NHTSA'S RESEARCH PROGRAM FOR VEHICLE AGGRESSIVITY AND FLEET COMPATIBILITY

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ABSTRACT

This paper presents an overview of NHTSA's vehicle aggressivity and fleet compatibility research activities. This research program is being conducted in close cooperation with the International Harmonized Research Agenda (IHRA) compatibility research group. NHTSA is monitoring the changing vehicle mix in the U.S. fleet, analyzing crash statistics, and evaluating any implications that these changes may have for U.S. occupant safety. NHTSA is also continuing full scale crash testing to develop a better understanding of vehicle compatibility and to investigate test methods to assess vehicle compatibility.

INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) has an ongoing research program to investigate the crash compatibility of passenger cars, light trucks, and vans in vehicle-to-vehicle crashes. The compatibility of a vehicle is a combination of its crashworthiness, its ability to protect occupants within the vehicle, and its aggressivity, its ability to protect the occupants within the collision partner vehicle. The objectives of this research program are to identify the nature and extent of the aggressivity problem within the U.S. fleet, to develop test procedures to evaluate vehicle compatibility, and to investigate potential countermeasures for vehicle aggressivity through both vehicle testing and fleet modeling. Additional discussion of NHTSA's fleet modeling efforts are found in references 1 and 2.

PROBLEM DEFINITION

NHTSA previously published several papers that describe the growing compatibility problem in the U.S. fleet.[3,4,5] This section is intended to provide an update of these previous reports using data from the most recent 5 years of the Fatality Analysis Reporting System (FARS) and the General Estimates System (GES). As shown in Figure 1, the sales and registrations of light trucks and vans (LTVs) has steadily increased, as a percentage of the fleet, since 1981.[6,7]

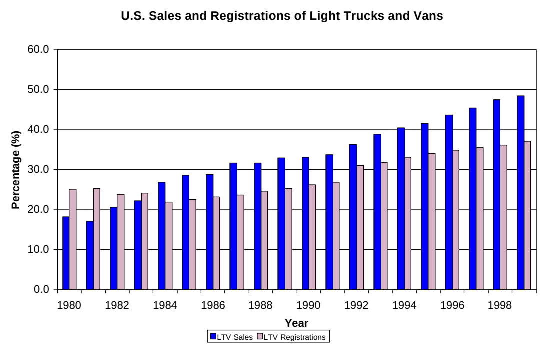

Figure 1. LTV sales and registrations.

The increasing number of LTVs is leading to an increasing number of fatalities for car occupants who are struck by LTVs, see Figure 2. This increase in passenger car fatalities is occurring even while the overall fatalities for the US fleet has stablized or decreased.

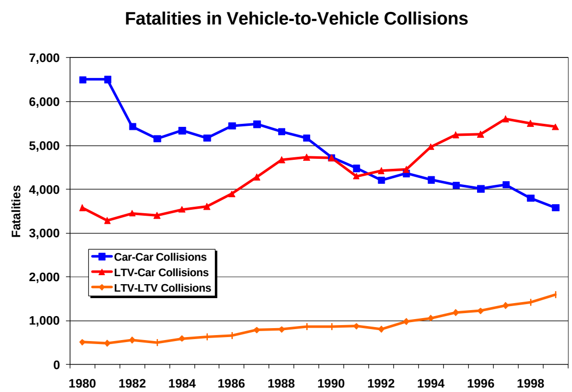

Figure 2. Occupant fatalities in 2-vehicle crashes

In order to characterize the compatibility problem, NHTSA defined an aggressivity metric based on FARS reported fatalities and GES reported crash involvements.[3,4,5] This aggressivity metric is defined as:

$$Aggressivity = \frac{Fatalities\ in\ Collision\ Partner}{Number\ of\ Crashes\ of\ Subject\ Vehicle}$$

The aggressivity metric normalizes the fatalities in the collision partners by the number of crashes in which the subject vehicle is involved. This normalization is intended to account for different vehicle populations and driver demographics. The aggressivity metrics were computed for vehicle categories using 1995 through 1999 FARS and GES databases. Only two-vehicle crashes where both vehicles were under 10,000 lbs and had model years 1990 and newer were included. Previous analyses[5,8] showed that vehicles with model years 1990 and newer had substantially lower aggressivity metrics than for all model years combined. Only struck driver fatalities are counted to remove any bias due to occupancy rates. Driver fatalities were also restricted to the ages of 26 and 55, inclusive, to remove the variation in injury tolerance shown by younger and older drivers. The LTV vehicle categories are a subset of the LTV categories provided by FARS and GES. Passenger cars were categorized using the NCAP vehicle weight ranges. The passenger car weights were obtained by decoding VIN numbers. This requirement restricted the passenger car data to only the GES regions that report VINs. These passenger car distributions were scaled to obtain national estimates. A recent report from the University of Michigan[9] demonstrated that national estimates for two-vehicle fatal crashes can be developed using only NASS GES regions that report VIN numbers. The aggressivity metrics for all two-vehicle crashes, including front, side, and rear crashes, are shown in Figure 3. The aggressivity metrics tend to increase for the larger, heavier vehicle categories. The large vans and pickups have over three times the fatality rate of large cars. SUV's have around twice the fatality rate of large cars. The compact pickup category is the only exception to the trend of increasing aggressivity with vehicle weight. The compact pickup category has an average weight similar to the large car category, yet it has an aggressivity metric that is over 50 percent higher.

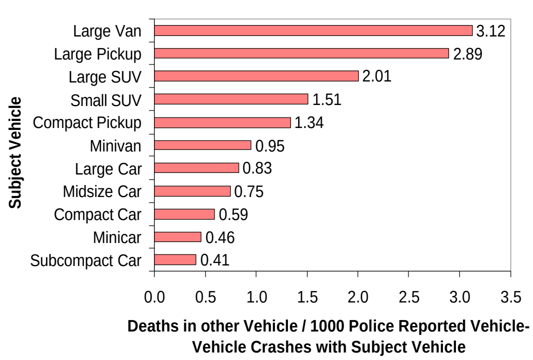

Figure 3. Aggressivity metrics for vehicle-to-vehicle crashes.

Frontal-frontal crashes represent about four percent of all two-vehicle crashes, yet averaged around 4300 annual fatalities between 1995 and 1999. The aggressivity metrics for frontal-frontal crashes are shown in Figure 4. These metrics are much higher than for all two-vehicle crashes, but the relative rankings of the vehicle categories is similar. Only the large pickup and the large van categories, exchanged rank orders when comparing frontal-frontal crashes to all two-vehicle crashes.

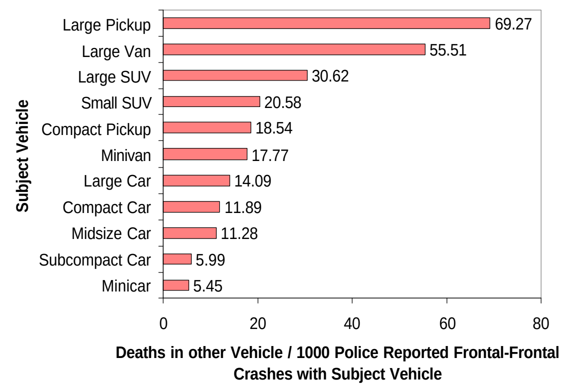

Figure 4. Aggressivity metrics for frontal-frontal crashes

The aggressivity metrics for two-vehicle side impact crashes results are shown Figure 5. Here the aggressivity metrics are not as large as they were for frontal-frontal crashes, but the relative order for the vehicle categories is identical to the order for all frontal-frontal crashes. The large van and pickup categories remain over three times as aggressive as the large car category, and the metric for the small SUV category is about twice as large as the large car category.

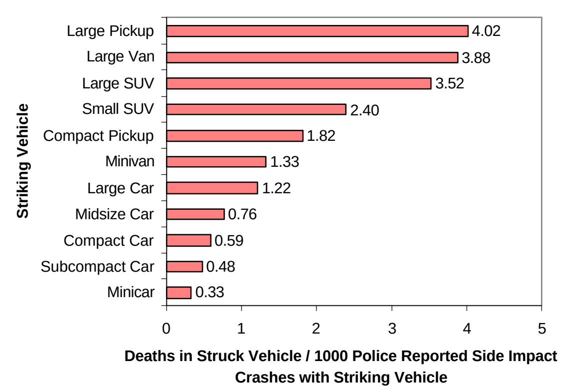

Figure 5. Aggressivity metrics for side impact crashes.

Since side impact crashes have a clear distinction between the striking and the struck vehicle, it is possible to evaluate the number of fatalities in the struck vehicle per 1000 NASS GES reported crashes, as shown in Figure 6. This "vulnerability metric" shows the number of fatalities in the struck vehicle when it is struck by all vehicle categories. This metric has some surprising results. The minicar category has a very high vulnerability metric. The small SUV category is very similar to the large car category, despite a substantial difference between all of the aggressivity metrics of the two categories. The large van, large pickup, and large SUV categories combined have only five struck driver fatalities and are omitted from Figure 6.

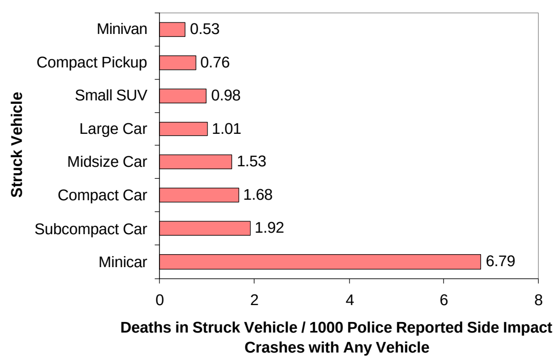

Figure 6. Vulnerability metrics for Side impact crashes.

Europe and other regions of the world are concerned with compatibility for car-to-car crashes. Restricting the crash population to crashes where both vehicles are passenger cars and including all two-car crashes, and all fatalities in the struck vehicle, with no model year, or driver age restrictions, produces the aggressivity metrics shown in Figure 7. The aggressivity metrics for car-to-car crashes are somewhat higher than the aggressivity metrics for the cars striking any vehicle shown in Figure 3. The large and midsize car categories have similar aggressivity metrics, 2.62 and 2.53 respectively. There is a substantial difference in aggressivity between the remaining passenger car categories.

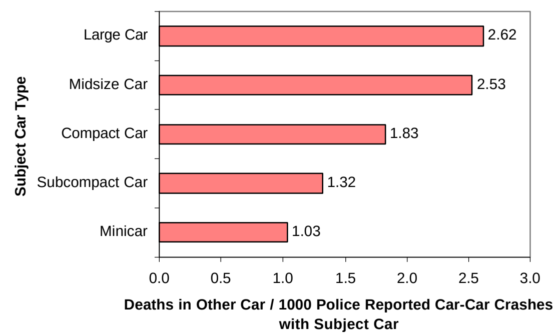

Figure 7. Aggressivity metrics for car-car crashes

These aggressivity metrics have established, by vehicle category, the aggressivity of the vehicle as it strikes any other vehicle in a given configuration. It is desired to examine the compatibility between specific vehicle categories, e.g. LTV into large car, rather than evaluating the aggressivity of a vehicle category striking any other vehicle. However due to data limitations, the aggressivity metrics for specific vehicle category-to-category crash configurations do not produce reliable estimates. Instead fatality ratios can be used to study the aggressivity of vehicle category-to-category crashes. Figure 8 shows the driver fatality ratios for all passenger cars struck by five vehicle categories. These ratios were computed only for two-vehicle crashes where both vehicles were model year 1990 or newer and both drivers were between ages 26 to 55, inclusive. These driver fatality ratios have not changed substantially from what was previously reported using 1992 to 1996 FARS data.[4,5] The fatality ratio for compact pickups has increased from 1.6 to 2.6 and the ratio for minivans had decreased from 3.3 to 2.6.

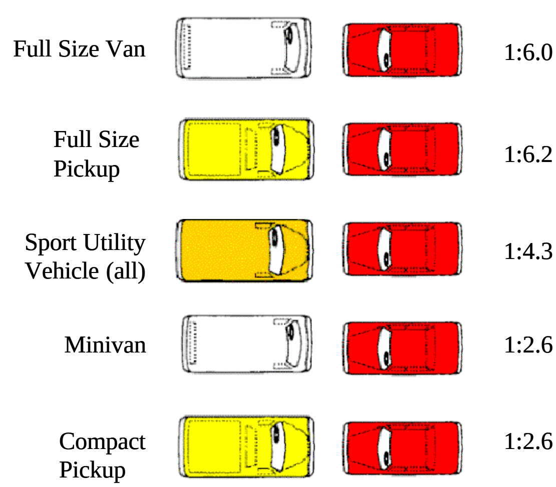

Figure 8. Driver fatality ratios for frontal-frontal LTV-to-car crashes.

Driver fatality ratios were similarly computed for the side impact crashes, as shown in Figure 9. In side impact crashes, the drivers of the struck vehicles are much more likely to be killed. It is important to remember that the 7.8 passenger car fatality ratio is the appropriate baseline for comparing the LTV into car fatality ratios. The side impact driver fatality ratios are somewhat unreliable. The large pickup and utility vehicle ratios are based on only seven driver fatalities each. The passenger car fatality ratio is based on 28 striking driver fatalities. The other vehicle categories had even fewer driver fatalities and were not included.

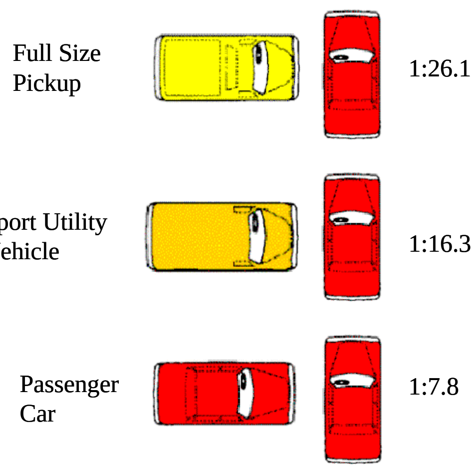

Figure 9. Driver fatality ratios for side impact crashes into passenger cars.

Analysis of the FARS and GES crash data from 1995 to 1999, shows that a significant compatibility problem still exists in the U.S. fleet. A disproportionate number of the fatalities in LTV-car crashes are incurred by the passenger car occupants. The aggressivity estimates are strongly, but not entirely, related to the weight differences in the vehicles. Vehicle crash compatibility continues to be a significant concern for occupant safety in the U.S. fleet.

TEST PROGRAM

NHTSA previously conducted a baseline series of vehicle-to-vehicle crash tests using both side impact and frontal oblique offset crash test configurations.[10] This test series was intended to provide comparative performance data to aid in understanding the causes behind the compatibility crash statistics. A 1997 Honda Accord was chosen as the target vehicle for a series of five oblique offset and five side impact crash tests. The vehicles shown in Table 1 were used for both the frontal and side impact test series.

Table 1.
Striking (bullet) vehicles for compatibility test series.

Vehicle	Weight (kg)
1998 Chevrolet S-10 Pickup	1655
1995 Chevrolet Lumina	1806
1997 Dodge Caravan	2073
1997 Ford Explorer	2123
1994 Chevrolet K2500	2539

The injury criteria measured by the driver dummy in the Honda Accord were used to evaluate the probability of injury and hence the compatibility of the striking vehicle. The oblique offset test series showed good correlation between the struck driver injury criteria and both the weight and aggressivity metric of the striking vehicle. Figure 10 plots the struck driver injury criteria against the aggressivity metrics from Figure 4. The head injury criteria (HIC) and chest acceleration show good correlation with the aggressivity metrics, R^2 of 0.98 and 0.85 respectively.

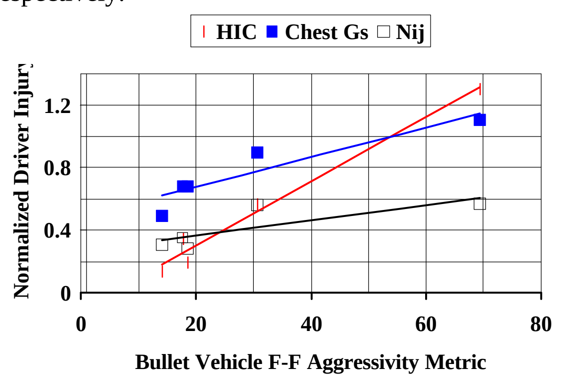

Figure 10. Injury criteria for the oblique offset tests.

The side impact tests series did not show a similar trend. The injury criteria for the struck driver in the side impact tests showed weaker correlation with the aggressivity metric of the striking vehicle (R^2 values of 0.36, 0.81, and 0.61 for HIC, TTI, and Pelvic acceleration respectively). Figure 11 shows the driver injury criteria versus the side impact aggressivity metrics reported in Figure 5. The HIC and thoracic trauma index (TTI) show a mild increase with aggressivity metrics, while the peak pelvic acceleration shows a negative relationship.

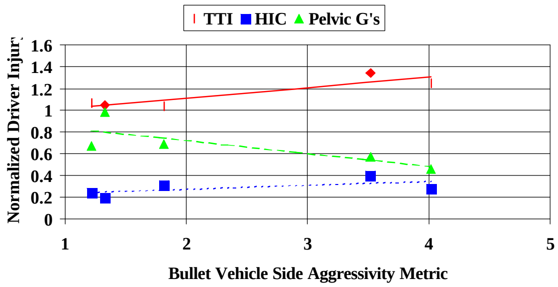

Figure 11. Injury criteria for the side impact tests.

In an effort to better understand the side impact vehicle compatibility, NHTSA conducted a follow up series of four side impact tests to evaluate the effect of weight and ride height in side impact collisions. It was desired to see if the effect of weight and ride height affects passenger cars and LTVs in a similar fashion. The 1997 Honda Accord was the struck or target vehicle, and the FMVSS No. 214 test configuration was used for these tests. The striking vehicles for the four tests were modified as shown in Table 2.

Table 2.
Modified side impact compatibility tests.

Test Number	Vehicle	Weight Change (kg)	Height Change (mm)
3492	1995 Chevrolet Lumina	+251	
3508	1995 Chevrolet Lumina		+90
3507	1994 Chevrolet K2500	-520	
3491	1994 Chevrolet K2500		-177

The vehicles ride height was adjusted using the springs. The ride height was also corrected for the vehicles with the weight changes to restore the height to match the baseline test. A comparison of the ride heights for the baseline and adjusted height vehicles can be seen in Figure 12.

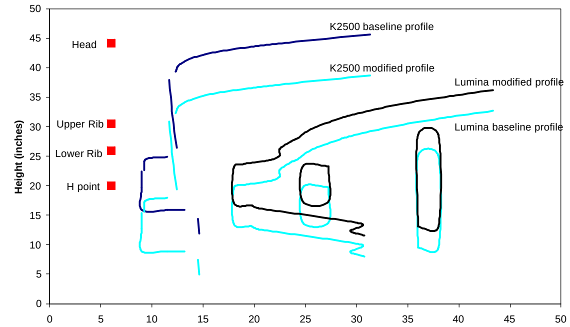

Figure 12. Modified vehicle profiles.

The injury measures for the Accord passengers struck in the Lumina tests are shown in Table 3. All of the occupants had low HIC values, with minor increases for the driver and decreases for the rear passenger dummies. The TTI values decreased for both occupants struck by the increased-weight Lumina, but were relatively unchanged for the occupants struck by the increased-height Lumina. The peak pelvic acceleration increased substantially for the driver struck by the increased-weight Lumina, while the rear passenger of the same vehicle showed a strong decrease. Increasing the height of the striking Lumina had a similar, but less significant trend, increasing pelvic acceleration for the driver and decreasing pelvic acceleration for the rear passenger. Overall, increasing the weight of the Lumina had a stronger effect on injury potential than the increase in ride height. The increase in weight raised the pelvic injury potential for the driver, while reducing overall injury potential for the rear seat passenger.

Table 3.
Lumina side impact test series, injury criteria.

	Baseline Lumina	Increased weight (+251 kg)	Increased height (+90 mm)
Accord Driver			
HIC 36	242	325.1	356.5
TTI	90.9	74.1	89.4
Pelvic G's	87.4	115.0	96.0
Accord Passenger			
HIC 36	392.3	148.0	325.7
TTI	44.6	31.8	42.0
Pelvic G's	68.1	29.6	50.8

The injury measures for the Accord passengers struck by the K2500 are shown in Table 4. Reducing the weight of the K2500 had little effect on the driver injury criteria. Lowering the K2500 had a more significant effect on the driver's HIC and TTI measurements. In the decreased weight K2500 test, the rear passenger was struck in the chin by the K2500, leading to the extremely high HIC value. The TTI measurements increased significantly for both of the rear passengers, while the peak pelvic acceleration was relatively unchanged.

The modifications to the K2500 were expected to decrease the vehicle's aggressivity. However, only decreasing the height of the K2500 had a substantial effect on the struck driver. Decreasing the weight of the K2500 increased the injury potential for the rear seat occupant, while decreasing the height produced mixed results.

Table 4.
K2500 side impact test series, injury criteria.

	Baseline K2500	Decreased weight (-520 kg)	Decreased height (-177 mm)
Accord Driver			
HIC 36	276.7	239.5	146.1
TTI	103.7	110.1	72.8
Pelvic G's	59.7	55.0	56.2
Accord Passenger			
HIC 36	830.9	2321.6	557.1
TTI	57.7	82.0	84.5
Pelvic G's	77.0	81.7	72.3

In all of these tests, the injury criteria for the occupants in the striking vehicle were low and generally unaffected by the vehicle modifications.

INTRUSION

Figures 13-18 show the side damage for the six Honda Accord vehicles in this study. The three vehicles struck by a Lumina all showed similar damage patterns. The Accord struck by the increased-weight Lumina had the most intrusion, as both front and rear doors intruded further into the vehicle. The Accord struck by the increased-height Lumina did not show a corresponding increase in the height of the damage pattern. The deformation measurements for the mid door level, shown in Figure 19 show a small but consistent increase in the measured intrusion profiles for the vehicles struck by the modified Luminas.

The Accords struck by a K2500 did not show as consistent a deformation pattern. The Accord struck by the decreased-height K2500 did not have roof rail buckling that was evident in the other two tests. However, this same vehicle had consistently larger intrusion measurements at the H point height, as shown in Figure 20. The Accord struck by the decreased-weight K2500 had a similar damage pattern to the baseline test, though the intrusion rearward of the B pillar was considerably reduced. The deformation patterns observed in these tests seem to reflect the physical modifications to the striking vehicles.

Figure 13. Target vehicle, baseline Lumina.

Figure 14. Target vehicle, increased weight Lumina.

Figure 15. Target vehicle, increased height Lumina.

Figure 16. Target vehicle, baseline K2500.

Figure 17. Target vehicle, decreased weight K2500.

Figure 18. Target vehicle, decreased height K2500.

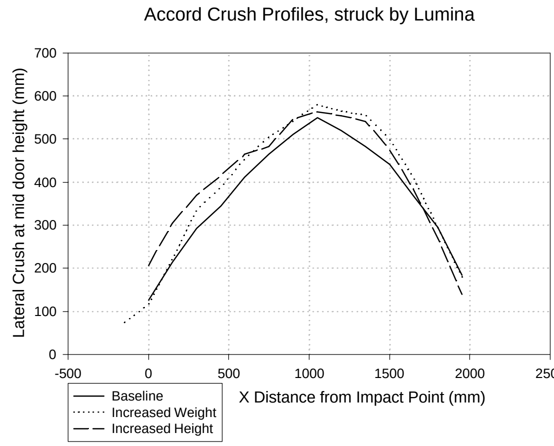

Figure 19. Intrusion measurements, Lumina series.

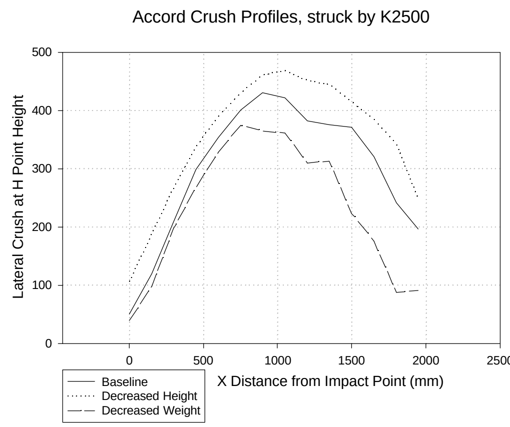

Figure 20. Intrusion measurements, K2500 series.

CONCLUSIONS

Light trucks and vans are continuing to increase as a percentage of the U.S. fleet. The number of occupant fatalities in cars struck by LTVs has stopped increasing in recent years. However, there still remains a significant difference in the fatality rates between LTVs and passenger cars. Large vans and large pickups are over three times more aggressive than passenger cars in all vehicle-to-vehicle crash configurations. Sport utility vehicles are over twice as aggressive as passenger cars for all vehicle-to-vehicle crash configurations. The compatibility measures for the 1995 to 1999 time period are similar to the measures previously reported for the 1992 to 1996 time period.

The vehicle factors involved in side impact compatibility are very complex. While the weight of the striking vehicle remains a significant factor, there is not a simple or direct relationship between the striking vehicle's weight and the measured probability of injury. Side impact compatibility also involves tradeoffs between the injury location both between the head, thorax, and pelvis injury measures, and between the front and rear seat occupants. Simple changes to the striking vehicle do not lead directly to a reduction in the injury criteria of the struck occupants. More research is necessary to better understand the tradeoffs and issues involved in improving side impact compatibility.

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