NHTSA'S VEHICLE AGGRESSIVITY AND COMPATIBILITY RESEARCH PROGRAM

Hampton C. Gabler
William T. Hollowell
U.S. National Highway Traffic Safety Administration
United States
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ABSTRACT

NHTSA has initiated a research program to investigate the problem of aggressive or incompatible vehicles in multi-vehicle crashes. Collisions between cars and light trucks and vans are one specific, but growing, aspect of this larger problem. Light trucks and vans (LTVs) currently account for over one-third of registered U.S. passenger vehicles. Yet, collisions between cars and LTVs account for over one half of all fatalities in light vehicle-to-vehicle crashes. In these crashes, 81 percent of the fatally-injured were occupants of the car. These statistics suggest that LTVs and passenger cars are incompatible in traffic crashes, and that LTVs are the more aggressive of the two vehicle classes. The availability of newer safety countermeasures, e.g., air bags, appears to improve compatibility indirectly by improving the crashworthiness of later model vehicles. However, the fundamental incompatibility between cars and LTVs is observed even when the analysis is restricted to collisions between vehicles of model year 1990 or later -- indicating that the aggressivity of LTVs will persist even in future fleets. This paper presents an overview of results to date from this research program.

INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) is conducting a research program to investigate the crash compatibility of passenger cars, light trucks and vans in vehicle-to-vehicle collisions. The compatibility of a vehicle is a combination of its crashworthiness and its aggressivity when involved in crashes with other members of the vehicle fleet. While crashworthiness focuses on the capability of a vehicle to protect its occupants in a collision, aggressivity is measured in terms of the casualities to occupants of the other vehicle involved in the collision. Improvements in crash compatibility may require improvements in crashworthiness coupled with simultaneous reductions in aggressivity.

The near term objective of this program is to identify and demonstrate the extent of the problem of incompatible vehicles in vehicle-to-vehicle collisions. The goal is to identify and characterize compatible vehicle designs with the expectation that improved vehicle compatibility will result in large reductions in crash related injuries. The research effort seeks to identify those vehicle structural categories, vehicle models, or vehicle design characteristics which are aggressive based upon crash statistics and crash test data. LTV-to-car collisions are one specific, but growing, aspect of this larger problem [1,2].

THE DEMOGRAPHICS OF LTV AGGRESSIVITY

During the past decade, a profound shift in the composition of the passenger vehicle fleet has been realized in the U.S.. Fueled by the growing popularity of pickup trucks, minivans, and, more recently, by sports utility vehicles, the demographics of the U.S. fleet are characterized by a growing population of light trucks and vans (LTVs). As a group, LTVs are heavier, of more rugged construction, and have higher ground clearance than the passenger cars with which they share the road. The concern is that these design features, introduced to allow specialized functions e.g. off-road driving, may make LTVs fundamentally incompatible with cars in highway crashes, and in some cases dangerous to the occupants of cars struck by LTVs.

As shown in Figure 1, registrations of LTVs currently account for over 1/3 of all light vehicle registrations (Polk, 1980-1996), and are a growing component of the U.S. fleet. During the period from 1980 to 1996, LTV vehicle registrations increased from 20 percent to 34 percent. Although LTVs only account for 1/3 of all registered vehicles, traffic crashes between an LTV and any other light vehicle now account for the majority of fatalities in vehicle-to-vehicle collisions. As shown in Table 1, in 1996 LTV-car crashes accounted for 5,259 fatalities while car-car crashes led to 4,013 deaths and LTV-LTV crashes resulted in 1,225 fatalities.

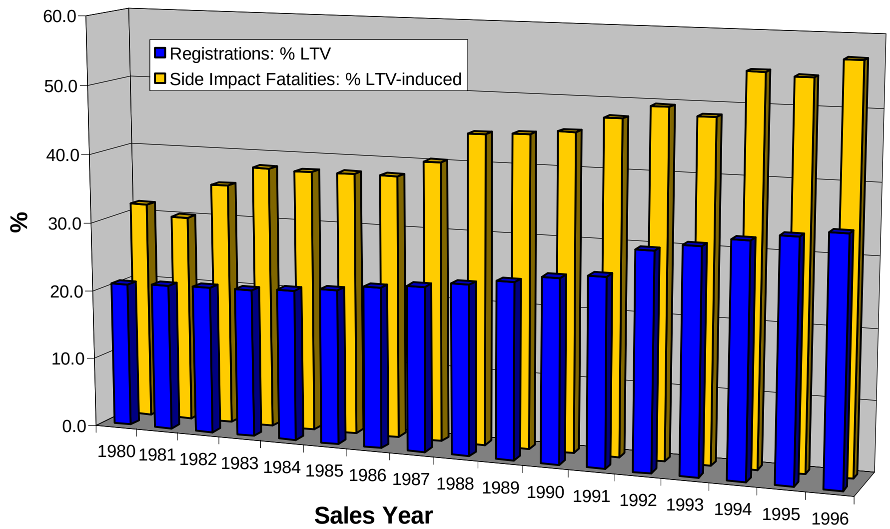

Figure 1. LTV Registrations vs. LTV-induced Side Impact Fatalities.
(Based on U.S. Light Truck and Van Registrations as a fraction of light vehicle registrations, R.L. Polk Co., 1980-96, and Side Impact Fatalities resulting from LTVs striking passenger cars and other LTVs as a fraction of total side impact fatalities, FARS 1980-96).

Year	All car-car	All LTV-car	All LTV-LTV	Total
1980	6506	3580	510	10596
1981	6510	3292	482	10284
1982	5437	3452	556	9445
1983	5157	3408	505	9070
1984	5340	3540	593	9473
1985	5174	3608	635	9417
1986	5450	3895	660	10005
1987	5489	4277	788	10554
1988	5320	4676	802	10798
1989	5175	4730	861	10766
1990	4726	4719	867	10312
1991	4482	4297	873	9652
1992	4208	4421	804	9433
1993	4364	4451	977	9792
1994	4219	4972	1059	10250
1995	4097	5238	1183	10518
1996	4013	5259	1225	10497

Table 1. Fatalities in Light Vehicle-to-Vehicle Crashes

Year	Car into Car	Car into LTV	LTV into Car	LTV into LTV	Total
1980	2071	170	962	78	3281
1981	2077	161	876	87	3201
1982	1881	174	1015	102	3172
1983	1848	190	1134	118	3290
1984	1996	153	1186	122	3457
1985	1943	178	1168	130	3419
1986	2149	192	1285	147	3773
1987	2121	246	1382	216	3965
1988	2026	262	1645	194	4127
1989	2144	231	1697	238	4310
1990	1976	255	1628	234	4093
1991	1812	216	1614	232	3874
1992	1705	252	1698	223	3878
1993	1759	224	1609	256	3848
1994	1667	229	1983	318	4197
1995	1749	237	2049	316	4351
1996	1613	276	2181	314	4384

Table 2. Light Vehicle-to-Vehicle Side Impacts: Fatalities in Side-Struck Vehicle

Year	Car-Car	Car-LTV (LTV Fatals)	Car-LTV (car Fatals)	LTV-LTV	Total
1980	3395	521	1254	303	5473
1981	3331	422	1208	278	5239
1982	2731	463	1197	330	4721
1983	2465	400	1115	283	4263
1984	2515	434	1159	351	4459
1985	2420	415	1217	362	4414
1986	2440	461	1289	373	4563
1987	2493	483	1407	404	4787
1988	2398	487	1498	437	4820
1989	2238	481	1478	446	4643
1990	2056	500	1538	450	4544
1991	1964	437	1321	432	4154
1992	1857	448	1282	418	4005
1993	1899	439	1460	543	4341
1994	1956	442	1548	521	4467
1995	1692	510	1658	656	4516
1996	1776	453	1529	651	4409

Table 3. Fatalities in Light Vehicle-to-Vehicle Frontal Impacts

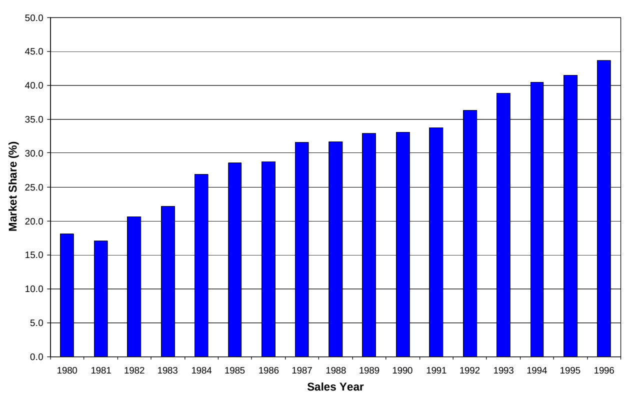

Figure 2. U.S. Sales of LTVs from 1980-1996 expressed as a fraction of light vehicle market share (Automotive News Market Data Book).

A disproportionate number of the fatalities in LTV-car crashes are incurred by the car occupants. Of the 5259 fatalities in LTV-car crashes in 1996, 81 percent of the fatally-injured were occupants of the car. As shown in Figure 1 and tabulated in Table 2, side impacts in which an LTV was the bullet vehicle led to 56.9 percent of all fatalities in side struck vehicles. As shown in Table 3, in 1996, frontal impacts in which an LTV was involved accounted for 2633 deaths (or 59.7%) of the 4409 fatalities in frontal impact in that year.

These statistics suggest that LTVs and passenger cars are incompatible in traffic crashes, and that LTVs are the more aggressive of the two vehicle classes. In particular, crashes with an LTV cause a disproportionate number of vehicle-to-vehicle fatalities.

Fatalities and injuries which arise from the incompatibility of LTVs and cars is a growing problem. As shown in Figure 2, LTV market share has risen steadily from 1980 to 1996 [2]. LTVs captured over 43 percent of all light vehicle sales in 1996. Comparison of LTV registrations and LTV-caused fatalities over the same period show that LTV impacts have always caused a disproportionate number of vehicle-to-vehicle fatalities. For example in 1980, LTVs accounted for 20 percent of the registered light vehicle fleet, but side impacts in which an LTV was the bullet vehicle led to 31 percent of all fatalities in side struck vehicles. The magnitude of this problem then is not only due to the aggressivity of LTVs in crashes, but also the result of the dramatic growth in the LTV fraction of the U.S. fleet.

PROBLEM DEFINITION

The research program examined U.S. crash statistics to determine the characteristics and extent of the vehicle compatibility problem. One obstacle to quantifying the compatibility of a vehicle is the lack of an accepted measure of compatibility. A primary objective of our research effort was to develop a clearly defined metric for measurement of vehicle aggressivity. To date, the NHTSA aggressivity research program has developed two potential aggressivity metrics.

Option 1:

$$Aggressivity = \frac{\text{Fatalities in collision partner}}{\text{Registrations of subject vehicle}}$$

Option 2:

$$Aggressivity = \frac{\text{Driver Fatalities in collision partner}}{\text{Number of Crashes of subject vehicle}}$$

The first metric was used in our early Aggressivity research as reported at the 15th ESV conference [2]. For each vehicle make / model, this metric determines the number of fatalities in the collision partner resulting from collisions with the subject vehicle. Only two-vehicle crashes in which both vehicles were either a car or an

LTV are considered. The fatality count is normalized by the total number of registrations of the subject vehicle so that vehicles with large populations are not unfairly penalized. Using this metric, the U.S. fleet was rank ordered by aggressivity as presented at the 15th ESV conference. This initial study indicated that LTVs as a group were twice as aggressive in crashes as passenger cars -- i.e., per vehicle, LTVs caused more than twice as many fatalities in their collision partners as do cars.

The second, more recent, metric represents a refinement to the earlier definition of aggressivity. The second metric defines aggressivity to be the number of driver fatalities in the collision partner normalized by the number of vehicle-to-vehicle crash involvements of the subject vehicle. Only two-vehicle crashes in which both vehicles were either a car or an LTV are considered in computing the fatality count and the crash involvement count. One of the confounding factors in determining aggressive vehicle designs is aggressive driver behavior. Because aggressive drivers are involved in more crashes than less aggressive drivers, normalizing by the number of crashes rather than vehicle registrations focuses the metric more on vehicle performance and less on driver behavior. Note also that the second metric keys on driver fatalities rather than all fatalities in the struck vehicle. Because all vehicles have only one driver, this refinement avoids any biases accruing from differences in vehicle occupancy rate between, for example, pickup trucks and minivans.

Approach

The analysis for the second metric used statistics from the Fatality Analysis Reporting System (FARS) to determine the number of fatalities, and statistics from the General Estimates System (GES) to determine the number of crash involvements. FARS provides a comprehensive census of all U.S. traffic related fatalities. GES is a large sample of over 60,000 police reported crashes collected annually. The scope of our analysis was constrained to cars, light trucks, and vans under 10,000 pounds in Gross Vehicle Weight Rating (GVWR). The focus was further narrowed to two vehicle collisions in which the vehicles were either cars or LTVs. The fatality counts in the struck vehicle were limited to driver fatalities.

Note that because GES is a sample of police-reported crashes, estimates from GES are subject to both sampling and nonsampling errors [9]. Initial analysis of GES revealed that approximately half of the make and model codes in this database were listed as unknown. For those GES cases with valid Vehicle Identification Numbers (VINs), the make and model was obtained by decoding the VIN using a combination of the VINDICATOR code, developed by the Highway Loss Data Institute, and the VINA code, developed by the R.L. Polk Company [4]. However, even after decoding the VINs, approximately 20 percent of all vehicle make and models remained unknown. The number of crash involvements for all vehicles was weighted accordingly in order to preserve the total number of crashes. Although this strategy maintains the total count of crash involvements, this approach has the disadvantage of preserving any reporting biases. An improved approach would be to explore the missing data as a function of vehicle body type and model year, and prorate unknown make-models within these categories if biases exist.

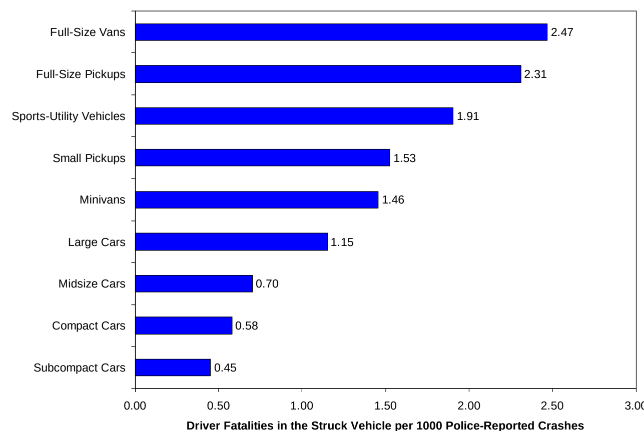

Figure 4. Vehicle Aggressivity by Vehicle Category (FARS/GES 1991-94).

Overall Fleet Aggressivity Ranking

The second metric, hereafter referred to as the aggressivity metric (AM), was used to rank order all passenger vehicles, cars and LTVs, by their relative aggressivity using 1991-94 FARS and GES. Only current production vehicles with at least 10,000 police-reported crashes over the period of 1991-94 were included in the ranking. The vehicles in the aggressivity ranking was aggregated by vehicle family into five categories of LTVs – sports utility vehicles, full-sized pickups, small pickups, minivans, and full-sized vans – and four categories of passenger cars – large, midsize, compact, and subcompact. The categories assigned to each vehicle were as tabulated in the Automotive News Market Data Book [3]. This study grouped luxury, near luxury, and large cars into a single large car category.

As shown in Figure 4, full-sized vans were found to be the most aggressive vehicle category with an AM = 2.47. This category was closely followed by Full-Size Pickups (AM=2.31), Sports-Utility Vehicles (AM = 1.91), and small pickups (AM = 1.53). Minivans were the least aggressive of all LTV groups with an average

AM = 1.46. The AM of passenger cars was significantly lower and ranged from AM= 0.45 for subcompacts to AM=1.15 for large cars.

Vehicle weight is not always the overriding factor dictating aggressivity as clearly demonstrated by Figure 4. Mid-sized cars, e.g., the Ford Taurus, and the small pickups, e.g., the Ford Ranger, both have approximately the same curb weight of 3,000 pounds. However, small pickups (AM = 1.51) are over twice as aggressive as mid-sized cars (AM = 0.70). The higher aggressivity of the small pickup class may be due to its greater structural stiffness and its higher ride height.

Among cars, the Aggressivity Metric is a strong function of vehicle weight. AM for the large car category, e.g., the Ford Crown Victoria, is 1.15. This is two to three times higher than the AM for the subcompact car category, e.g., Geo Metro, which is 0.45. The conservation of momentum in a collision places smaller cars at a fundamental disadvantage when the collision partner is a heavier vehicle. The importance of car size in providing occupant protection has been demonstrated in several studies of the U.S. crash statistics [5,6].

Aggressivity by Impact Mode.

Having established that LTVs are incompatible with cars in traffic crashes, the next requirement was to determine the relationship between aggressivity and impact direction. The analysis computed the ratio of driver fatalities in the subject vehicle vs. driver fatalities in the collision partner for cars versus each of five LTV categories: full-size vans, minivans, utility vehicles, small pickup trucks and full-size pickup trucks. The counts of fatalities were obtained from 1992-96 FARS. All occupant restraint conditions, i.e., belts, air bags, and no restraints, were included.

As noted by Joksch [7], driver age has a strong effect on the evaluation of crashworthiness and aggressivity. Younger drivers are more injury tolerant and, therefore, less likely to die from their injuries. In contrast, older drivers are less injury tolerant, and are less likely to die from their injuries. Using the approach developed by Joksch, the results presented below were corrected for the bias which would be introduced by differences in age between the two colliding drivers by restricting the analysis to cases in which both drivers were of age 26-55.

It should be noted in the discussion which follows that this analysis was based on small numbers of fatal crashes (on the order of a hundred for each case), and the results should be regarded as preliminary. For example, in the case of minivans striking cars in side impact, the ratio of 16:1 was determined based upon 106 fatalities in the car versus 7 fatalities in the minivan. For this particular case, note that small changes in the number of minivan fatalities would make large differences in the fatality ratio.

The ratio of driver fatalities in the subject vehicle to driver fatalities in its collision partner driver resulting from frontal-frontal impacts is presented in Figure 5. In collisions between full-size vans and cars, 6 drivers died in the car for every driver who was killed in the van. In collisions between full-size pickup trucks and cars, 5.3 drivers died in the car for every driver who was killed in the pickup. In collisions between utility vehicles and cars, 4.1 drivers died in the car for every driver who was killed in the utility vehicle. Clearly, the fatality toll in car-LTV frontal crashes is disproportionately shouldered by the drivers of passenger cars.

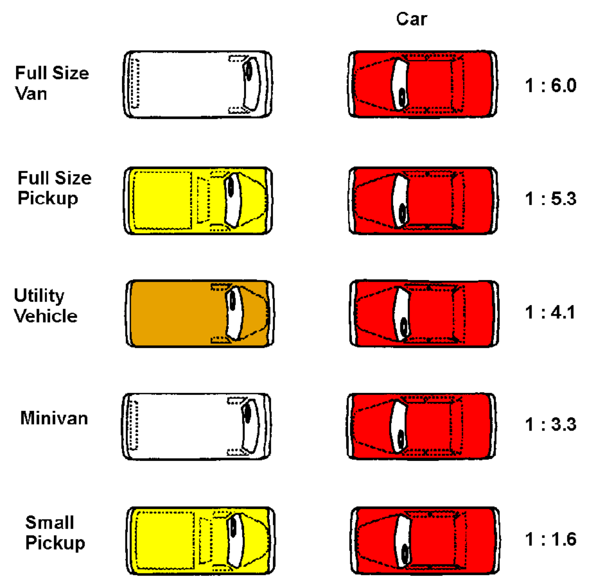

Figure 5. Ratio of Fatally-Injured Drivers in LTV-to-Car Frontal Collisions. FARS 1992-96.

The ratio of striking-to-struck driver fatalities resulting from side impacts are presented in Figure 6. This analysis includes both left and right side impacts. As a control configuration, note first that in car-to-car impacts approximately 6 side-struck drivers are fatally injured for every fatally-injured driver in the bullet car. This imbalance is not unexpected as the side structure of passenger vehicles provides little protection for the side-struck occupant when compared with the significantly greater protection afforded by the front structure to the bullet vehicle driver.

The analysis is even more startling for LTVs striking cars in side impact. As shown in Figure 6, 23 side-struck car drivers are fatally injured for every driver who dies in a striking full-size van. For every driver who dies in a striking utility vehicle, 20 side-struck car drivers are fatally injured. For every fatally-injured driver of a striking full-size pickup truck, 17 side-struck car drivers are killed.

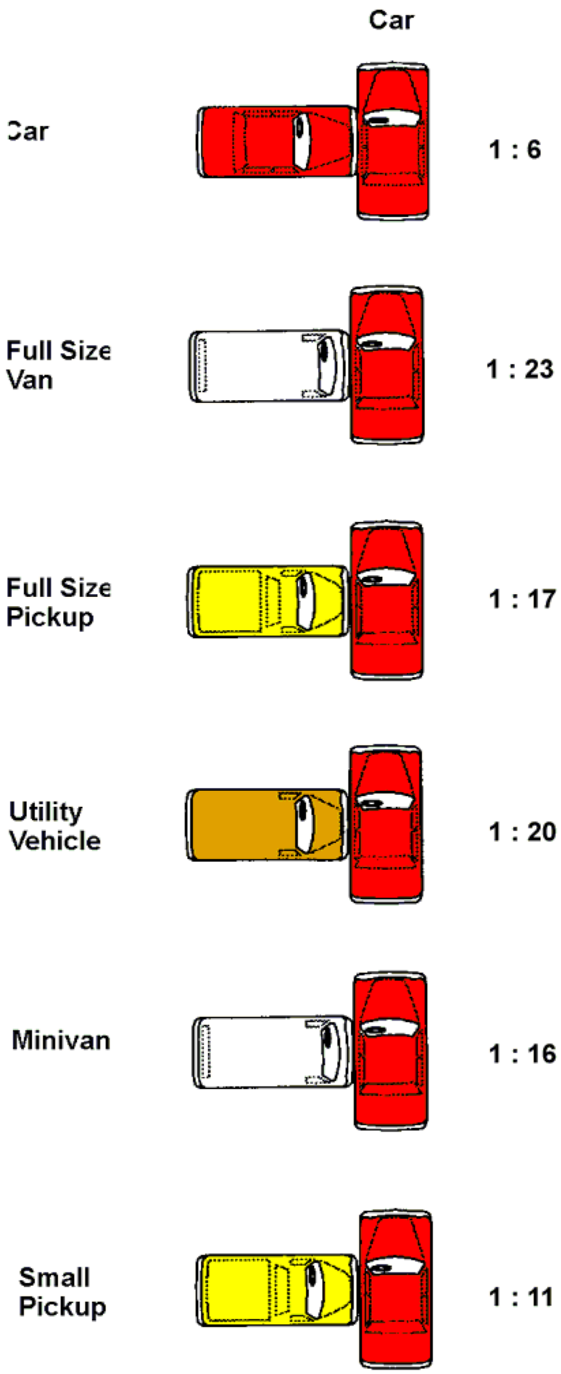

Figure 6. Ratio of Fatally-Injured Drivers in LTV-to-Car Side Impacts. FARS 1992-96.

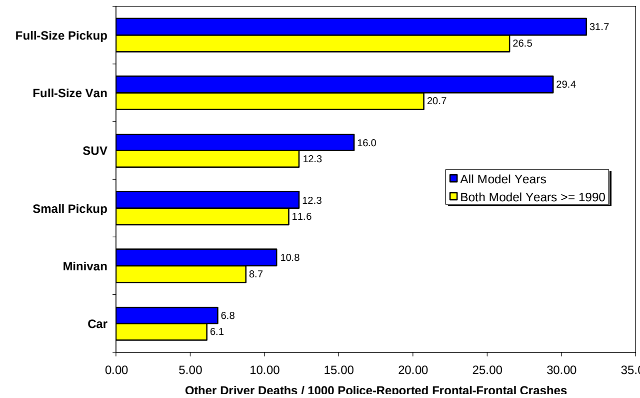

Figure 7. Aggressivity by Vehicle Category in Frontal-Frontal Impacts. (1992-96 FARS and GES)

Aggressivity in Future Fleets

The previous analyses have examined crash compatibility in vehicle-to-vehicle collisions between cars, light trucks and vans in the current fleet, and included all model years. Recent model year cars and LTVs however have safety countermeasures, e.g., air bags which were not available in earlier models, but will be a standard component of future fleets. To understand the nature of aggressivity of light trucks and vans in future fleets, the preceding analyses were repeated for vehicle-to-vehicle collisions in which both vehicles were of model year 1990 or later.

Because a filter of this type sharply restricts the number of cases available for analysis, sufficient numbers were not available to compute meaningful fatality ratios. However, sufficient counts were available for calculation of the Aggressivity Metric presented earlier. The analysis presented below were based on 1992-96 FARS and GES for frontal vehicle-to-vehicle collisions in which both vehicles were either a car or LTV of model year 1990 or later. Note that by examining frontal impacts only, the analysis focuses on the effect of widespread air bag availability in future fleets.

Figure 7 presents aggressivity by vehicle category for all frontal-frontal collisions (no restriction on model year), and for frontal-frontal collisions in which both vehicles were of model year 1990 or later. Comparing the two aggressivity rankings, with and without the model year restriction, the first observation is that, for the late model fleet, the aggressivity metric is lower for all vehicle categories. This is presumably due more to the availability of airbags in the struck vehicle than due to any reduction in aggressivity in the striking vehicle. The second observation is that, despite a reduction in the aggressivity metric in the later model fleet, in every case

LTVs were more aggressive as a group than were cars. The conclusion is that, even with an airbag-equipped late model fleet, there persists a fundamental incompatibility between cars and LTVs in frontal impacts.

WHY ARE LTVS MORE AGGRESSIVE?

The preceding analysis of crash statistics has clearly demonstrated the incompatibility between cars and LTVs in highway crashes. Still remaining to be determined however are the design characteristics of LTVs which lead to their incompatibility with cars. In general, crash incompatibility arises due to the three factors:

- Mass Incompatibility.
- Stiffness Incompatibility
- Geometric Incompatibility.

The following section will examine the relationship between LTV-car compatibility and these sources of incompatibility.

Mass Incompatibility

LTVs are 900 pounds heavier than cars on average [6]. The conservation of momentum in a collision places smaller vehicles at a fundamental disadvantage when the collision partner is a heavier vehicle. As shown in Figure 8, LTVs, as a group, tend to be heavier than passenger cars [8]. Figure 8 crossplots AM as a function of vehicle weight, and demonstrates the relationship between mass and aggressivity.

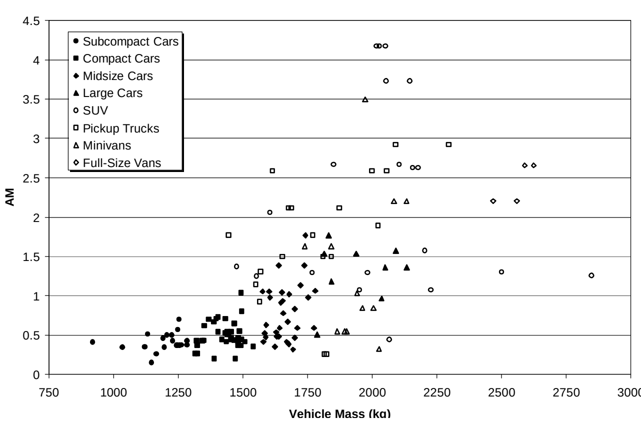

Figure 8. Aggressivity as a function of Vehicle Mass.

Stiffness Incompatibility

As a group, LTV frontal structures are more stiff than passenger cars. LTVs frequently use a stiff frame-rail design as opposed to the softer unibody design favored for cars. Drawing on NHTSA New Car Assessment Program crash test results, the linear stiffness of a selection of LTVs and cars was estimated using the following relationship:

$$k = (mv^2) / x^2 \text{ (Eqn. 1)}$$

where m is the mass of the vehicle, v is the initial velocity of the vehicle, and x is the maximum dynamic crush of the vehicle. The relationship between linear stiffness and AM is shown in Figure 9. Figure 9 indicates that stiffness is a contributing factor to the aggressivity of a vehicle. Because the stiffness of a vehicle is also somewhat related to its mass, as shown in Figure 10, stiffness may not prove to be as dominant an aggressivity factor as mass. Although stiffness and mass are related in many cases, stiffness is not totally driven by the mass of the vehicle. Figure 10 shows that for any given mass, there is a wide distribution of linear stiffness values. For example for 1750 kg vehicles, the least stiff vehicles are passenger cars while the most stiff vehicles are LTVs.

Figure 11 compares the frontal stiffness of a Ford Taurus and a Ford Ranger pickup. Both vehicles have approximately the same mass, but note that the Ranger pickup is significantly stiffer than the Taurus. In a frontal collision between the two, the bulk of the crash energy would be absorbed by Taurus and the Taurus occupants. Far less energy would be absorbed by the Ranger. From a compatibility perspective, a more ideal scenario would be for the Taurus and Ranger structures to each share the crash energy rather than forcing one of the collision partners to absorb the bulk of the crash.

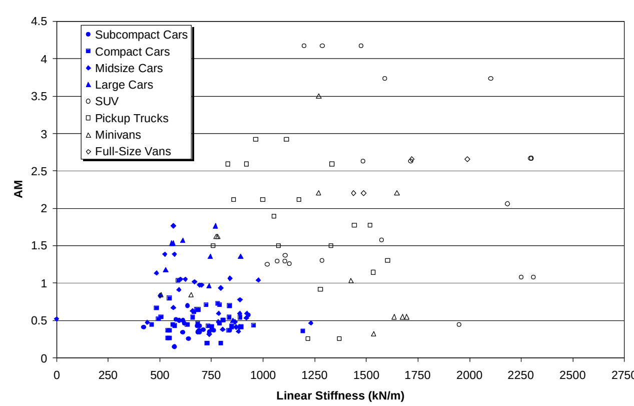

Figure 9. Aggressivity as a Function of Linear Stiffness as computed from NCAP crash test results.

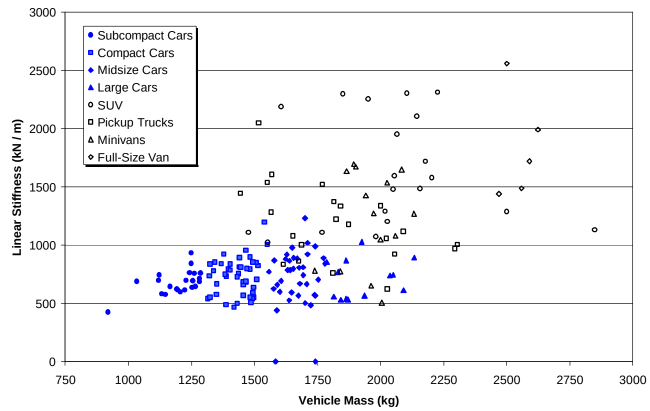

Figure 10. Relationship between Frontal Stiffness and Vehicle Mass as determined from NCAP Crash Tests.

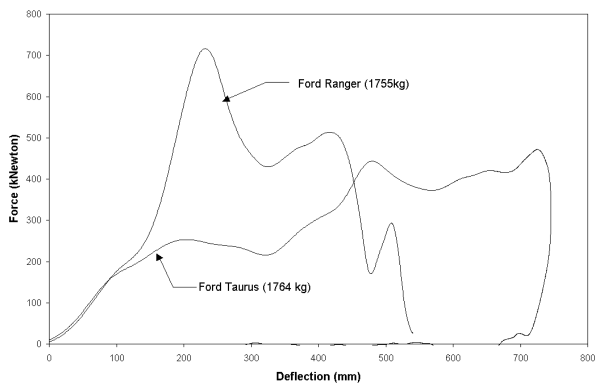

Figure 11. Frontal Stiffness: Small Pickup (Ford Ranger) vs. Midsize Car (Ford Taurus)

Geometric Incompatibility

LTVs, especially four-wheel drive sport utility vehicles, ride higher than cars. This creates a mismatch in the structural load paths in frontal impacts, and may prevent proper interaction of the two vehicle structures in a collision. In a side impact, this imbalance in ride height allows the LTV structure to override the car door sill, and contributes to the intrusion of the side-impacted vehicle.

Ideally, the ride height used in an analysis of this type would be the height of the forward-most load bearing structural member of the vehicle. The location of this forward-most structural element however has no precise definition, and must be estimated from other measurements. Some analyses have used bumper height as the height of this load bearing member. However, because in the U.S., the bumper must only meet a 2-½ mile/hour bumper impact standard, and LTVs have no bumper standard, our belief is that, with respect to occupant protection, bumpers are largely ornamental, and their location provides little evidence of the location of load bearing members. The rocker panel, on the other hand, is a much more substantial structural member, and because the rocker panel is typically lower than the forward-most structure, serves as a superior lower bound on the location of the frame structure.

Figure 12 shows that ride height is related somewhat with vehicle mass. For this analysis, ride height is defined to be the ground clearance to the bottom trailing edge of the front wheel well [8]. However note that the rocker panel height across all masses of passenger cars is relatively consistent – perhaps due to the bumper standard with which all passenger cars must comply. On the other hand, LTVs, which have no bumper standard, exhibit a wide variation in ride height and are in general much higher than passenger cars.

Figure 13 presents average ride height by vehicle category. Sport utility vehicles have the highest ride height with an average rocker panel height of 390 mm. Subcompact cars have the lowest-riding height with an average rocker panel height of 175 mm. SUVs ride almost 200 mm higher than mid-sized cars – a geometric incompatibility that would readily permit the SUV to override any side structure in a car and directly strike the car occupant.

It should be noted that the data for the preceding analysis was drawn from AAMA Vehicle Specification Sheets supplied by vehicle manufacturers, and collected in the NHTSA Vehicle Attributes Database [8]. While geometric data was available for most passenger car models, the Vehicle Specification sheets for LTVs was much more limited. The LTV data presented here was primarily obtained from foreign manufacturers, and contains no data on full-sized pickups or vans.

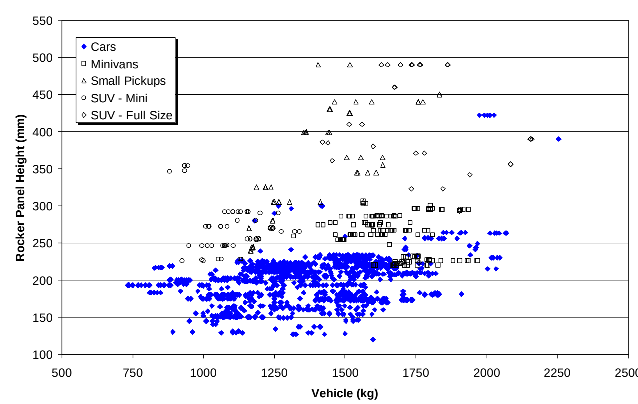

Figure 12. Relationship between Vehicle Mass and Ride Height as estimated by Rocker Panel Height. Reference: AAMA Vehicle Specification Sheets (1990-94).

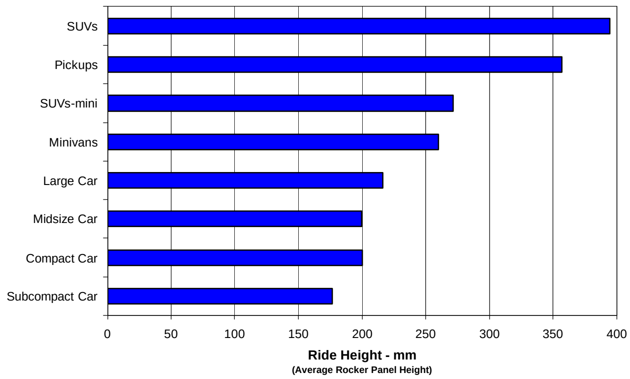

Figure 13. Geometric Compatibility: Average Ride Height vs. Vehicle Category as determined from AAMA Vehicle Specification Sheets (1990-94).

DISCUSSION

The study presented in this paper based its measure of aggressivity upon fatalities per 1000 police reported crashes. No effort was made to control for the severity of the crashes as this information is not available in the GES files. Some make-model vehicles, such as high performance sports cars, may have more severe crashes more because of the driver than because of the vehicle structure. Normalizing fatalities by number of crash involvements removes much of this driver aggressivity effect but does not completely eliminate this effect. Future work will explore refinements to the aggressivity metric which account for crash severity in addition to crash frequency.

The aggressivity metric used in this study assumes that all make-models strike the same cross-section of the vehicle population, i.e., the same proportion of small cars, large cars, minivans, pickups, and so forth. The influence of this assumption upon the aggressivity ranking will be explored in future work. Joksch [7] has noted that the age distribution of struck drivers varies somewhat from make-model to make-model. As injury tolerance is a strong function of age, his analysis suggests an additional refinement to the aggressivity metric which corrects for any differences in age distribution from vehicle model to model.

The crash statistics presented in this paper demonstrate a clear incompatibility between cars and LTVs. A comparison of mass distribution, stiffness distribution, and ride height geometry confirm that these two categories of vehicles are incompatible from a design point-of-view. However, this study has not attempted to assign what proportion of the aggressivity of LTVs is a function of each of these three separate sources of incompatibility. To determine the relationship between LTV design features and crash aggressivity, NHTSA plans to conduct a series of LTV-to-car crash tests in conjunction with a series of finite element simulations of LTV-to-car crash events.

FUTURE WORK

Compatibility between light trucks and cars is one aspect of a larger study at NHTSA on improving crash compatibility between all categories of light passenger vehicles. Improvements in crash compatibility, in general, and between light trucks and cars, specifically, will likely require design modifications to the struck vehicle, to improve its crashworthiness, as well as to the striking vehicle to reduce its aggressivity. This paper has reported on problem definition based upon U.S. crash statistics. Follow-on work is underway or planned which will expand upon these initial analyses as a precursor to potential rulemaking in this area. Specific tasks include:

- **Crash Testing.** To demonstrate and better understand the nature of the compatibility problem, in general, and the LTV aggressivity problem specifically, NHTSA is currently conducting a series of crash tests in which a mid-sized car is impacted by (1) a small pickup, (2) a sports-utility vehicle, (3) a minivan, and (4) another mid-sized car. Both frontal-side and frontal-frontal impact modes will be investigated for a total of eight tests.

  These crash test results will be coupled with the results of detailed finite element simulations to suggest design enhancements necessary to improve compatibility. The results of this study may also serve as the foundation to determine directions for any potential rulemaking in this area. Additional tests will be conducted based on results of the first test series.

- **Simulation and Systems Modeling.** This task will develop a large scale systems model which will evaluate vehicle crashworthiness based on the safety performance of the vehicle when exposed to the entire traffic accident environment, i.e., across the full spectrum of expected collision partners, collision speeds, occupant heights, occupant ages, and occupant injury tolerance levels. The foundation for the Systems model will be a comprehensive suite of finite element models and articulated mass models constructed to represent nine light vehicle categories -- five LTV and four passenger car – and their occupants.

- **Test Procedure Development**. Development of test procedures and test devices for a standardized evaluation of vehicle aggressivity/compatibility.

- **International Harmonization Efforts**. Under this task, NHTSA will collaborate with international regulatory bodies and research organizations in vehicle compatibility research, e.g., the International Harmonized Research Activities committee. This committee was organized at the 15th ESV Conference and is led by representatives of the EC/EEVC. This will be a challenging effort due to differences in U.S. and international fleet composition (i.e., the U.S. has a large LTV fleet constituent which is not present in other continents/countries).

CONCLUSIONS

This paper has examined the compatibility of LTVs and cars in vehicle-to-vehicle collisions. Using struck driver fatalities per crash involvement of the subject vehicle as an aggressivity metric, examination of U.S. crash statistics has clearly shown a striking incompatibility between cars and all categories of LTVs. LTVs now account for over one-third of light vehicles on U.S. highways, but collisions between cars and LTVs lead to over 50% of all fatalities in light vehicle-to-vehicle collisions. Furthermore, a disproportionate number of the fatalities in LTV-car crashes are incurred by the car occupants. The availability of newer safety countermeasures, e.g., air bags, appears to improve compatibility indirectly by improving the crashworthiness of later model vehicles. However, the fundamental incompatibility between cars and LTVs is observed even when the analysis is restricted to collisions between vehicles of model year 1990 or later -- indicating that the aggressivity of LTVs will persist even in future fleets. A comparison of LTVs and cars reveals that LTVs are more aggressive than cars for a number of reasons including their greater weight, stiffer structure, and higher ride height. This mismatch in design has serious consequences for crash safety as approximately one-half of all passenger vehicles sold in the U.S. are LTVs, and presents a growing source of incompatibility within the fleet.

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