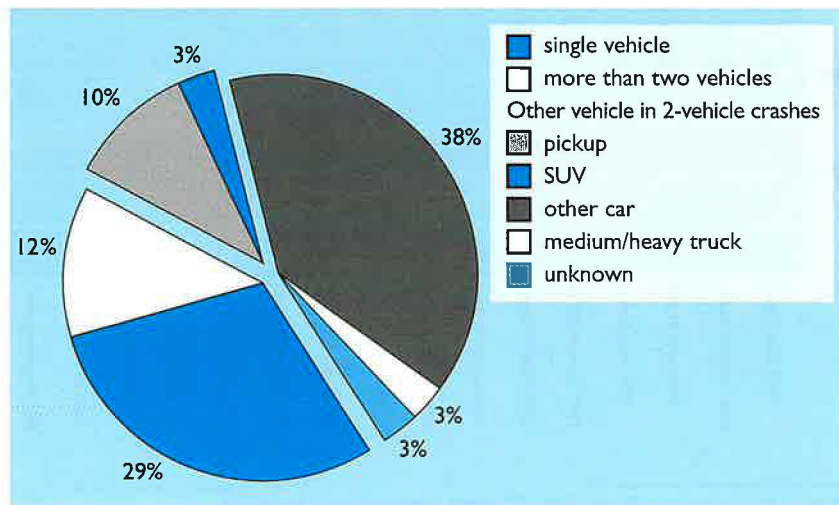
Compatible Crashes?

The need to constrain the aggressive characteristics of large pickups and SUVs has gained much attention in the United States. As shown by the data presented here, the front-end geometry of the vehicles makes them more aggressive in two-vehicle crashes than cars of similar weight. The findings also suggest that some relatively simple modifications of SUV and pickup front ends could reduce aggressivity by improving interactions between the stiff structures and the structural elements of other vehicles, even in side impacts.

However, the data also suggest other conclusions that are somewhat inconsistent with current popular conceptions. For example,

- ◆ SUVs and pickups are not the major threat to occupants of cars. Single-vehicle crashes are the most common causes of fatalities to car occupants; collisions with other cars rank second.

FIGURE 10 Distribution of car occupant injuries (AIS 2+) by crash type, 1990–1996 model cars.



◆ Improvements in the crashworthiness of cars—for example, side airbags and structural improvements to limit intrusion in all kinds of crashes—will reduce vehicle crash incompatibility and also will reduce fatalities and injuries in other crashes. In short, vehicle design changes that improve crashworthiness and reduce the vulnerability of the vehicle's occupants have more potential for improving the public health than strategies that reduce vehicle aggressivity.

◆ Concerns that improving crashworthiness could increase vehicle stiffness—and therefore aggressivity—appear to be misplaced, as side-impact tests have shown. Although higher overall stiffness of vehicle front ends increases intrusion, the effect on crash injuries seems to be minor compared with the effects of geometric design and mass. Moreover, logical changes in the geometry of front-end structure apparently mitigate the effect of stiffness.

Finally, there is no such thing as a compatible crash. Crashes between vehicles of similar mass and matching geometry and stiffness may be more fair in that the chance of injury or death is equal in a frontal crash, and the risk each car poses to the other is similar in front-to-side impacts. But the crashes are not compatible. Most serious injuries to car occupants in two-vehicle crashes occur in collisions with other cars of similar size and weight. Improvements in the protection of a vehicle's occupants, therefore, are needed to prevent car-crash injuries and deaths.

Acknowledgment

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