



## Aggressivity Literature Review

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### **Major Findings:**

- Light trucks are more aggressive than cars. Some studies suggest that SUVs are the most aggressive, others suggest that pickups and large vans are the most aggressive.
- Design, weight, height, stiffness, curvature of a vehicle's front end, width, mass, geometry, and vehicle quality all correlate with vehicle aggressivity.
- Reduced vehicle weight does not necessarily result in vehicle safety.
- In 1996, 2000 lives could have been saved if light truck drivers had instead chosen to drive cars of the same weight as the trucks they did drive.
- A lower load path in a crash is preferable and less likely to cause a fatality in side impact crashes.
- Stiffness and center of force for vehicles, as measured in load cell tests, vary with vehicle weight, showing that weight alone does not adequately account for variations in aggressivity.
- The combined risk of SUVs and pickups (both to their drivers and to drivers of vehicles struck by them) is higher than the risk of other vehicle types. Ford, General Motors and Daimler Chrysler have higher risk rates for their combined fleets than do Nissan, Honda, and Toyota.
- The occupants of large cars and small SUVs are similarly vulnerable to fatalities when struck by other vehicles.
- In crashes between two light trucks, drivers are at more of a risk than in crashes between two cars.
- Discussions about crashworthiness have led to a misconception about the net effect of vehicle size on road safety, skewing policy and vehicle redesign discussions away from aggressivity and towards occupant protection.
- Manufacturers should be held liable for the unnecessary danger posed by SUVs because of their aggressive design.

**Some suggested remedies:**

- The most aggressive light trucks should be made to be less aggressive:
  - Make light trucks less stiff.
  - Reduce design incompatibilities and gross differences among vehicles.
  - Build SUVs on car chassis, not pickup chassis.
  - Lightweight materials should be used more often, as should technologies that can lighten the heaviest vehicles without compromising their performance or safety.
- Courts should hold manufacturers liable for SUV aggressivity in order to provide incentives for manufacturers to redesign them.

**Areas for additional research:**

- An aggressivity matrix should be developed that:
  - Establishes a realistic model and accounts for confounding variables such as speed, age of driver, time of day, etc.
  - Accurately corresponds with FARS and NASS data.
  - Uses the maximum possible range of model years and crash dates.
- Additional load cell advancements would enable researchers to more accurately map crash pulses and suggest vehicle modifications that would improve safety. Also, developments in load cell testing would analyze the findings in conjunction with real-world crash data.

## Literature Review

### **Aggressivity – design and compatibility**

Stephen M. Summers, Alope Prasad, William T. Hollowell, “NHTSA’s Research Program for Vehicle Aggressivity and Fleet Compatibility,” Proceedings of the Seventeenth International Conference on Enhanced Safety of Vehicles, Paper No. 249, Amsterdam, Netherlands. June 2001.

- **Findings:**

- The steady increase in light trucks is leading to a steady increase in fatalities in cars struck by light trucks. This increase is occurring as overall fatalities in the U.S. are stabilizing or declining.
- The aggressivity metric – the fatality rate discussed in this report – is defined as:
  - $\text{Aggressivity} = \text{Fatalities in collision partner} / \text{Number of crashes of subject vehicle}$  (using 1995-1999 FARS and GES data for 2-vehicle crashes, both under 10,000, with model years >1990, counting deaths for drivers between 26-55).
- For all crashes (frontal, side, and rear) the fatality rate (aggressivity metric) for large vans (3.12) and large pickups (2.89) is over three times the fatality rate for large cars (.083) and SUVs (large 2.10, small 1.51) have around twice the fatality rate of large cars. Small pickups (1.34) weighing the same as large cars still have nearly twice the fatality rate.
- Frontal-frontal impact crashes have higher fatality rates (aggressivity metrics) across the board than all two-vehicle crashes combined. The frontal-frontal aggressivity metrics range from large pickups (69.27) to minicars (5.45). Frontal-side crashes have lower fatality rates than do frontal-frontal crashes, but also have rates higher than the combined two-vehicle rates. The frontal-side metrics range from large pickup (4.02) to minicar (0.33). The relative rankings, however, for both frontal-frontal and frontal-side crashes are similar to the rankings for the combined crashes and identical to each other.
- The “vulnerability metric” for struck cars in side impact crashes ranks shows minicars to be highly vulnerable (6.79) followed by subcompact cars (1.92), compact cars (1.68) and midsize cars (1.53). Notably, large cars (1.10) and small SUVs (0.98) have relatively similar rankings, leaving minivans (0.53) as the least vulnerable followed by compact pickups (0.76). Large vans, pickups and SUVs were omitted.
- Aggressivity estimates are strongly, but not completely, related to weight differences.
  - The researchers addressed weight and aggressivity by conducting crash tests, crashing Chevy S-10 pickups, Chevy Lumina (passenger cars), Dodge Caravans (minivans), Ford Explorers (SUVs), and Chevy K2500s (pickups) with Honda Accords (passenger cars). The results of the basic oblique offset test used correlated with the weight and aggressivity metrics. The side impact tests did not correlate with the aggressivity metrics.
  - Increasing the weight of the Lumina (+251 kg – 14 percent of the vehicle’s original weight) as a striking vehicle had a stronger effect on the injury

potential than increasing the ride height (+90 mm) (increased driver pelvic injury, decreased rear seat passenger injury).

- Decreasing the height of the K2500 (-177) as a striking vehicle had a stronger effect than decreasing the weight (-520 – 20 percent of the vehicle’s original weight).
- **Vehicle factors addressed:** Aggressivity metric, weight, ride height,

Hans Joksh, “Vehicle Design versus Aggressivity,” Report No. DOT HS 809 194, April 2000.

- **Findings:**
  - This is the report from which Bradsher concluded that 2,000 lives had been lost because people chose to drive light trucks instead of passenger cars.
  - Study included all collisions involving car and light trucks, including front-front, front-left, front-right, where the vehicle struck in the side was a car as reported by FARS and NAS 1991-1997.
  - Aggressivity ratios, using a model based on the numbers of struck-vehicle occupants that would have survived had the striking light truck been a car of the same weight and if the crash occurred under the same speed limit, were: car (1.0), SUV (3.4), van (1.9), pickup truck (2.3).
  - Weight, height of center of force, static stiffness, and dynamic stiffness are all correlated with aggressivity when testing all vehicles together.
  - For SUVs and pickups, weight, the height of the center of force, static stiffness, and dynamic stiffness showed all positive relations with aggressivity. For SUVs, the effect of weight appeared strongest, for pickups the effect of static stiffness.
  - The aggressivity of SUVs is higher than that of vans or pickups.
  - A model including vehicle weight and the height of the center of force and broken down into make/model corresponds well with the data for overall aggressivity for these vehicles and explains the aggressivity of SUVs better than the rest of the vehicle groups studied, yet the model continues to need modification to adequately predict aggressivity for all vehicle types.
- **Vehicle factors addressed:** Internal factors: driver’s age, sex, availability of an air bag, vehicle weight. External factors: speed limit of highway, ratio of the two vehicles’ weights, weight of striking vehicle. They did not use age, speed limit, sex, or air bag availability in their final analysis. They also looked at height of center of force and static and dynamic front stiffness, as measured in crash tests.
- **Remedies:** Findings about co-varying factors suggest a engineering review of the Isuzu Trooper because if the Trooper were excluded from the study, stiffness would be an adequate predictor of aggressivity while weight and height are not. Likewise, including the Trooper makes weight and height strong predictors and stiffness has no effect. A review of the Trooper might help researchers determine whether it has specific features that distinguish it from other SUVs and which of these features increase aggressivity.

Richard Tay, "Tin Cans of Assault Vehicles? The Role of Crashworthiness and Non-aggressiveness in Vehicle Safety Design, Promotion and Regulation" *International Association of Traffic and Safety Sciences Research*, 26(2), 92-98 (2002).

- **Findings:**

- The conventional discussion of crashworthiness has led to a misconception about the safety effects of vehicle size on road safety and to a program of vehicle safety regulation that focuses on occupant protection, not aggressivity.
- While larger cars, including SUVs, are safer in terms of occupant protection, smaller cars are actually safer in their net effects because they have a lower level of aggressivity.
- Japanese, US and Australian research point to similar conclusions.
- It is both selfish and unsafe to choose a large car over a small one because while it makes the driver 'more safe,' it raises the overall fatality risk for all drivers. Likewise, a trend of a shift towards smaller cars would reduce overall traffic fatalities.
- Fatality rates of small cars in the U.S. and Japan are significantly lower than the rates for larger cars. He suggests that this might be due larger car driver driving more recklessly because of their assumed protection over small cars in accidents, therefore making small car drivers relatively more cautious.

**Vehicle factors addressed:** Size.

- **Remedies:** Focus information campaigns and policy on aggressivity reduction, not occupant protection. Policy makers and media should provide a more complete set of vehicle safety information and research programs should devote more effort to aggressivity.

### **Aggressivity and Legal Precedent**

Howard Latin and Bobby Kasolas, "Bad Designs, Lethal Profits: The Duty to Protect Other Motorists against SUV Collision Risks," *Boston University Law Review*, December 2002.

- **Findings**

- SUV are dangerous products and manufacturers of them should be held liable for the design defects that have led to their high level of aggressivity.
- The problems with SUVs are more than the weight and size which are inherent to them – design, stiffness, height, width, and curvature of a vehicle's front end (etc.) are also important.
- A judge has found that manufacturers have "no duty" to protect other occupants. The "no duty" decisions are wrong, however, based on precedent products liability law – particularly "bystander" case precedents.
- The manufacturers' indifference to the dangers posed by their SUVs has led to billions of dollars in profits for industry while thousands of motorists, hit by SUVs, have had no way to protect themselves or recoup damages.
- Three crash types looked at:
  - Rollover – if SUV occupants can bring defects cases against manufacturers for design problems leading to rollover crashes, occupants of other vehicles

involved in multi-vehicle crashes where SUVs rollover should be able to as well.

- Override – design of SUVs is unnecessarily dangerous. Courts have not addressed manufacturer’s admissions of and changes to the override problems.
- Level plane – size and weight matter here, but design issues such as frame rigidity and vehicle deformation should be looked at as well, as should unnecessary SUV mass and the behemoth models.
- Loss of utility argument not valid – all design features noted by the authors have been changed in some SUVs and psychological benefits of SUV drivers should be weighed with the psychological degradation of people not in SUVs.
- **Vehicle factors addressed:** Design as primary problem – high ride-height, high center of gravity, rigid structural frames, inflexible suspensions. High frames override crush zones of passenger cars and upwardly curving ‘horns’ make it worse. SUVs do not have crumple zones or override protections.
- **Remedies:** Manufacturers should be held liable to the foreseeable accident victims. Manufacturers should produce more SUVs that are lower riding, smaller, and lighter on car chassis (which would also help with rollover). Manufacturers should also overcome disparities in height with additions such as ”blocker beams” or other car-bumper-height hollow steel structures that can engage with car bumpers and absorb crash pulse.

#### **Aggressivity measured by load-cell data**

K. Digges and A. Eigen “Measurements of Stiffness and Geometric Compatibility in front-to-side crashes,” ESV Conference, Amsterdam, Holland, Paper Number 349, 2001.

- **Findings:**
  - The crash compatibility between vehicles has been attributed to 1) mass incompatibility, 2) stiffness incompatibility, and 3) geometric incompatibility. (These are the same metrics used throughout the load-cell research that follows.)
  - Using NHTSA’s load cell data, one can see how cars, such as the Dodge Neon, have much lower and more uniform crash forces than do larger vehicles, such as the Ford Clubwagon.
  - Current data help to provide useful insights into geometry and stiffness of vehicle frontal structure in a barrier crash. To look at front-to-side compatibility, a combination of the center of force and the stiffness distribution would be required.
- **Vehicle factors addressed:** Mass incompatibility, stiffness incompatibility, and geometric incompatibility.
- **Holes/next steps for research:** Additional resolution in the cells is needed to more accurately assess the impact of high-load vehicles.

K. Digges, A. Eigen and J. Harrison, "Application of Load Cell Barrier Data to Assess Vehicle Crash Performance and Compatibility," SAE paper no. 1999-01-0720, 1999.

- **Findings:**
  - The crash footprint of the Jeep Grand Cherokee shows a higher load path than the Dodge Neon giving rise to a geometric incompatibility in frontal vehicle-to-vehicle crashes.
  - In a crush of 250 mm, the Jeep exerts twice the force as the Neon. This difference in stiffness will result in a higher extent of crush for the Neon in a frontal crash between these two vehicles.
  - Side impact protection is reduced when the intrusion at the chest level precedes the intrusion at the pelvic level (cites Hobbs 1989, Dalmotas 1991) which means that a lower load path is safer. A lower load path also is more likely to engage the sill so the force is not taken by the seat, door, upper pillars, and the passenger. This is favorable and is shown by a high percentage of force recorded on the lower load cells.
  - Height of the striking vehicle's hood is important because there is a high prevalence of head impacts with the hood of the striking vehicle in crashes between incompatible vehicles.
- **Vehicle factors addressed:** Aggressiveness metrics: (frontal crashes) force at 250 mm of crush, the linear stiffness at various levels of crush, and the height of the center of force at 250mm of crush, (front-to-side) the force distribution when the loading is sufficient to cause intrusion of the side door.
- **Remedies:** Lowering load path will decrease serious injuries and deaths in side impacts.

K. Digges and A. Eigen, "Analysis of Load Cell Barrier Data to Assess Vehicle Compatibility," SAE paper no. 2000-01-0051 (March 2000).

- **Findings:**
  - Because the side stiffness of vehicles is much lower than the frontal stiffness, metrics for front-to-side compatibility should be measured using a relatively low level of side impact. This is because the force that can be recorded in the lower crush ranges is sufficient and, coupled with the height of force, may be the critical compatibility parameters.
  - Both stiffness and center of force vary with vehicle weight which shows that the vehicle weight may not adequately account for variations in the stiffness and geometry of vehicles in the fleet. This is particularly true for trucks and multi-passenger vehicles.
  - Impact above the vehicle sill is more likely to cause serious injuries and death than impact below the sill.
- **Vehicle factors addressed:** Primarily geometric and stiffness incompatibility.

K. H. Digges and A.M.Eigen, " Load Cell Barrier Measurements of Geometric Compatibility," Vehicle Safety 2000, I Mech E, London, June 2000.

- **Findings:**
  - Much of this report is identical to Digges and Eigen (March 2000).
  - "Center of Force" provides a metric for the height of crash forces.

- Comparing Center of Force findings for passenger cars and light trucks show a substantial range between the two vehicle types.
- Center of Force findings show that light trucks have the highest force at the vehicle center which suggests high geometric incompatibility for crashes between light trucks and other vehicles when the center part of the light truck's structure is engaged.

**Vehicle factors addressed:** Center of Force. Frontal and side stiffness.

### **Aggressivity and driver death rates**

Tom Wenzel and Marc Ross "Are SUVs Really Safer than Cars?" Access (31) 2-7, 2002. (Also: presentations by the same title given on July 30, 2002 and January 15, 2003.)

**Also:** Mark Ross and Tom Wenzel "An Analysis of the Traffic Deaths by Vehicle Type and Model," American Council for an Energy-Efficient Economy (ACEEE), Report Number T021, March 2002.

- **Findings:**
  - Reduced vehicle weight does not imply reduced safety.
  - "Risk" = driver deaths per year per million vehicles sold.
  - Risk to drivers and others within each model of vehicle ranges broadly.
  - The risk to drivers of the average mid and large car is about the same as the average SUV. A large fraction of the fatalities for SUV drivers are caused in rollovers. Similarly, risks to the safest mid and large cars are about the same as risks for the safest SUV.
  - SUVs pose almost twice the risk to drivers of other vehicles than do mid and large cars. Thus, the combined risk for SUVs (129) is higher than the combined risk for mid (105) and large (100) cars.
  - The combined risk for the average subcompact (141) and compact car (136) is only slightly higher than for SUVs, but the combined risk for the safest sub and compact cars is far lower than that of the safest SUVs.
  - Driver risk for the safest subcompact and compact vehicles is about the same as the average SUV.
  - There is a wide range in safety for compact and subcompact cars. This shows that small cars are not necessarily unsafe, but perhaps that relatively inexpensive cars are unsafe. This contradicts the National Association of Scientists assumption that the low weight of cars with high fuel economy has resulted in excess deaths.
  - Minivans have the lowest driver risk and the lowest combined risk – due both to driver behavior and design (they are on car chassis not truck chassis).
  - The car chassis Grand Cherokee has a driver risk that is twenty-percent lower than the truck-based Cherokee.
  - Pickup trucks are riskier than any other type of vehicle (besides sports cars). The risk to others is highest and the risk to drivers is partially due to where these vehicles are driven and their rollover tendency.
  - Import cars have the lowest combined risk while sports cars have the highest.
  - No evidence that age and gender difference affects these findings.

- **Additional findings in Ross and Wenzel’s presentations:**
  - Fatalities in car-car collisions decreased in last 20 years while truck-car collisions increased.
  - High risk to others from pickups because of their chassis stiffness and height.
  - High risk to drivers of pickups and SUVs because of rollover.
  - SUV drivers have lower fraction of young males and elderly drivers than the average vehicle – therefore, after correcting for these risk factors, SUVs would have an even higher risk.
  - Quality of vehicle design seems to have more correlation with safety than does weight.
    - Design “quality” = corporate location of manufacturer, resale value, and consumer reports ratings. Foreign cars, cars with higher resale, and better consumer reports ratings all have lower risk ratings than other vehicles.
- **Additional findings in Ross and Wenzel’s ACEEE report:**
  - A list of risk by make and model of the 40 vehicles used in their analysis (on page 10), shows, numerically, the trends of risk as well as the variations between different models within each vehicle type.
  - A breakdown of “sensitive groups” of risky drivers (young male drivers (<26) and elderly drivers (>65)) shows that there is a relatively weak correlation between these risk groups and the variation of risk for various vehicle groups.
  - Foreign subcompact and compact cars have nearly the same risk as domestic large and luxury models. Also, foreign midsize cars have a substantially lower risk than large domestic cars.
  - The big three have higher risk rates over all than do Nissan, Honda, and Toyota (Honda and Toyota are the safest).
- **Vehicle factors addressed:** Size, weight, vehicle body, safety design features.
- **Remedies:** Vehicles can be made lighter (more fuel efficient) without decreasing their safety.

### **Aggressivity and Weight**

Ross, Marc and Tom Wenzel. 2001. *Losing Weight to Save Lives: A Review of the Role of Automobile Weight and Size in Traffic Fatalities*. ACEEE-T013. Washington, D.C.: American Council for an Energy-Efficient Economy.

- **Findings:**
  - Similar findings as “Are SUVs Really Safer than Cars” as to correlation between vehicle groups and risk as well as driver behavior.
  - While low weight correlates strongly with high risk (used by Kahane and the IIHS), low quality also “explains” high risk. Once quality is considered, weight is not a strong factor in risk (except in the case of the lightest cars, which are also often the cheapest).
  - It may be difficult to design a really safe car in the US context.
  - The high risk of SUVs and pickups to other drivers is largely to due to the frontal height and stiffness, not just the mass of the vehicles. SUVs built on car chassis,

for example, without the stiff rails of pickup chassis, are less risky for others in collisions.

- In crashes between two light trucks, drivers are at more of a risk than in crashes between two cars (noting Joksch).
- Weight and size are correlated so closely in contemporary models so it is difficult to distinguish their roles in crash statistics.
- **Vehicle factors addressed:** Weight, “quality” (which Ross and Wenzel tie to be used-car price or Consumers Report safety ratings, or quality of manufacture, and stiffness).
- **Remedies:**
  - Reduce gross differences among vehicles (would reduce greenhouse gas emissions as well as traffic fatalities). The gross of heavy vehicles should be shifted downwards while the gross of light vehicles should stay relatively the same.
  - Design incompatibilities should also be reduced.
  - SUVs should be built on car chassis and made with a softer front end.
  - Lightweight materials should be used.
  - High-efficiency propulsion systems that are lightweight should be used.

## Additional Bibliographical References

Background articles for the NHTSA 2001 Aggressivity study:

- Hollowell Gabler, "NHTSA's Vehicle Aggressivity and Compatibility Research Program," 16<sup>th</sup> International ESV Conference, Paper No. 98-S#-O-01 (1996)
- Hollowell Gabler "The Aggressivity of Light Trucks and Vans in Traffic Crashes," SAE Paper No. 980908 (1998)
- Gabler, Hampton C. and Hollowell, William T., "The Crash Compatibility of Cars and Light Trucks," Journal of Crash Protections and Injury Control, Volume 2, Issue 1, pp. 19-31, March 2000.

Lit review from Latin and Kasolis article:

- Keith Bradsher, Carmakers to Alter S.U.V.'s to Reduce Risk to Other Autos, N.Y. Times, Mar. 21, 2000, at A1.  
High collision fatality risks for other motorists arising from crashes between SUVs and passenger cars have been thoroughly documented: One statistical study by the National Highway Traffic and Safety Administration (NHTSA) derived from 1999 data concluded that SUV designs were causing nearly 1000 "unnecessary deaths a year in other vehicles."
- Joseph B. Treaster & Keith Bradsher, 2 Insurers Raising Liability Coverage on Bigger Vehicles, N.Y. Times, Dec. 2, 2000, at A1.  
Another NHTSA study found that midsize SUVs, such as the Chevrolet Blazer and Nissan Pathfinder, were three times as likely to kill other motorists in a collision as large passenger cars of approximately the same weight.  
Based on IIHS and NHTSA evidence of striking disparities in SUV collision risks for occupants of other vehicles, some of the nation's largest auto insurance companies have begun to raise their liability insurance premiums for SUVs.
- Keith Bradsher, High Fatality Rate Found in Cars that Crash With Explorers, N.Y. Times, Feb. 14, 2001, at C7.  
A study by a prominent traffic-safety statistician commissioned by NHTSA concluded that Ford Explorers killed ten passenger car occupants for every 1,000 crashes reported to police between 1991 and 1997, while competing midsize SUVs, such as the Jeep Grand Cherokee, Toyota 4Runner, and Chevy Blazer, killed five to seven car occupants for every 1,000 collisions between these SUVs and passenger cars. In comparison, the fatality rate for multi-vehicle crashes among passenger cars was six-tenths of a death per 1,000 collisions. In other words, the Ford Explorer was more than a dozen times more likely to kill the occupants of other vehicles in collisions during this seven-year period compared to the fatality rate in crashes among passenger cars.
- Insurance Inst. for Highway Safety, Status Report: Crash Compatibility, How Vehicle Type, Weight Affect Outcomes, Feb. 14, 1998, at 10.
- David Holtzman, Protect Us From SUVs and Ourselves, Boston Globe, Aug. 29, 1999, at E1.  
With regard to side-impact crashes, research conducted by the Insurance Institute for Highway Safety ("IIHS") found that when a large SUV, such as a Chevrolet

- Suburban, hits the side of an average-size car, the car driver is forty-eight times more likely to die than the driver of the SUV.
- Insurance Inst. for Highway Safety, Status Report: Putting the Crash Compatibility Issue in Perspective, Oct. 30, 1999, at 7.  
The IIHS concluded that the occupants of a car hit in the side by another passenger car were approximately seven times more likely to die than occupants in the encroaching auto, but the fatality rate was twenty-six times higher when a car was broadsided by an SUV or pickup truck.

Ross and Wenzel additional cites:

- Davis, Stacy C. and Lorena F. Truett. 2000. *An Analysis of the Impact of Sport Utility Vehicles in the United States*. ORNL/TM-2000/147. Washington, D.C.: U.S. Department of Energy, Office of Transportation Technologies.
- Malliaris, C. and Kennerly H. Digges. 1999. *Crash Exposure and Crashworthiness of Sport Utility Vehicles*. SAE Technical Paper Series 1999-01-0063. Warrendale, Penn.: Society of Automotive Engineers.

Additional resources from Digges and Eigen:

- Digges, K., Eigen, A., and Harrison, J., "Application of Load Cell Barrier Data to Assess Vehicle Crash Performance and Compatibility," SAE, 1999-01-1720, March, 1999.

Additional NHTSA document:

- Park B.T., Hackney J.R., Morgan R.M., Chan H., Lowrie J.C. and Devlin H.E., "The New Car Assessment Program: Has It Led to Stiffer Light Trucks and Vans over the Years?" Paper presented at the 1999 SAE International Congress Exposition, March 1- 4, 1999, Detroit, Michigan.