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Relationships between Fatality Risk, Mass, and Footprint in Model Year 2003-2010 Passenger Cars and LTVs

Preliminary Report

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The authors credit Charles Kahane, Ph.D., who developed the models used in this report.

16. Abstract

Mass reduction while holding a vehicle's footprint (size) constant is a potential strategy for meeting footprint-based CAFE and GHG standards. An important corollary issue is the possible effect of mass reduction that maintains footprint on fatal crashes. One way to estimate these effects is statistical analyses of societal fatality rates per VMT, by vehicles' mass and footprint, for the current on-road vehicle fleet. Societal fatality rates include occupants of all vehicles in the crash as well as pedestrians. The analyses comprised MY 2003-2010 cars and LTVs in CY 2005-2011 crashes, updating NHTSA's 2012 report on the same subject by 3 model years and 3 calendar years. Fatality rates were derived from FARS data, 13 State crash files, and registration and mileage data from IHS Automotive. The table presents the estimated percent increase in societal fatality rates per 100-pound mass reduction while holding footprint constant for five classes of vehicles:

MY 2003-2010 CY 2005-2011	Fatality Increase (%) Per 100-Pound Mass Reduction While Holding Footprint Constant	
	Point Estimate	95% Confidence Bounds
Cars < 3,197 pounds	1.49	- .30 to +3.27
Cars ≥ 3,197 pounds	.50	- .59 to +1.60
CUVs and minivans	- .99	-2.17 to + .19
Truck-based LTVs < 4,947 pounds	- .10	-1.08 to + .88
Truck-based LTVs ≥ 4,947 pounds	- .72	-1.45 to + .02

None of the estimated risk impacts are statistically significant at the 95-percent level. Three estimated risk impacts are statistically significant at the 90-percent confidence level: the 1.49 percent risk increase in the lighter cars, the 0.72 percent risk decrease in the heavier LTVs, and the .99 percent risk decrease in CUVs and minivans. There are non-significant increases in the heavier cars, and non-significant societal benefits for mass reduction in the lighter truck-based LTVs. Based on these results, potential combinations of mass reductions that maintain footprint and are proportionately somewhat higher for the heavier vehicles may be safety-neutral or better as point estimates and, in any case, unlikely to significantly increase fatalities. The non-significant (at the 95-percent confidence level) of the results is driven by two key factors: (1) the societal effect of mass reduction while maintaining footprint, if any, is small; and (2) a continuing downward trend in traffic fatalities yielded a dataset with approximately 30 percent fewer fatal incidents than in the 2012 database.

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List of Abbreviations

ABS	Antilock brake system
AWD	All-wheel drive
BAC	Blood alcohol concentration, measured in grams per deciliter (g/dL)
CAFE	Corporate Average Fuel Economy
CARB	California Environmental Protection Agency Air Resources Board
cg	Center of gravity
CUV	Crossover utility vehicle
CY	Calendar year
DC, D.C.	District of Columbia
df	Degrees of freedom
DOE	United States Department of Energy
DOT	United States Department of Transportation
DRI	Dynamic Research, Inc.
EISA	Energy Independence and Security Act of 2007
EPA	United States Environmental Protection Agency
ESC	Electronic stability control
FARS	Fatality Analysis Reporting System, a census of fatal crashes in the United States since 1975
FIPS	Federal Information Processing Standard
FMVSS	Federal Motor Vehicle Safety Standard
FPC	Finite population correction
FRIA	Final Regulatory Impact Analysis
FWD	Front-wheel drive
GES	General Estimates System of NASS
GHG	Greenhouse gases
GMC	General Motors Corporation
GVWR	Gross vehicle weight rating, specified by the manufacturer, equals the vehicle's curb weight plus maximum recommended loading
HLDI	Highway Loss Data Institute
IIHS	Insurance Institute for Highway Safety

LTV	Light trucks and vans, includes pickup trucks, SUVs, minivans, and full-size vans
mpg	Miles per gallon
MY	Model year
NAS	National Academy of Sciences
NASS	National Automotive Sampling System, a probability sample of police-reported crashes in the United States since 1979, investigated in detail
NHTSA	National Highway Traffic Safety Administration
NPRM	Notice of Proposed Rulemaking
NVPP	IHS Automotive's National Vehicle Population Profiles
OMB	Office of Management and Budget of the United States Government
PRIA	Preliminary Regulatory Impact Analysis
PSU	Primary sampling unit
RWD	Rear-wheel drive
SAS	Statistical and database management software produced by SAS Institute, Inc.
SRS	Simple random sample, simple random sampling
SUV	Sport utility vehicle
UMTRI	University of Michigan Transportation Research Institute
VIF	Variance inflation factor
VIN	Vehicle Identification Number
VMT	Vehicle miles of travel

Executive Summary

A new analysis of fatality risk, mass, and footprint

On October 15, 2012, the National Highway Traffic Safety Administration (NHTSA) and the Environmental Protection Agency (EPA) published a joint final rule to establish Corporate Average Fuel Economy (CAFE) standards and greenhouse-gas (GHG) emission standards for passenger cars and light trucks manufactured in model years (MYs) 2017-2021.[1] The standards for MY 2017-2021 are "footprint-based," with footprint being defined as a measure of a vehicle's size, roughly equal to the wheelbase times the average of the front and rear track widths. Basing standards on vehicle footprint ideally helps to discourage vehicle manufacturers from downsizing their vehicles, because the agencies set higher (more stringent) mpg targets for smaller-footprint vehicles, but would not similarly discourage mass reduction that maintains footprint while potentially improving fuel economy. Several technologies, such as substitution of light, high-strength materials for conventional materials during vehicle redesigns, have the potential to reduce weight and conserve fuel while maintaining a vehicle's footprint and maintaining or possibly improving the vehicle's structural strength and handling.

In considering what technologies are available for improving fuel economy, including mass reduction, an important corollary issue for NHTSA to consider is the potential effect that those technologies may have on safety. NHTSA has thus far specifically considered the likely effect of mass reduction that maintains footprint on fatal crashes. The relationship between a vehicle's mass, size, and fatality risk is complex, and it varies in different types of crashes. NHTSA, along with others, has been examining this relationship for over a decade. The safety chapter of NHTSA's April 2012 final regulatory impact analysis (FRIA) of CAFE standards for MY 2017-2021 passenger cars and light trucks included a statistical analysis of relationships between fatality risk, mass, and footprint in MY 2000-2007 passenger cars and LTVs (light trucks and vans), based on calendar year (CY) 2002-2008 crash and vehicle-registration data.[2]

The principal findings and conclusions of NHTSA's 2012 report were that mass reduction in the lighter cars, even while holding footprint constant would significantly increase fatality risk, whereas mass reduction in the heavier LTVs would reduce societal fatality risk by reducing the fatality risk of occupants of lighter vehicles colliding with those heavier LTVs. NHTSA concluded that, as a result, any *reasonable* combination of mass reductions that held footprint constant in MY 2017-2021 vehicles – concentrated, at least to some extent, in the heavier LTVs and limited in the lighter cars – would likely be approximately safety-neutral; it would not significantly increase fatalities and might well decrease them.

The 2012 joint final rule also presented provisional "augural" standards for MY 2022 through 2025 vehicles. NHTSA will propose and establish Corporate Average Fuel Economy (CAFE) standards for MYs 2022-2025 through a comprehensive rulemaking that will be informed by the latest available data.

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[1] 77 Fed. Reg. 62623-63200 (October 15, 2012).

[2] Kahane, C. J. (2012). "Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2000-2007 Passenger Cars and LTVs – Final Report," Technical Report. Washington, DC: National Highway Traffic Safety Administration, Report No. DOT-HS-811-665.

The first phase of the rulemaking is an EPA midterm evaluation of longer-term standards for MYs 2022-2025. The midterm evaluation will inform a decision of whether to maintain the GHG standards for MYs 2022-2025. In the midterm evaluation process, NHTSA is coordinating with EPA and the California Air Resources Board (CARB) to examine factors including vehicle light-weighting and associated vehicle safety impacts.

The midterm evaluation consists of three phases: a joint draft technical assessment report (TAR); a notice of proposed rulemaking (NPRM) by NHTSA and corresponding proposed determination or NPRM by EPA; and a final rule by NHTSA and final determination or rule by EPA. The TAR was issued jointly by NHTSA, EPA and CARB; the TAR is a technical report, not a decision document, and examines safety, economic and technological factors relevant to the MYs 2022-2025 standards.

Public input on the Draft TAR, along with any new data and information, will inform NHTSA's NPRM and EPA's proposed determination or NPRM. The NHTSA NPRM will be conducted as per statute, to establish final CAFE standards for MYs 2022-2025. The NHTSA NPRM will go through the full public comment process and comply with all established Federal rulemaking requirements.

Following the public comment period for the NPRM, NHTSA will address comments and issue a final rule on CAFE standards for MYs 2022-2025 in conjunction with EPA's final determination or final rule; the final determination is required no later than April 1, 2018. If the EPA determination is that the standards will not change, NHTSA will issue its CAFE final rule concurrently with the EPA final determination (77 FR 62652, October 15, 2012). If the EPA determination is that the standards will change, NHTSA and EPA will issue a joint final rule for MYs 2022-2025 with at least 18 months of lead time.

This report details NHTSA research supporting the development of potential safety impacts from this rulemaking. The focus of this report is an update to safety databases and associated statistical analyses of societal fatality risk as a function of vehicle mass and size. This preliminary report has been released concurrently with the Draft TAR, is available for public comment, and may be subsequently revised in response to the comments or other review.

For this report and the Draft TAR, NHTSA, working closely with EPA and the Department of Energy (DOE), performed an updated statistical analysis of the relationships between fatality rates, mass and footprint, updating the crash and exposure databases to the latest available model years. The new databases analyzed within this report, comprising MY 2003-2010 vehicles in CY 2005-2011, crashes are the most up-to-date possible, given the processing time for crash data and the need for enough crash cases to permit statistically meaningful analyses. NHTSA has made the new databases available to the public at http://www.nhtsa.gov/fuel-economy, enabling other researchers to analyze the same data and hopefully minimizing discrepancies in the results that would have been due to inconsistencies across databases.

What's new in MY 2003-2010 vehicles and in this report?

The basic analytical method used in this report is the same as in NHTSA's 2012 report: cross-sectional analyses of the societal fatality rate per billion vehicle miles of travel (VMT) by mass and footprint, while controlling for driver age, gender, and other factors, in separate logistic regressions by vehicle class and crash type. "Societal" fatality rates include fatalities to occupants of all the vehicles involved in the collisions, plus any pedestrians. The data is now MY 2003-2010 vehicles in CY 2005-2011, updated from the previous database of MY 2000-2007 vehicles in CY 2002-2008. The new data has improved VMT estimates, derived in part from a file of odometer readings by make, model, and model year recently developed by IHS Automotive (formerly R.L. Polk) and purchased by NHTSA. As in the 2012 report, the vehicles are grouped into three classes rather than two, for the reasons discussed above: passenger cars (including both 2-door and 4-door cars); CUVs and minivans; and truck-based LTVs.

There are nine types of crashes specified in the analysis. Single-vehicle crashes in the analysis include first-event rollovers, collisions with fixed objects, and collisions with pedestrians, bicycles and motorcycles. Two-vehicle crashes in the analysis include collisions with: heavy-duty vehicles; car, CUV, or minivan < 3,157 pounds (the median curb weight of other, non-case, cars, CUVs and minivans in fatal crashes in the database); car, CUV, or minivan ≥ 3,157 pounds; truck-based LTV < 4,303 pounds (the median curb weight of other truck-based LTVs in fatal crashes in the database); and truck-based LTV ≥ 4,303 pounds. An additional crash type includes all other fatal crash types (e.g., collisions involving more than two vehicles, animals, or trains). Splitting the "other" vehicles into a lighter and a heavier group permits more accurate analyses of the mass effect in collisions of two light vehicles. Grouping partner-vehicle CUVs and minivans with cars rather than LTVs is more appropriate because their front-end profile and rigidity more closely resembles a car than a typical truck-based LTV.

The curb weight of passenger cars is formulated, as in the 2012 report, as a two-piece linear variable in order to estimate one effect of mass reduction in the lighter cars and another effect in the heavier cars. The boundary between "lighter" and "heavier" cars is 3,197 pounds (which is the median mass of MY 2003-2010 cars in fatal crashes in CY 2005-2011, up from 3,106 for MY 2000-2007 cars in CY 2002-2008 in the 2012 NHTSA safety database). Likewise, for truck-based LTVs, curb weight is a two-piece linear variable with the boundary at 4,947 pounds (again, the 2003-2010 median, higher than the median of 4,594 for MY 2000-2007 LTVs in CY 2002-2008). Curb weight is formulated as a simple linear variable for CUVs and minivans: Because CUVs and minivans account for a relatively small share of new-vehicle sales, there is less crash data available than for cars or truck-based LTVs.

For a given vehicle class and weight range (if applicable), the regression coefficients for mass (while holding footprint constant) in the nine types of crashes are averaged, weighted by the number of baseline fatalities that would have occurred for the subgroup MY 2007-2010 vehicles in CY 2007-2011 if these vehicles had all been equipped with ESC. The adjustment for ESC, a feature of the analysis added in 2012, takes into account that the results will be used to analyze effects of mass reduction in future vehicles, which will all be ESC-equipped, as required by NHTSA's regulations.

Techniques developed in the 2011 and 2012 reports have been retained to test statistical significance and to estimate 95 percent confidence bounds (sampling error) for mass effects and to estimate the combined annual effect of removing 100 pounds of mass from every vehicle (or of removing different amounts of mass from the various classes of vehicles), while holding footprint constant.

NHTSA considered the near multicollinearity of mass and footprint to be a major issue in the 2010 report and voiced concern about inaccurately estimated regression coefficients.[3] The high correlations between mass and footprint and variance inflation factors (VIF) have not changed from MY 1991-1999 to MY 2003-2010; large vehicles continued to be, on the average, heavier than small vehicles to the same extent as in the previous decade.[4] Nevertheless, multicollinearity appears to have become less of a problem in the 2012 and 2016 analyses. The "decile" analysis comparing fatality rates of vehicles of different mass but nearly identical footprint (modified in 2012 in response to peer-review comments to control for factors such as driver age and gender) largely corroborates the main regression results. Ultimately, only three of the 27 core models of fatality risk by vehicle type indicate the potential presence of effects of multicollinearity, with estimated effects of mass and footprint reduction greater than two percent per 100-pound mass reduction and one-square-foot footprint reduction, respectively: passenger cars and CUVs in first-event rollovers, and CUVs in fixed-object collisions.

The analysis presented in this report includes one minor methodological update relative to the 2012 report: separate VMT schedules (annual VMT by vehicle age) were applied for passenger cars versus all other vehicles. The use of distinct VMT schedules was selected to preserve the information available on driving activity by vehicle type from the updated version of the source data used to develop the aggregate VMT schedule in the 2012 report.

Results

The immediate purpose of this report is to develop five parameters that the CAFE Compliance and Effects Modeling System (usually referred to as the "Volpe model," developed for NHTSA by the Volpe National Transportation Systems Center) will use in the PRIA to estimate the safety effects, if any, of the modeled mass reductions in MY 2017-2025 vehicles over their lifetime. The five numbers are the overall percentage increases or decreases, per 100-pound mass reduction while holding footprint constant, in societal fatalities per billion VMT involving five classes of vehicles:

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[3] Van Auken and Green also discussed the issue in their presentations at the NHTSA Workshop on Vehicle Mass-Size-Safety in Washington, DC on February 25, 2011, http://www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/NHTSA+Workshop+on+Vehicle+Mass-Size-Safety.

[4] Greene, W. H. (1993). *Econometric Analysis*, Second Edition. New York: Macmillan Publishing Company, pp. 266-268; Allison, P.D. (1999), *Logistic Regression Using the SAS System*. Cary, NC: SAS Institute Inc., pp. 48-51. VIF scores are in the 6-9 range for curb weight and footprint in NHTSA's new database – i.e., in the somewhat unfavorable 2.5-10 range where near multicollinearity begins to become a concern in logistic regression analyses.

Principal Findings: MY 2003-2010, CY 2005-2011

Fatality Increase (%) per 100-Pound Mass Reduction While Holding Footprint Constant

	Point Estimate	95% Confidence Bounds
Cars < 3,197 pounds	1.49	- .30 to +3.27
Cars ≥ 3,197 pounds	.50	- .59 to +1.60
CUVs and minivans	- .99	-2.17 to + .19
Truck-based LTVs < 4,947 pounds	-.10	-1.08 to + .88
Truck-based LTVs ≥ 4,947 pounds	- .72	-1.45 to + .02

None of the estimated effects have 95-percent confidence bounds that exclude zero, so are not statistically significant at the 95 percent confidence level; but three of the effects are statistically significant at the 90 percent level. Societal fatality risk is estimated to: (1) increase by 1.49 percent if mass is reduced by 100 pounds in the lighter cars; (2) decrease by .72 percent if mass is reduced by 100 pounds in the heavier truck-based LTVs; and (3) decrease by .99 percent if mass is reduced by 100 pounds in CUVs and minivans. The increases in societal fatality risk for mass reduction in the heavier cars, and the decreases in societal fatality risk for mass reduction in the lighter truck-based LTVs, are not significant, even at the 90 percent confidence level.

The confidence bounds estimate only the sampling error internal to the data used in the specific analysis that generated the point estimate. Additional uncertainty, more difficult to quantify, could be attributed to sensitivity of the point estimate to modifying features of the analysis (e.g., selection of control variables).

It is useful to compare the new results to NHTSA's 2012 analysis of MY 2000-2007 vehicles in CY 2002-2008:

Fatality Increase (%) per 100-Pound Mass Reduction While Holding Footprint Constant

Vehicle Class[5]	2012 Report Point Estimate	2016 Report Point Estimate	2012 Report 95% Confidence Bounds	2016 Report 95% Confidence Bounds
Lighter Passenger Cars	1.56	1.49	+.39 to +2.73	- .30 to +3.27
Heavier Passenger Cars	.51	.50	- .59 to +1.60	- .59 to +1.60
CUVs and minivans	- .37	-.99	-1.55 to + .81	-2.17 to + .19
Lighter Truck-based LTVs	.52	-.10	.45 to +1.48	-1.08 to + .88
Heavier Truck-based LTVs	- .34	-.72	- .97 to + .30	-1.45 to + .02

[5] Median curb weights in the 2012 report: 3,106 pounds for cars, 4,594 pounds for truck-based LTVs. Median curb weights in this report: 3,197 pounds for cars, 4,947 pounds for truck-based LTVs.

The new results are directionally the same as in 2012, with the exception of the estimate for lighter LTVs. Consistent with the 2012 report, mass reductions in lighter cars are estimated to lead to increases in fatalities, and mass reductions in heavier LTVs are estimated to lead to safety benefits. However, NHTSA does not consider this conclusion to be definitive because of the relatively wide confidence bounds of the estimates. The estimated mass effects are similar between the 2012 report and this analysis for both classes of passenger cars; for both reports the estimate for lighter passenger cars is statistically significant at the 90-percent confidence level, while the estimate for heavier passenger cars is insignificant.

The estimated mass effects for heavier truck-based LTVs and CUVs and minivans are stronger in this report than in the 2012 report; both estimates are statistically significant at the 90-percent confidence level, unlike the corresponding insignificant estimates in the 2012 report. The estimated mass effect for lighter truck-based LTVs is insignificant and negative in this report; the corresponding estimate in the 2012 report was insignificant and positive.

One way of looking at the estimated safety effects, albeit one that is not truly under consideration, would be an across-the-board 100-pound reduction in all vehicles. The estimated effect of simultaneously reducing all new vehicles by exactly 100 pounds (a higher proportion of the mass of a light car than of a heavy LTV) while maintaining footprint is that fatalities would increase by 90.5 per year – not statistically significant, but again, also not really under consideration. A second combination that would still average over the fleet to 100 pounds per vehicle – namely, a proportionate 2.55 percent reduction in the mass of all vehicles while maintaining footprint – would increase fatalities by an estimated 36.6 lives per year. A third combination would yield a safety-neutral outcome for a fleet-average reduction of 100 pounds per vehicle: a 1.78 percent reduction in the mass of the lighter cars, a 2.63 percent reduction in the mass of heavier cars, a 2.67 percent reduction in the mass of lighter truck-based LTVs, a 2.62 percent reduction in the mass of CUVs and minivans, and a 3.23 percent reduction in the mass of heavier truck-based LTVs.

In other words, just as in the 2012 report, any combination of mass reductions that maintain footprint and are proportionately somewhat higher for the heavier vehicles may well be safety-neutral or better as a point estimate and, in any case, may be very unlikely to significantly increase fatalities. The above estimates are offered only as computational examples. The estimated safety effects that will appear in the midterm evaluation, unlike these, will be based on either NHTSA's Volpe model or EPA's OMEGA model, which forecasts the mass reductions of individual makes and models on a year-by-year basis based on the cost of mass reduction relative to other technologies to increase fuel economy.

The principal difference between the heavier vehicles, especially truck-based LTVs, and the lighter vehicles, especially passenger cars, is that mass reduction has a different effect in collisions with another car or LTV. When two vehicles of unequal mass collide, the delta V is higher in the lighter vehicle, in the same proportion as the mass ratio. As a result, the fatality risk is also higher. Removing some mass from the heavy vehicle reduces delta V in the lighter vehicle, where fatality risk is high, resulting in a large benefit, offset by a small penalty because delta V increases in the heavy vehicle, where fatality risk is low – adding up to a net societal benefit. Removing some mass from the lighter vehicle results in a large penalty offset by a small benefit – adding up to net harm.

These considerations drive the overall result: mass reduction is associated with an increase in fatality risk in the lighter cars, a decrease in fatality risk in the heavier LTVs, CUVs and minivans, and with smaller effects in the intermediate groups. However, in some types of crashes that do not involve collisions between cars and LTVs, especially first-event rollovers and impacts with fixed objects, mass reduction is usually not harmful and often beneficial, because the lighter vehicles respond more quickly to braking and steering, are often more stable because their center of gravity is lower.

The discussion concludes with a review of 11 sensitivity analyses, in which the baseline model specification is changed to incorporate one or more of the following: alternative input data (e.g., restricting the exposure data to stopped-vehicle cases, sober drivers or good drivers; including AWD cars, muscle cars, police cars and full-size vans), alternative independent variables (e.g., separating footprint into track width and wheelbase; manufacturer-specific indicator variables), and restricted independent variables (e.g., removing CY indicators, removing all insignificant variables). The sensitivity analyses were originally presented in the 2012 report; we present the sensitivity analyses in this report to add context to the new baseline analysis that are the focus of the report (e.g., robustness of parameter estimates to analytical assumptions).

Scope and limitations of the analyses

The power of this report's results is constrained because the focal effects to estimate are small. This raises a question of the extent to which the estimates for the various crash types, most of which are individually not statistically significant, can be combined to produce meaningful composite effects across crash types. The individual estimates are just intermediate computational tools used to obtain the composite effect; the key issue is the significance of the composite, not its component parts. Specifically, this report's analysis uses nine separate crash types and three vehicle types because it creates a better model; however, the additional subdivision of the data further decreases the likelihood of significant results within the individual cells.

An associated question is the extent to which the non-significant estimates provide insight to support decision-making. The regulatory analysis must provide the best estimate of the expected effect of mass reduction. The estimate has to be there, regardless of whether it is statistically significant – but with confidence bounds that indicate the range of uncertainty. One reason that the regulatory analysis must have such an estimate is that it, too, is ultimately an intermediate computational tool in estimating the overall health and societal impact of CAFE and GHG regulation.

The estimates of this report are based on statistical analyses of historical data, which puts some limitations on their value for predicting the effects of future mass reductions. Analyses of historical data necessarily lag behind the latest developments in vehicles and in driving patterns because it takes years for sufficient crash data to accumulate. It is important to note that while the MY 2003-2010 database represents a more recent fleet of vehicles with technologies more representative of vehicles on the road today than the previous report's MY 2000-2007 database, it still does not represent the newer vehicles that will be on the road in the 2022-2025 timeframe.

The vehicles manufactured in the 2003-2010 timeframe were not subject to a footprint-based fuel-economy standard. NHTSA and EPA expect that the attribute-based standard will affect the design of vehicles such that manufacturers may reduce mass while maintaining footprint more than has occurred prior to 2022-2025. Therefore, it is likely that the analysis for 2003-2010 vehicles may not be fully representative of those vehicles that interact with the existing fleet in 2022 and beyond.

Statistical analyses can control for many factors such as a driver's age and gender, but there are other factors they do not control for, such as driver characteristics and behavior that cannot be quantified with available demographic variables. Furthermore, the analyses of this report are "cross-sectional": they compare the fatality rates for vehicles weighing *n*-100 pounds relative to other models weighing *n* pounds, rather than directly comparing the fatality rates for a specific make and model before and after a mass reduction had been implemented for the purpose of improving fuel economy.

The estimates of the model are formulated for 100-pound mass reductions; the estimated effects of mass reduction are assumed to be linear with the magnitude of mass reduction. That is, according to the model, if risk increases by 1 percent for 100 pounds, it would increase by 2 percent for 200 pounds and 3 percent for 300 pounds. The confidence bounds would grow wider by the same proportions.

The most difficult associated question is the relevant range of mass reduction for which the model can provide meaningful predictions. The model is best suited to predict the effect of a small change in mass, but everything else staying the same as it is now (MY 2003-2010 in CY 2005-2011). With each additional change from the current environment, the model may become somewhat less accurate. As stated above, the environment in 2022-2025 is bound to differ from 2003-2010. Nevertheless, one consideration provides some basis for confidence. This is NHTSA's sixth evaluation of the effects of mass reduction and/or downsizing, comprising databases ranging from MY 1985 to 2010. The results of the five studies are not identical, but they have been consistent up to a point. Across the interval for which NHTSA's studies have evaluated societal fatality risk, curb weights of some vehicle models have increased by around 30 to 40 percent. If the statistical analysis has, over the past years, been able to accommodate these gains on the order of 30-40 percent, perhaps it will also succeed in modeling the effects of mass reductions within this range, if they occur in the future.

In view of these considerations, NHTSA believes that only limited conclusions can be drawn from the statistical analysis. As stated above, the societal effect of mass reduction while maintaining footprint, if any, is usually small relative to the uncertainty in the statistics. The estimated effect of mass reduction in the 2003-2010 fleet is statistically significant at the 90-percent confidence level for three out of five vehicle classes, but is not statistically significant at the 95-percent level for any vehicle class.

Estimates can be generated for the combined effects of mass reductions in various groups of vehicles, as required for the regulatory analysis of CAFE, with confidence bounds. In general, these estimates will not be statistically significant (except if mass reduction is limited to vehicle classes with statistically significant estimates). In other words, it cannot be concluded from the statistical analysis that mass reduction would have been harmful if it had been applied uniformly across the 2003-2010 fleet.

Additional uncertainties are introduced if the results are used for predicting what might happen in the 2022-2025 fleet, since that future fleet will differ in various respects from the 2003-2010 fleet. The statistical results, by themselves, are not an unconditional warrant for mass reduction in the 2022-2025 fleet, but neither do they necessarily raise a red flag against mass reduction. Further research, combined with this analysis, will better help inform the agency's decision.

1. Background for a New Analysis of Fatality Risk, Mass, and Footprint

1.1 Supporting CAFE and Greenhouse Gas Emissions Standards

In October 2012, the National Highway Traffic Safety Administration (NHTSA) and the U.S. Environmental Protection Agency (EPA) issued joint final rules to improve fuel economy and reduce greenhouse gas (GHG) emissions for passenger cars and light trucks for model years (MYs) 2017 through 2021. The joint final rules also presented provisional "augural" standards for MY 2022 through 2025 vehicles. NHTSA will propose and establish Corporate Average Fuel Economy (CAFE) standards for MYs 2022-2025 through a comprehensive rulemaking that will be informed by the latest available data.

The first phase of the rulemaking is an EPA midterm evaluation of longer-term standards for MYs 2022-2025. The midterm evaluation will inform a decision of whether to maintain the GHG standards for MYs 2022-2025. In the midterm evaluation process, NHTSA is coordinating with EPA and the California Air Resources Board (CARB) to examine factors including vehicle light-weighting and associated vehicle safety impacts.

The midterm evaluation consists of three phases: a joint draft technical assessment report (TAR); a notice of proposed rulemaking (NPRM) by NHTSA and corresponding proposed determination or NPRM by EPA; and a final rule by NHTSA and final determination or rule by EPA. The TAR was issued jointly by NHTSA, EPA and CARB; the TAR is a technical report, not a decision document, and examines safety, economic and technological factors relevant to the MYs 2022-2025 standards.

Public input on the Draft TAR, along with any new data and information, will inform NHTSA's NPRM and EPA's proposed determination or NPRM. The NHTSA NPRM will be conducted as per statute, to establish final CAFE standards for MYs 2022-2025. The NHTSA NPRM will go through the full public comment process and comply with all established Federal rulemaking requirements.

Following the public comment period for the NPRM, NHTSA will address comments and issue a final rule on CAFE standards for MYs 2022-2025 in conjunction with EPA's final determination or final rule; the final determination is required no later than April 1, 2018. If the EPA determination is that the standards will not change, NHTSA will issue its CAFE final rule concurrently with the EPA final determination (77 FR 62652, October 15, 2012). If the EPA determination is that the standards will change, NHTSA and EPA will issue a joint final rule for MYs 2022-2025 with at least 18 months of lead time.

This report details NHTSA research supporting the development of potential safety impacts from this rulemaking. The focus of this report is an update to safety databases and associated statistical analyses of societal fatality risk as a function of vehicle mass and size. This preliminary report has been released concurrently with the Draft TAR, is available for public comment, and may be subsequently revised in response to the comments or other review.

The standards for MYs 2017-2025 are "footprint-based," with footprint being defined as a measure of a vehicle's size, roughly equal to the wheelbase times the average of the front and rear track widths. Basing standards on vehicle footprint ideally helps to discourage vehicle manufacturers from downsizing their vehicles, because the agencies set higher (more stringent) fuel economy targets for smaller-footprint vehicles, but would not similarly discourage mass reduction that maintains footprint while potentially improving fuel economy. Several technologies, such as substitution of light, high-strength materials for conventional materials during vehicle redesigns, have the potential to reduce weight and conserve fuel while maintaining a vehicle's footprint and maintaining or possibly improving the vehicle's structural strength and handling.

In considering what technologies are available for improving fuel economy, including mass reduction, an important corollary issue for NHTSA to consider is the potential effect that those technologies may have on safety. NHTSA has thus far specifically considered the likely effect of mass reduction that maintains footprint on fatal crashes. The relationship between a vehicle's mass, size, and fatality risk is complex, and it varies in different types of crashes. NHTSA, along with others, has been examining this relationship for over a decade, including statistical analyses of relationships between fatality risk, mass, and footprint in passenger cars, and light trucks and vans (LTVs).

In preparation for the next phases of rulemaking, NHTSA, working closely with EPA and the Department of Energy (DOE), performed a new statistical analysis of the relationships between fatality rates, mass and footprint, updating the crash and exposure databases to the latest available model years. The new databases analyzed within this report, comprising MY 2003-2010 vehicles in CY 2005-2011, crashes are the most up-to-date possible, given the processing time for crash data and the need for enough crash cases to permit statistically meaningful analyses. NHTSA has made the new databases available to the public at http://www.nhtsa.gov/fuel-economy, enabling other researchers to analyze the same data and hopefully minimizing discrepancies in the results that would have been due to inconsistencies across databases.[6]

One way to estimate the effect of mass reduction on safety is the use of statistical analyses of societal fatality risk per vehicle miles traveled (VMT) for the current on-road vehicle fleet. Consistent with this, the analysis follows the identical approach employed in the 2012 NHTSA report, centering on cross-sectional logistic regressions of societal fatality risk per billion vehicle miles of travel (the dependent variable), as a function of driver- (e.g., driver age and gender), vehicle- (e.g., safety features) and crash-specific factors (e.g., times, locations). Societal fatality risk represents total fatalities to all vehicle occupants, pedestrians, cyclists and motorcyclists involved in collisions per volume of VMT.

The paramount purpose of the analysis is to develop five parameters for use in the CAFE Compliance and Effects Modeling System (usually referred to as the "Volpe model," developed for NHTSA by the Volpe National Transportation Systems Center) to estimate the safety effects, if any, of the modeled mass reductions in MY 2022-2025 vehicles over their lifetime. The

[6] 75 Fed. Reg. 25324 (May 7, 2010); the discussion of planned statistical analyses is on pp. 25395-25396.

primary difference from the 2012 report is that the set of case vehicles and time period for observed vehicle incidents is more recent, involving model year (MY) 2003-2010 vehicles in calendar year (CY) 2005-2011, versus MY2000-2007 vehicles in CY2002-2008 in the 2012 report. The most notable vehicle-specific factors for this analysis are curb weight and vehicle size (represented as footprint in the preferred model structure).

Separate regressions were run for five vehicle classes – passenger cars (including 2-door and 4-door cars, but excluding police cars and high-performance "muscle" cars[7], as well as AWD cars), truck-based LTVs (pickup trucks and SUVs, but excluding full-sized vans), and CUVs and minivans. Curb weight was formulated as a two-piece linear variable in order to estimate separate effects of mass reduction for five vehicle classes: cars < 3,197 pounds (the median mass of MY 2003-2010 cars in fatal crashes); cars ≥ 3,197 pounds; truck-based LTVs < 4,947 pounds (the median mass of MY 2003-2010 truck-based LTVs in fatal crashes); truck-based LTVs ≥ 4,947 pounds; and CUVs and minivans.

For a given vehicle class and weight range, the regression coefficients for mass in the nine types of crashes were averaged, weighted by the number of baseline fatalities for the subgroup of MY 2007-2010 vehicles in CY 2007-2011. Consistent with previous NHTSA analyses, the paramount conclusion confirms a hypothesis based on momentum considerations: Any reasonable combination of mass reductions in future vehicles – concentrated, at least to some extent, in the heavier LTVs, CUVs and minivans, and limited in the lighter cars – would not significantly increase fatalities and might well decrease them.

The relatively short interval between the 2012 report and this update enables a generally direct comparison of findings between the two studies. However, there are at least two key empirical outcomes associated with the updated safety dataset that limit its comparability with the 2012 analysis. Firstly, CY2009-2011 data replace CY2002-2004 data within the sample. New vehicle registrations were below trend for CY2009-2011 (and hence, below corresponding levels in CY2002-2004). In turn, and in conjunction with general (improving) trends in vehicle safety, the number of fatal crashes in CY2009-2011 is about 25 percent lower than the number of crashes in CY2002-2004. Hence, the results of the analysis are calibrated with respect to a smaller number of fatal crashes, resulting in larger estimated standard errors and associated confidence bounds for the point estimates in the analysis.

Secondly, as noted in the 2012 report, light-duty trucks (LTVs) began increasing in mass around the year 2000; this trend did not appear to abate for MY2008-2010 LTVs. The heavier (relative to similar models from previous model years on or near 2000) LTVs comprised a relatively small share of the sample in the 2012 report, because relatively early-model vehicles comprise a much larger share of the observations in the database than late-model vehicles. However, the sample in the update involves not only a large share of relatively heavy LTVs in common with models in

[7] Police cars and muscle cars have exceptionally high fatality rates, compared to other cars of the same size and mass, because of unusual driving patterns. Given that police and muscle cars are relatively heavy and that, moreover, muscle cars tend to have small footprint (short wheelbase), the regression analyses might attribute the high fatality rates to mass or footprint rather than the unusual driving patterns; see Kahane (2003), pp. 41-42 and 171-173, Kahane (2010), pp. 483-486 and 512-514.

the 2012 report, but also MY2008-2010 vehicles that tend to be heavier than the MY2000-2002 vehicles no longer in the sample.

1.2 Developments in MY 2003-2010 vehicles

There were two key developments across the sales periods for new MY 2003-2010 vehicles. First, as noted in the 2012 report, crossover utility vehicles (CUV) continued to gain market share. CUVs are SUVs of unibody construction, often but not always upon a platform shared with passenger cars, such as Ford Escape or Toyota RAV4. Appendix A lists the 2003-2010 vehicles that are considered CUVs in this report. Table 1-3 shows that CUVs doubled from 8.90 percent of new light-vehicle sales (as represented as registrations of MY *t* vehicles in CY *t+1*) in MY 2003 to 17.17 percent by 2008:

TABLE 1-3: PERCENT OF NEW LIGHT-VEHICLE SALES BY VEHICLE TYPE

	Cars			Truck-Based			Full-Size
	2-Dr	4-Dr	Pickup	SUV	CUV	Minivan	Van
2003	8.21	41.14	16.79	17.51	8.90	5.76	1.69
2004	7.42	38.94	18.04	18.17	10.91	5.21	1.32
2005	6.82	41.38	15.84	13.89	13.08	7.54	1.46
2006	7.19	42.39	17.10	11.36	13.77	6.31	1.87
2007	7.37	44.48	14.11	12.67	15.55	4.63	1.20
2008	7.79	43.30	14.50	11.29	17.17	4.60	1.35
2009	6.72	52.96	11.14	10.02	14.83	3.26	1.06
2010	6.06	48.14	12.08	12.99	15.22	4.52	0.98

Table 1-3 confirms that CUVs displaced the more traditional truck-based SUVs only to a limited extent (i.e., truck-based SUVs did not lose market share on a one-to-one basis with gains in CUV market share). Some of the gain in CUV sales may have come, directly or indirectly, from minivans and 2-door cars, both of which lost market share in 2003-2010. The statistics in Table 1-3 and throughout Section 1.3 are generated from the databases created for this report.

CUVs are somewhere between cars and trucks not only in their design and structure but also in their driving patterns: who and where. CUVs have the highest percentage of female drivers (63%), even more than minivans (61%), cars (56%), truck-based SUVs (53%), and pickup trucks (just 14%). CUVs also have the highest percentage of urban VMT, even more than cars and minivans. Urban female drivers have low fatality risk (see Section 3.2), which suggests that CUVs will also tend to have low fatality risk.

Second, during the nadir of the economic downturn, new vehicle sales fell dramatically in 2009, and only slowly began to recover in 2010. Concurrent with the decline in overall new vehicle sales, Table 1-3 confirms a strong change in the market share of new vehicle sales by vehicle type. Sales of four-door cars increased sharply relative to other vehicle types in 2009, and tapered in 2010. The relative increase in sales of four-door cars was offset by relative decreases in sales across all other vehicle types, with the strongest relative effects in sales of pickup trucks and minivans (decreases of approximately 25 to 30 percent relative to 2008).

Heavier and larger, too: Another salient development in MY 2003-2010 is that the various classes of vehicles continued a trend observed in the 2012 report, in which vehicles have tended to become heavier and larger on average. In particular, the mean curb weight of pickup trucks, CUVs and minivans increased by nearly 10 percent from 2003 to 2010, while the mean curb weight of cars increased only 2 percent, and the mean curb weight of SUVs decreased 5 percent:

- Cars: from 3,143 pounds to 3,221 pounds (2%); from 44.3 to 45.2 square feet
- Pickup trucks: from 4,675 pounds to 5,091 pounds (9%); from 60.0 to 64.4 square feet
- Truck-based SUVs: from 4,691 pounds to 4,437 pounds (-5%); from 50.1 to 49.3 square feet
- CUVs: from 3,600 pounds to 3,856 pounds (7%); from 44.9 to 47.3 square feet
- Minivans: from 4,084 pounds to 4,391 pounds (8%); from 52.1 to 54.3 square feet

A review of the specifications of individual makes and models during 2000-2007 showed that major redesigns usually added weight and size; "refreshing" between redesigns added new features; LTVs grew especially as consumers opted for stretched versions (such as crew cabs) and 4-wheel drive. The early CUVs tended to be relatively light and small, but by 2007 they came in all sizes.

Safer: The 2000s were a decade of exceptional progress in vehicle safety. Unlike the vehicles in the databases in NHTSA's earlier studies, essentially all light vehicles in MY 2003-2010 were equipped with frontal air bags. Technologies that could meet Federal Motor Vehicle Safety Standards (FMVSS) or the voluntary agreement for LTV compatibility going into effect near the end of the decade already became widely available during 2003-2010 (values below weighted by registrations of MY *t* vehicles in CY *t+1*):

	MY 2003	MY 2010
Electronic stability control (ESC)	13%	85%
Antilock brake system (ABS)	74%	98%
Curtain and side air bags	32%	97%
Torso air bags	23%	86%
Curtain air bags	13%	94%
Curtains that deploy in rollovers	2%	40%
Compatibility certification (truck-based LTVs)	54%	69%

But safety improvement was not limited to these specific technologies. Crash-test ratings issued as consumer information by NHTSA and the Insurance Institute for Highway Safety (IIHS) encouraged the design of vehicles to achieve good ratings. IIHS initiated offset-frontal testing in 1995. In MY 2000, still only 24 percent of new vehicles achieved a "good" overall rating, with 35 percent "acceptable," 20 percent "marginal," and 21 percent "poor." By MY 2007, 86 percent of new vehicles rated good, with 13 percent acceptable, under 1 percent marginal, and no poor ratings at all.[8]

The databases indicate that MY 2003-2010 CUVs had lower societal fatality rates in CY 2005-2011 than seen in the previous databases. Without any adjustment for driver age and gender or driving environment, CUVs had a rate of just 8.8 societal fatalities per billion miles (i.e., counting not only their own occupants but also the occupants of the other vehicles in the crashes and any pedestrians or bicyclists) for MY 2003-2010 in CY 2005-2011, as compared to rates of 9.5 for minivans, 12.3 for cars, 13.3 for truck-based SUVs, and 17.7 for pickup trucks. Of course, without such adjustments (beyond the scope of this report), the rates are not directly comparable: Pickup trucks, for example, are extensively driven in the most rural areas and primarily by males. Another indication of CUV safety is that 4.5 percent of their societal fatalities are in 1st-event rollover crashes, a proportion comparable to cars (5.1%) and minivans (3.9%). By contrast, 10.8 percent of the societal fatalities of truck-based SUVs were 1st-event rollovers, down from 19 percent in the 2000-2007 database.

Across MY 2003-2010 (and, as noted in the 2012 report, for some years before), many of the lightest and smallest vehicles were phased out, likely in response to dwindling sales and changing consumer preferences. This has been partially offset by the introduction of light-and-small vehicle designs including the Smart Fortwo (with a curb weight of between 1,807 and 1,852 pounds and a footprint of 26.8 square feet), which is included in this analysis, and more recent designs such as the Fiat 500. Many poor safety performers, which were often holdovers from outdated designs and platforms, were phased out, likely in response to poor or marginal crash-test ratings. It so happens that those two groups extensively overlapped.

Specifically, in model year 2000, new car models with sales totaling 1,543,000 had poor or marginal overall performance on the IIHS offset-frontal test: 1,276,000 of these cars weighed less than 3,106 pounds (the median mass of MY 2000-2007 cars involved in fatal crashes in the 2012 report), whereas only 267,000 exceeded 3,106 pounds. By model year 2006, not a single new car had poor or marginal overall performance. In model year 2000, new truck-based LTV models with sales totaling 2,775,000 had poor or marginal overall performance on the IIHS offset-frontal test: 2,429,000 of these LTVs weighed less than 4,594 pounds (the 2000-2007 median in fatal crashes) in the 2012 report, whereas only 346,000 exceeded 4,594 pounds. By model year 2007, new LTVs with sales of just 79,774 had marginal performance and none had poor performance. In model year 2000, new CUV and minivan models with sales totaling 896,000 had poor or marginal overall performance on the IIHS offset-frontal test: 595,000 of these vehicles weighed less than 3,862 pounds (the 2000-2007 median in the 2012 report), but only 301,000 exceeded 3,862 pounds. By model year 2006, not a single new CUV or minivan had poor or marginal overall performance.

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[8] Bean, J.D., Kahane, C. J., Mynatt, M., Rudd, R.W., Rush, C.J., and Wiacek, C. (2009). *Fatalities in Frontal Crashes Despite Seat Belts and Air Bags*, NHTSA Technical Report. DOT HS 811 202. Washington, DC: National Highway Traffic Safety Administration, http://www-nrd.nhtsa.dot.gov/pubs/811102.pdf, pp. 6-8.

1.3 Earlier studies

The key issue – mass versus size – has been variously perceived over the years. Soon after it became possible to statistically analyze large crash databases, researchers saw that lighter and smaller cars had higher fatality and injury rates (e.g., Mela's analysis of New York State data in 1974).[9] During the 1980s and 1990s, NHTSA and others pursued increasingly complex analyses that attempted to isolate the effect of car mass and size from other covariant factors such as driver age.[10] A shared feature of the early studies is that "mass" and "size" were to a large extent used interchangeably. There was less need to distinguish between mass and size because historic (especially 1975-1980) reductions in vehicle mass were accomplished by manufacturers reducing size when they redesigned a model, or by consumers simply retiring large, heavy cars and purchasing small, light cars of a different model. By 2002, the majority opinion of the National Academy of Sciences' expert panel was that "the downsizing and weight reduction that occurred in the late 1970s and early 1980s most likely produced between 1,300 and 2,600 crash fatalities and between 13,000 and 26,000 serious injuries in 1993."[11]

Nevertheless, researchers recognized mass and "size" as theoretically separate although historically confounded factors. Unlike mass, the right kind of "size" intuitively helps a vehicle without increasing harm to occupants of other vehicles in a crash. A wide track increases stability and reduces the likelihood of a rollover; crush space can protect a vehicle's occupants in crashes with an object or another vehicle. A dissent by two panel members in an appendix to the NAS report, for example, argued that mass dissociated from size ought to have little influence on fatality risk except in determining the risk in one vehicle relative to another in a multi-vehicle collision – and even this has little net societal effect because, as one vehicle gets lighter and the risk for its own occupants increases, the risk will decrease for the occupants of the other vehicle by a more-or-less equal amount.

The issue became more directly relevant after 2000. The 2002 NAS report proposed restructuring CAFE standards in a way that would discourage harmful downsizing, for example, by setting higher CAFE targets for smaller vehicles rather than setting a universal standard applicable to the entire fleet of passenger cars or light trucks. In response, NHTSA developed footprint-based standards for MY 2008-2011 light trucks that were intended to discourage downsizing (by setting higher mpg levels for smaller footprints) but not necessarily mass reduction. Congress subsequently mandated an "attribute-based" approach for both passenger car and light truck CAFE standards in the Energy Independence and Security Act (EISA) of 2007.[12] Several technologies, most notably substitution of light, high-strength materials for conventional materials, have been proposed and in some cases implemented by vehicle manufacturers to reduce mass while maintaining not only footprint but also the structural strength of a vehicle.

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[9] Mela, D. F. (1974). "How Safe Can We Be in Small Cars?" *International Congress on Automotive Safety, 3rd,* NHTSA Technical Report. DOT HS 801 481. Washington, DC: National Highway Traffic Safety Administration.
[10] NHTSA (1991). *Effect of Car Size on Fatality and Injury Risk.* Washington, DC: National Highway Traffic Safety Administration; Kahane, C. J. (1997). *Relationships Between Vehicle Size and Fatality Risk in Model Year 1985-93 Passenger Cars and Light Trucks*, NHTSA Technical Report. DOT HS 808 570. Washington, DC: National Highway Traffic Safety Administration, http://www-nrd.nhtsa.dot.gov/Pubs/808570.PDF.
[11] NAS (2002). *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*. Washington, DC: National Research Council, p. 77.
[12] 49 U.S.C. § 32902(b).

The statistical analyses published by DRI in 2003 and 2005, often cited in the literature, have strongly supported the idea that mass and size can and should be analyzed independently. These regression analyses included curb weight, wheelbase, and track width as three separate independent variables and estimated an effect for each of them – unlike NHTSA's 1997 and 2003 analyses that use a single attribute, curb weight, which implicitly incorporated the size reductions that historically accompanied lower mass. DRI's analyses made it possible to estimate the effects of mass reduction without accompanying size reduction.[13] In fact, DRI's analyses estimated significant overall benefits for mass reduction in both passenger cars and LTVs if wheelbase and track width were maintained. Given the development of attribute-based standards and the prospect that materials substitution would allow future mass reduction without downsizing, NHTSA acknowledged it was essential to analyze mass and size independently and did so in its 2010 report. While the 2010 report did not show an overall benefit in all vehicles for mass reduction while maintaining footprint, it did show a benefit in some vehicles (heavy LTVs) as well as in some types of crashes – and it showed that mass reduction while maintaining footprint had a substantially more favorable impact than downsizing. In the meantime, NHTSA, DRI and others have performed many sensitivity tests on their databases and models, generating estimates that fall between the two initial sets of results.

1.4 Hypothetical relationships between mass and societal fatality risk in the data

There is a strong historical trend of lighter vehicles having higher fatality rates for their own occupants. Two obvious factors contribute to the trend:

- Light vehicles have been, on the average, smaller than heavy vehicles and do not have the advantages of stability and crush space associated with large size.
- In a collision between two vehicles, increasing the mass differential between the two vehicles (all else staying the same), increases the delta V for the lighter vehicle and thus also the risk for its occupants relative to the occupants of the heavier vehicle.

But the first factor might "drop out of the equation" if the analysis controls for size – e.g., by adding a size parameter such as footprint as an independent variable. The second factor might drop out if the dependent variable is the societal fatality rate including the fatalities in the partner vehicles – because the increase in fatality risk for the occupants of the light vehicle is offset by lower fatality risk for the occupants of the other vehicles in the collision. With these two factors out of the picture, would mass still have any residual statistical relationship with societal fatality risk in an analysis that controls for footprint – and in what direction?

Effects of conservation of momentum (delta V): In a collision of two light vehicles (cars or LTVs), reducing the mass of one of the vehicles would have increased its delta V (ΔV) and its occupants' risk, but it would have reduced both in the other vehicle. However, the two opposite effects do not necessarily cancel out to zero. When relatively light vehicles (e.g., cars < 3,000 pounds) collide with heavier ones (e.g., LTVs > 4,000 pounds), there are substantially more fatalities in the cars than in the LTVs. The lower relative risk in LTVs in such collisions are not due solely to their higher mass; rather, LTVs have higher bumpers and stiffer front ends, which also affect fatality risk in the two vehicle types. A reduction in the mass of the cars would

[13] Van Auken and Zellner (2003); Van Auken and Zellner (2005a); Van Auken and Zellner (2005b).

augment societal fatality risk, because an *x* percent increase in the many car-occupant fatalities would exceed in absolute terms the *x* percent reduction of the few occupant fatalities in the partner LTVs.[14] But mass reduction in the LTVs would diminish societal risk, because a *y* percent reduction in the many car-occupant fatalities would exceed in absolute terms the *y* percent increase of the few occupant fatalities in the LTVs. A safety-neutral effect can still be achieved by simultaneously reducing mass in both vehicles. But the statistical analyses of this report, which estimate effects of reducing mass in the case vehicle while the other vehicle remains unchanged, will tend to show, in collisions of two light vehicles, net harm for mass reduction in the lighter vehicles and net benefits for mass reduction in the heavier vehicles. This, more than any other factor will drive this report's as well as the 2012 report's results by vehicle class: namely, overall harm from mass reduction in the lighter cars, overall benefit in the heavier LTVs.

There are, however, occasional situations where increased mass could benefit the occupants of the case vehicle without harming any other person. A heavy vehicle may be able to knock down a medium-size tree and continue moving forward, whereas a lighter vehicle would have come to a complete stop – and likewise for collisions with other partially moveable objects such as unoccupied parked vehicles, deformable poles, or large animals. This is not merely an academic point, as shown in Partyka's analysis of frontal impacts of passenger cars into trees or poles in NASS data: 56% of the heaviest cars significantly damaged the tree or pole, as compared to only 28-32% of the subcompact or compact cars.[15] "Significant damage to a tree or pole" includes cracking, shearing, or tilting a tree or pole; uprooting a tree; separating a pole from its base; or damage that resulted in replacement of the pole. In other words, extra mass reduced the car's ΔV at least to some extent in approximately ¼ of the frontal collisions with fixed objects. Even in such cases, there could be exceptions; it might be better for a guardrail to stop a vehicle completely than to let it go through, if there is something dangerous on the other side.

Similarly, in a collision of a light vehicle with a medium-size truck (including LTVs with GVWR $\geq$ 10,000 pounds, not yet regulated by CAFE), additional mass in the light vehicle would make it transfer more of its momentum to the truck, reducing the light vehicle's ΔV and the fatality risk of its own occupants. Thus, the fatality risk in the truck is so low that its slight increase in ΔV will not offset the benefit for the car's occupants.

Energy absorption in single-vehicle crashes: In collisions with fixed objects, reducing mass of the vehicle while leaving its size and structural strength unchanged would translate to lower energy absorption required by the vehicle structure, which would tend to reduce fatality risk. Similarly, in rollovers, reducing a vehicle's mass while leaving its roof structure unchanged could reduce the force applied on the roof once the vehicle has overturned.

Benefits of enlarging footprint: Additional track width contributes directly to the static stability of a vehicle and its resistance to rollover. Wheelbase and track width are also protective because they enhance directional stability (preventing loss of control). Having more vehicle around the

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[14] Kahane (2003), pp. 105, 107, and 159; *New Crash Tests Demonstrate the Influence of Vehicle Size and Weight on Safety in Crashes*, IIHS News Release, April 14, 2009, http://www.iihs.org/news/rss/pr041409.html.
[15] Partyka, S.C. (1995). *Impacts with Yielding Fixed Objects by Vehicle Weight*. NHTSA Technical Report. DOT HS 808 574. Washington, DC: National Highway Traffic Safety Administration.

occupants could also create more potential crush space for the occupant's ride-down (an opportunity to enhance crashworthiness).[16]

Effects of mass on handling and stability: Adding mass to a vehicle while changing nothing else will make it slower to respond to steering, braking, or acceleration while reinforcing its tendency to proceed in a straight line at the same speed. Mass reduction through material substitution has the potential to enhance steering and braking capabilities, if the vehicle's brake and steering systems are left unchanged (or at least not reduced in capacity to an extent fully commensurate with the mass reduction). This enhanced performance and vehicle control would usually benefit crash avoidance. Specifically, when drivers initiate emergency maneuvers upon finding their vehicles out of control or pointed in the wrong direction, any extra mass could make it even more difficult for them to regain directional control.

Historically, mass has rarely been added or removed "while changing nothing else." Often, mass added by more comfortable interiors, luxury features, or more powerful engines has resulted in raising a vehicle's center of gravity (cg), making it more rollover-prone. But some features that add mass tend to lower the cg, such as 4-wheel drive equipment in some of the heavier LTVs. The statistical analyses of this report generally show a reduction of rollovers and impacts with fixed objects for lighter vehicles of the same footprint, consistent with the hypothesis that steering and braking capabilities are enhanced.

Factors historically correlated with mass: Several factors have been historically more correlated with mass than with footprint even though (unlike momentum conservation and braking/steering response) they are not features of mass *per se*. These factors will nevertheless contribute to the effects of mass reduction estimated in statistical analyses of historical data. Before the more widespread use of light, high-strength materials, less mass for the same footprint may have signified a structurally weaker vehicle. Potentially protective structure on the front and side of a vehicle beyond the wheels (overhang) adds mass without adding footprint. Similarly, raising a vehicle's sills for protection in side impact can add mass without footprint.[17] Historically, the frontal profile of small cars has been pedestrian-unfriendly: Because the hood is short, the pedestrian's head is more likely to contact rigid structures such as the windshield header.[18] This is evidently not an issue of mass *per se*; nevertheless, higher rates of pedestrian fatalities continue to be statistically more associated with low mass than with small footprint.

Possible driver-vehicle interface factors: Historically (1976-2009), small, light vehicles have had higher collision-involvement rates (with or without injury) than larger, heavier vehicles of the same type, even after controlling for urbanization. In 1988, for example, the Highway Loss Data Institute (HLDI) reported that "small cars have consistently more injury and collision claims than large cars. This has been true for every year that HLDI has published insurance

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[16] Van Auken and Zellner (2005b), pp. 10-22.

[17] Kahane (2003), pp. 249-273 indicates the high fatality risk when light cars are hit in the side by LTVs and that the height mismatch (called D_AHOF in the report) accounts for a significant portion of the increased risk.

[18] Kahane (2003), pp. 98-99; Blodgett, R. J. (1983). *Pedestrian Injuries and the Downsizing of Cars*. Paper No. 830050. Warrendale, PA: Society of Automotive Engineers; MacLaughlin, T.F., and Kessler, J.W. (1990). *Pedestrian Head Impact Against the Central Hood of Motor Vehicles – Test Procedure and Results*. Paper No. 902315. Warrendale, PA: Society of Automotive Engineers.

claim information [1976 onwards]."[19] A chart in HLDI's report showed that claims were more frequent for small cars than large cars within urban areas and likewise within rural areas. In 1998 HLDI announced, "Claims for crash damage are more frequent for small cars than for large ones"[20] and in 2009, "Small 4-door cars had higher frequencies than larger 4-door cars."[21] The higher incidence of smaller cars going out of control and running off the road explains some of this phenomenon. But in 1999-2000, 84 percent of cars' crash involvements (with or without injury) were collisions with other vehicles and less than 2 percent of those collisions involved loss of control[22] – yet small, light cars had higher crash rates there, too. It is unclear if the historical trends toward higher crash rates were primarily associated with size, mass or both; the studies did not attempt to isolate the effect of mass from size. For example, the HLDI reports compare various size classes of vehicles, but the vehicles larger size classes also tend to be heavier. The higher crash rates of small, light vehicles suggest there may be another factor – namely that, at least historically, for reasons that are not necessarily understood, small, light vehicles have not been driven as well as larger, heavier ones, as will be discussed in the next section.

1.5 Culpability in 2-vehicle crashes: relationships with mass and footprint

Key evidence to support the hypothesis that small, light vehicles are less well driven than larger and heavier vehicles of the same type comes from statistical analyses of who is culpable in 2-vehicle crashes. The data show that the lighter and smaller the vehicle, the more likely the driver of that vehicle was culpable. These are the findings of new analyses of the MY 2003-2010 FARS database created for this report as well as NHTSA's 2011 and 2012 analyses of the MY 2000-2007 FARS databases. However, a review of these analyses suggests the results may be changing to some extent over time.

The new analyses use the FARS database of MY 2003-2010 case vehicles involved in fatal crashes during CY 2005-2011 (see Section 2.2) and logistic regressions with many of the variables described in Sections 3.1 and 3.2 (but here applied only to the FARS data, not the induced-exposure data as in Chapter 3). They examine the subset of crashes involving exactly two vehicles and no pedestrians or bicyclists. The case vehicle is a MY 2003-2010 car or LTV, but the "other" vehicle can be any type (including heavy trucks and motorcycles) and any model year.

"Culpability" is initially defined by the FARS variables for "driver contributing factors" (up to four coded for each driver). If the driver of the case vehicle has any of the codes indicating a specific action that may lead to a crash[23] (not merely a condition such as fatigue) and the other driver does not, the case vehicle is defined to be culpable. Conversely, if the driver of the other

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[19] IIHS Advisory No. 5, July 1988, http://www.iihs.org/research/advisories/iihs_advisory_5.html.
[20] News Release, February 24, 1998, http://www.iihs.org/news/1998/hldi_news_022498.pdf.
[21] Auto Insurance Loss Facts, September 2009, http://www.iihs.org/research/hldi/fact_sheets/CollisionLoss_0910.pdf.
[22] NHTSA (2000). *Traffic Safety Facts 1999.* Report No. DOT HS 809 100. Washington, DC: National Highway Traffic Safety Administration, p. 71; Najm, W.G., Sen, B., Smith, J.D., and Campbell, B.N. (2003). *Analysis of Light Vehicle Crashes and Pre-Crash Scenarios Based on the 2000 General Estimates System,* Report No. DOT HS 809 573. Washington, DC: National Highway Traffic Safety Administration, p. 48.
[23] DR_CF codes 3, 6, 8, 26, 27, 28, 30, 31, 33, 35, 36, 38, 39, 44, 46, 47, 48, 50, 51, 57, 58, 79, or 87.

vehicle has any of these codes and the case driver has none, the other vehicle is culpable. If neither driver has any of the codes, a vehicle is also defined to be culpable if it is moving and hits a stationary vehicle or if it frontally impacts the rear of a vehicle that was not backing up. Examples of culpable vehicles include: the striking vehicle in a front-to-rear collision, being on the wrong side of the centerline prior to a head-on collision, encroaching on somebody else's lane, and failing to yield the right of way at an intersection or a left turn across traffic. The analysis is limited to cases where, according to the above criteria, one of the drivers is culpable and the other is not.

An empirical problem with fatal-crash data is the tendency of a surviving driver to blame the deceased driver – and this may influence the assignment of culpability when there is no physical evidence or witnesses to the contrary. For example, in the subset of 6,723 crashes where both vehicles were MY 2003-2010 cars or LTVs, one vehicle was judged culpable, and one driver died, the deceased driver was judged culpable 66 percent of the time. When a lighter and heavier vehicle collide, the driver of the heavier vehicle is more likely to survive – and blame the driver of the lighter vehicle, who did not survive. To avoid this potentially serious confounding, the analysis was further limited to 7,997 collisions of MY 2003-2010 "case" cars or LTVs with another vehicle in which:

- Both drivers died; or
- Neither driver died (i.e., only passengers died); or
- The "other" vehicle was a heavy truck (because the case-vehicle driver hardly ever survived, no matter how heavy the case vehicle was); or
- The other vehicle was a motorcycle (because the case-vehicle driver almost always survived, no matter how light the case vehicle was)

Two-vehicle collisions were subdivided into seven types:

- Moving vehicle hit stationary vehicle
- Front-to-rear
- Head-on, both going straight, one vehicle in the wrong lane
- One vehicle changing lanes, encroaching on another vehicle going straight ahead
- Meet at intersection or right angle, neither vehicle turning, one fails to yield right of way
- One turning left, one coming straight the opposite way, one fails to yield right of way
- All others

Using the MY 2003-2010 database, here are the results of the logistic regression of the last five collision types, combined, of the odds that the case vehicle was culpable, by curb weight of the case vehicle (LBS100, in hundreds of pounds), the case vehicle type (4-door car being the default), and many of the control variables discussed in Sections 2.2, 3.1, and 3.2, such as driver age and gender. Footprint is <u>not</u> a variable in this regression, which estimates the trend for lower mass with historically commensurate reductions in footprint (downsizing):

The LOGISTIC Procedure:
2-vehicle crashes excluding moving-to-stopped and front-to-rear, no 'blame-the-victim' issues

Response Profile

Ordered Value	CULPABLE	Total Frequency
1	1	4593
2	2	3404

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	10910.757	10449.793
SC	10917.744	10596.517
-2 Log L	10908.757	10407.793

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	500.9640	20	<.0001
Score	477.8684	20	<.0001
Wald	446.0537	20	<.0001

Analysis of Maximum Likelihood Estimates

Parameter	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	0.6953	0.1765	15.5182	<.0001
LBS100	-0.0153	0.00492	9.6193	0.0019
TWODOOR	0.2186	0.1105	3.9156	0.0478
CUV	-0.0274	0.0917	0.0894	0.7650
MINIVAN	-0.4613	0.1109	17.2940	<.0001
SUV	-0.1282	0.1001	1.6394	0.2004
REG_PKP	-0.00545	0.0978	0.0031	0.9555
HD_PKP	-0.2037	0.1750	1.3550	0.2444
DRVMALE	-0.0224	0.1129	0.0393	0.8428
M14_30	0.0571	0.0108	28.0061	<.0001
M30_50	0.0140	0.00589	5.6783	0.0172
M50_70	0.0105	0.00678	2.4137	0.1203
M70_96	0.0985	0.0137	51.8973	<.0001
F14_30	0.0514	0.0126	16.6394	<.0001
F30_50	0.00215	0.00699	0.0949	0.7581
F50_70	0.0292	0.00839	12.0981	0.0005
F70_96	0.0751	0.0194	15.0360	0.0001
ABS	-0.0959	0.0825	1.3522	0.2449
ESC	-0.1629	0.0793	4.2156	0.0401
AWD	-0.0535	0.0681	0.6164	0.4324
VEHAGE	0.00869	0.0145	0.3587	0.5493

A vehicle that is 100 pounds lighter than another vehicle, with historically commensurate smaller footprint is 1.53 percent more likely to be the culpable vehicle, after controlling for vehicle type, driver age and gender, and some other factors. This is a statistically significant trend to higher odds of culpability as evidenced by Wald chi-square of 9.62 for the LBS100 coefficient (3.84 or more indicates statistical significance at the two-sided .05 level). The coefficients for the control variables indicate: 2-door cars are significantly more likely to be culpable than 4-door cars, minivans are significantly less likely to be culpable; gender (DRVMALE) matters little; drivers of both genders are much more likely to be at fault for each year of age they are under 30 or over 70 (M14_30, M70_96, F14_30, and F70_96); and ESC significantly reduces culpability. All of these results are consistent with the 2012 report, with one exception: The 2012 report found a significant positive relationship between vehicle age (VEHAGE) and culpability.

Because approximately half of the involvements in collisions with other vehicles are culpable involvements, a 1.53 percent increase in culpable involvements corresponds to an approximately 0.77 percent increase in all involvements with other vehicles (assuming no change in the non-culpable involvements) per 100-pound downsizing. This result indicates a slightly moderated relationship between mass and culpability relative to the 2012 report, which estimated a 2.18 percent increase in the rate of culpability per 100-pound mass reduction.

The regression results indicate that lighter (and, by proxy, smaller) vehicles are significantly more likely to be culpable in crashes (i.e., their drivers committed errors, such as failing to yield, that precipitated collisions). However, when footprint is added to the regression variables (which already include curb weight) to allow separate estimates of the effects of "lighter" and "smaller," neither has a significant effect. The coefficients for curb weight and footprint become:

Parameter	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
LBS100	-0.00983	0.0187	0.2769	0.5988
FOOTPRNT	-0.0173	0.0211	0.6705	0.4129

Basically, the new regression splits the effect for LBS100 in the first regression (reducing mass and footprint), placing roughly twice as much importance on square feet of footprint (holding mass constant) as hundreds of pounds of mass (holding footprint constant). However, with neither effect statistically significant, this result cannot be considered a precise division. Furthermore, the standard error of the LBS100 coefficient increases from .00492 in the previous regression to .0187, indicating a much higher degree of uncertainty in the statistical relationship between mass and culpability. A stronger split occurs, with an additional increase in standard error, if the two variables track width (TRAKWDTH) and wheelbase (WHEELB) are substituted for footprint:

Parameter	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
LBS100	-0.00497	0.0211	0.0522	0.8143
TRAKWDTH	-0.0235	0.0392	0.3575	0.5499
WHEELB	-0.00866	0.0103	0.7013	0.4024

Additional analyses of the MY 2003-2010 database confirm the presence of similar trends to higher culpability in lighter and smaller vehicles in cars, CUVs, and minivans (1.64% per 100 pounds) as in truck-based LTVs (1.27%); both estimates are statistically significant at the 95-percent confidence level. In the analysis of cars, CUVs, and minivans, if mass is entered as a two-piece linear variable, the effect of mass reduction is distinct in lighter versus the heavier vehicles, with a significant effect in heavier vehicles (2.55%) but no significant effect in lighter vehicles.

Conversely, in the analysis of truck-based LTVs, a two-piece linear representation of mass yields a significant effect in lighter vehicles (1.49%), but no significant effect in heavier vehicles. Considered in concert, these results indicate the presence of a critical local relationship between mass and culpability, in which changes in mass over a particular range of vehicle curb weights (relatively heavy cars, CUVs and minivans, and relatively light truck-based LTVs) are associated with meaningful changes in culpability.

The preceding analyses are all statistical; they indicate that lighter and smaller vehicles are less well driven, but they do not say why. One hypothesis ("self-selection") is that, for some reason, less effective drivers are more likely to choose lighter and smaller vehicles – but the lightness or smallness of the vehicles is not the cause of the ineffective driving. Another hypothesis ("driver-vehicle interface") is that certain aspects of lightness and/or smallness in a car or LTV give a driver a perception of greater maneuverability that ultimately results in driving with less of a "safety margin," for example weaving in traffic. That may appear paradoxical at first glance, as maneuverability is, in the abstract, a plus. But the situation is not unlike powerful engines that theoretically enable a driver to escape some hazards but in reality have long been associated with high crash and fatality rates.[24]

If lighter and smaller vehicles are driven less well, regardless of the reason, a cross-sectional statistical analysis of the historical data will associate a higher fatal-crash rate with lower mass and/or footprint, even after controlling for other factors. The effect is real in a statistical sense. However, it is only important for predicting the effect of future mass or size reductions if the lightness or smallness somehow causes the ineffective driving (driver-vehicle interface). If the observed effect is primarily self-selection, if the entire fleet were to proportionally lose mass or footprint, it presumably would not make everyone's driving proportionally worse.

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[24] Robertson, L.S. (1991), "How to Save Fuel and Reduce Injuries in Automobiles," *The Journal of Trauma*, Vol. 31, pp. 107-109; Kahane, C.J. (1994). Correlation of NCAP Performance with Fatality Risk in Actual Head-On Collisions, NHTSA Technical Report No. DOT HS 808 061. Washington, DC: National Highway Traffic Safety Administration, http://www-nrd.nhtsa.dot.gov/Pubs/808061.PDF, pp. 4-7.

1.6 Limitations of statistical analyses of historical crash and exposure data

The statistical analyses – logistic regressions – of trends in MY 2003-2010 vehicles generate a set of estimates of the possible effects of reducing mass by 100 pounds while maintaining footprint. While these effects might conceivably carry over to future mass reductions, there are reasons that future safety impacts of mass reduction could differ from projections from historical data:

- The statistical analyses are "cross-sectional" analyses that estimate the increase in fatality rates for vehicles weighing *n*-100 pounds relative to vehicles weighing n pounds, across the spectrum of vehicles on the road, from the lightest to the heaviest. They do not directly compare the fatality rates for a specific make and model before and after a mass reduction had been implemented for the purpose of improving fuel economy (which was rare in MY 2003-2010). Instead, they use the differences across makes and models as a surrogate for the effects of actual reductions within a specific model; those cross-sectional differences could include trends that are statistically, but not causally related to mass.

- While statistical analyses can control for many factors such as a driver's age and gender, there are other factors they do not control. If, for example, riskier drivers tend to prefer lighter and smaller vehicles and if the characteristics of these drivers cannot be quantified with available demographic variables, the analysis would probably attribute the higher crash rates to the mass and size of the vehicles.

- Analyses of historical data lag behind the latest developments in vehicles because it takes years for sufficient crash data to accumulate for the newer vehicles. Vehicles became heavier on the average, not lighter, during MY 2003-2010 and if they became heavier it was usually to provide additional features. While there were examples of materials substitution to reduce mass of some components or structure without degrading a vehicle's performance, most makes and models did not yet exhibit year-to-year trends of decreasing overall mass.

- Although the MY 2003-2010 database offers a more recent representation of the vehicle fleet and corresponding technologies than the previous report's MY 2000-2007 database, it still does not represent what vehicles will be on the road in the 2022-2025 timeframe. The vehicles manufactured in the 2003-2010 timeframe were not subject to a footprint-based fuel-economy standard. NHTSA and EPA expect that the attribute-based standard will affect the design of vehicles such that manufacturers may reduce mass while maintaining footprint more than has occurred prior to 2022-2025. Therefore, it is possible that the analysis for 2003-2010 vehicles may not be representative of those vehicles that interact with the existing fleet in 2022 and beyond.

2. New Databases to Study Fatalities per Billion VMT

2.0 Summary

The objective of this study is to compare the fatality rates of MY 2003-2010 cars and LTVs during CY 2005-2011 on as "level a playing field" as possible, in order to discover the intrinsic difference in the safety of light and/or small-footprint versus heavy and/or large-footprint vehicles. The databases must include information about drivers' age and gender, and other factors that differ by vehicle weight or type, in order to allow adjustments for those differences.

For example, since heavy cars have older drivers, on the average, than light cars, putting heavy and light cars "on a level playing field" requires computing fatality rates for heavy versus light cars for drivers of any specific age. Since pickup trucks are driven more in higher-risk rural areas than cars, a fair comparison of pickup trucks and cars requires computing both rural and urban fatality rates for each. Since some makes and models are driven more miles per year than others, it is appropriate to compare the fatality rates per mile rather than per registration year.

The databases applied within this report's analysis include records of three new model years (MY 2008-2010) and three new calendar years (CY 2009-2011) relative to the databases applied in NHTSA's 2012 report. The direct effects of updating the databases by three years include:

- The replacement of MY 2000-2002 vehicles with MY 2008-2010 vehicles;
- The replacement of CY 2002-2004 records with CY 2009-2011 records;
- An increased proportion of records involving MY 2003-2007 vehicles; and
- An increased proportion of records from CY 2005-2008.

The proportion of records involving MY 2003-2007 vehicles and CY 2005-2008 crashes is larger in the new databases due to three factors. First, for calendar years that are common across the 2012 and 2016 databases, MY 2000-2002 vehicles are no longer included. Second, MY 2003-2007 vehicles appear in more (and, in the case of MY 2003-2005 vehicles, all) of the calendar years included in the new databases than in the previous databases (i.e., CY 2002 records only included MY 2000-2002 vehicles, CY 2003 records only included MY 2000-2003 vehicles, and CY 2004 records only included MY 2000-2004 vehicles). Third, the now-removed MY 2000-2002 vehicles comprised the largest share of records in the previous database, appearing in all calendar years in the analysis; the now-included MY 2008-2010 vehicles comprise the smallest share in the new database, appearing in only CY 2008-2011 records.

The replacement of older vehicles and the increased proportion of MY 2003-2007 vehicles within the databases improves the degree to which the database represents the current (and likely short-term) vehicle fleet, including the prevalence of new safety technologies, vehicle designs and materials. Key safety technologies represented in the analysis include ESC, high-strength steel and aluminum. The updated database includes a greater share of CUVs, reflecting recent trends in consumer preferences.

The replacement of older records and the increased proportion of CY 2005-2008 records within the databases improves the degree to which the database represents current (and likely short-term) crash risks due both to changes in the vehicle fleet, travel demand and driver behavior. Overall, the new databases comprising MY 2003-2010 vehicles in CY 2005-2011 crashes are the most up-to-date possible, given the processing time for crash data and the need for enough crash cases to permit statistically meaningful analyses.

The Fatality Analysis Reporting System (FARS) provides most of the information about fatal crashes needed for this study: the type of crash and number of fatalities, the age and gender of the driver(s), the time and location. No single database has comparable exposure information for the "denominators" needed to compute fatality rates. IHS Automotive's (formerly R.L. Polk) National Vehicle Population Profiles (NVPP) count the number of vehicles of a given make-model and model year registered in any calendar year. A file of odometer readings, also supplied by IHS Automotive, was used to derive estimates of annual VMT by make and model. State data on primarily nonfatal crashes, specifically, on "induced-exposure" crashes, allow classification of the mileage by age, gender, urban/rural and other characteristics corresponding to the FARS data. Induced-exposure crashes are involvements as the non-culpable vehicle, in a two-vehicle collision. The distribution of such involvements within a particular area is believed to be an essentially random sample of travel through that area. Accurate estimates of the curb weight and footprint of vehicles, as well as other attributes such as the presence of electronic stability control (ESC), antilock brake systems (ABS), and side or curtain air bags are assembled from several publications.

This chapter describes how the various sources are merged to generate a database of fatal crash involvements and a database of induced-exposure crash involvements for model year 2003-2010 vehicles in calendar years 2005-2011. The procedure for generating the databases is identical to the procedure applied to generate the previous databases. The databases parse vehicle miles by vehicle mass, footprint, driver age, gender, urban versus rural, posted speed limits and other contextual factors, and are suitable for direct use in logistic regressions to estimate fatality risk as a function of these variables. The new databases are available to the public at http://www.nhtsa.gov/fuel-economy. NHTSA expects to update the databases to add more recent State and FARS crash data, and to incorporate updated information on VMT by vehicle make and model (as discussed in Section 2.5). NHTSA may update the databases in response to public comments on the report, as well. Researchers are encouraged to check http://www.nhtsa.gov/fuel-economy from time to time to ascertain they have the current version.

2.1 Vehicle classification, curb weight, footprint, and other attributes

The Vehicle Identification Number (VIN) allows precise classification of vehicles and analysis of their body style and safety equipment. The VIN is known, with few missing data on FARS (fatal crashes) and 13 State files (induced-exposure crashes) available for analysis at NHTSA for all calendar years 2005-2011: Alabama, Florida, Kansas, Kentucky, Maryland, Michigan, Missouri, Nebraska, New Jersey, Pennsylvania, Washington, Wisconsin, and Wyoming. The VIN itself, however, is not coded on IHS Automotive registration files, or listed in publications that specify curb weights.

NHTSA staff developed a series of VIN analysis programs in 1991 for use in evaluations of Federal Motor Vehicle Safety Standards and other vehicle safety analyses.[25] The programs are updated periodically. They were extended to model year 2011 in preparation for this study and are available to the public at http://www.nhtsa.gov/fuel-economy. Based entirely on the VIN, the programs identify a vehicle's make-model, model year and body type, and the type of restraint system for the driver and the right-front passenger. Each vehicle is assigned two five-digit codes: a fundamental vehicle group (that includes all of a manufacturer's vehicles of the same type and wheelbase, and runs for several years, until those vehicles are redesigned) and a specific make-model.

For example, Nissan Altima and Nissan Maxima four-door sedans, for model years 2007-2011 are two make-models that comprise a single car group. For LTVs, NHTSA's VIN decoder generally assigns separate 5-digit make-model codes to the various cab/body styles and drive trains.[26] But for passenger cars, and for the few LTVs that FARS assigns "car-like" make-model codes (i.e., a zero in the hundreds place), NHTSA's VIN decoder uses codes similar to FARS; here, vehicles with conventional and all-wheel drive may have the same make-model code. Body styles of passenger cars, based on the VIN, are 2-door convertibles, 2-door coupe/sedans, 3-door hatchbacks, 4-door sedans, 5-door hatchbacks, and station wagons. LTV types are pickup trucks, crossover utility vehicles (CUV), truck-based SUVs, minivans, and full-sized vans. A CUV is an SUV of unibody construction, often but not always upon a platform shared with passenger cars. Appendix A lists the 2003-2010 vehicles that are considered CUVs in this report; other SUVs are considered truck-based SUVs in this report.

Whereas IHS Automotive NVPP data do not include the actual VIN, their VIN-derived classification variables suffice to define the fundamental vehicle group, specific make-model and body style/truck type as above,[27] and permitted the IHS Automotive NVPP data to be merged with FARS or State crash data. NVPP data specify the number of vehicles registered as of July 1 of every calendar year. The file of odometer readings supplied by IHS Automotive classifies vehicles by the same variables as NVPP.

"Curb weight" is the weight of a ready-to-drive vehicle with a full tank of fuel and all other fluids, but no driver, passengers or cargo (as opposed to the "shipping weight," that excludes some fluids, and the "gross vehicle weight rating," that includes the vehicle and its permissible maximum load of occupants and cargo). Curb-weight information is derived from five sources:

1. *Branham Automobile Reference Books*, Branham Publishing Co., Santa Monica, CA (nearly all cars and LTVs)
2. *Ward's Automotive Yearbooks* (electronic version)
3. IHS Automotive's NVPP database (cars only)
4. FARS cases (most cars and minivans, many CUVs and SUVs, some full-sized vans, but no pickup trucks; FARS now usually specifies curb weights, and not shipping weights as it did in some earlier years)

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[25] Kahane (1994), pp. 18-19.
[26] For example, a Ford F-150 4x2 pickup truck with 2-door cab is 12210; 4x4 with 2-door cab, 12211; 4x2 extended cab, 12212; 4x4 extended cab, 12213; 4x2 crew cab, 12214; and 4x4 crew cab, 12215.
[27] But not the reverse: IHS Automotive's more detailed classification variables cannot be derived from these NHTSA codes.

5. www.cars.com
6. www.edmunds.com
7. www.motortrend.com

All of these, in turn derive from the same original source: manufacturers' official weights for vehicles of a specified make-model and subseries (and, perhaps, engine + transmission), with all equipment standard for that subseries, but without any additional, purely optional equipment.

The weights in the Branham Automobile Reference Books and Ward's Automotive Yearbooks are usually quite detailed and complete. Corresponding to any one of NHTSA's specific 5-digit vehicle-group and make-model codes and body style, Branham and Ward's may list a single curb weight or a range. If a range of weights is specified, however, it is not obvious how to identify the average within that range. Therefore, if NVPP provides the same or nearly the same range as Branham or Ward's, but also provides a count of registrations for each figure in the range, the registration-weighted average curb weight in the NVPP is used. Likewise, if FARS (but not NVPP) provides a range similar to Branham or Ward's, the *N*-of-crashes-weighted average is employed.

For the residual of vehicles where Branham or WardsAuto specifies weights that seem inconsistent with the preceding or following model year or out of line with similar vehicles (e.g., the same LTV but with a different drive system or cab style), www.cars.com, www.edmunds.com or www.motortrend.com may be consulted, or, for example, the average of the preceding and following model year's Branham or WardsAuto weight may be substituted for that year's weight.[28] When Branham or WardsAuto specify a range of weights, and neither NVPP nor FARS offer a reliable average, a central point in the range is identified based on the statistics for those makes and models where Branham has a range and NVPP or FARS do have a reliable average.[29]

Published, manufacturer-defined weights for vehicles usually include only standard equipment, but NHTSA's compliance- and crash-test contractors weigh "typical" vehicles (including popular options) from the stock of retail dealerships. However, NHTSA's 2003 report showed that already by the 1990s, the average discrepancy between measured and published curb weights had shrunk to an average of 1 percent in cars and 2 percent in LTVs. That is because once-optional

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[28] Or if, for example, year after year a 4x4 model weighs 400 pounds more than the 4x2 model, and in one model year they are listed as having the same weight, 400 pounds is added to the weight for the 4x4 model if the weight for the 4x2 model appears consistent with the previous and following years' 4x2 models.

[29] In general, these statistics show that the wider the range of weights (bran_lo to bran_hi) specified in Branham, the relatively closer the registration- or N-of-crashes-weighted average, branwt is to bran_lo – because, typically, sales are somewhat lower for the premium subseries or high-performance engines than for the more basic subseries. Based on GLM analyses of car models where Branham and NVPP or FARS weights are available, if bran_hi-bran_lo is exactly 124 pounds, branwt is .424 of the way up the range (53 pounds up from bran_lo) if the vehicle is an LTV and .325 of the way up (40 pounds up from bran_lo) if it is a car. If the bran_hi-bran_lo is greater or less than 124 pounds, branwt is proportionately (.039*log(nurange/124)) less or more of the way up, where nurange = bran_hi – bran_lo, but not less than 20 or more than 398 pounds. For example, for a car with bran_hi-bran_lo=200, branwt-bran_lo = 200x(.325-.039log(200/124)) = 61.27; for a car with bran_hi-bran_lo=500 (if such a car existed), branwt-bran_lo = 500x(.325-.039log(398/124)) = 139.76

features such as automatic transmissions and air-conditioning have increasingly become standard equipment on entire make-models or subseries of them.[30]

Footprint is a measure of a vehicle's size, defined as the wheelbase times the average of the front and rear track widths. The Department of Energy (Wenzel) gathered measurements of wheelbase and track width from motortrend.com into a spreadsheet and provided it to NHTSA. Consistent with NHTSA's 2012 report, footprint is not assumed to be identical for all vehicles of the same 5-digit car or LTV group. Track widths may vary slightly for vehicles built on the same or similar platforms. In the databases, wheelbase and track widths are measured in inches, footprint in square feet.

The other vehicle attributes included in the databases are:

- ABS (4-wheel)
- ESC
- Side air bags, including:
  - Curtain air bags
    - Rollover curtain bags that deploy and stay inflated in rollover crashes
  - Torso bags
  - Combination bags that provide torso and head protection
- Voluntary vehicle-to-vehicle compatibility certification for pickup trucks and SUVs[31], including:
  - Option 1: the primary energy-absorbing structure is low enough to adequately overlap the bumper height of passenger cars without additional structure
  - Option 2: a secondary energy-absorbing structure, often called a "blocker beam," below the primary structure
- All-wheel or 4-wheel drive (AWD)

The ABS, ESC, AWD, and side-air-bag variables are coded 1 if the feature is standard equipment for that VIN, 0 if it is not available, or a number between 0 and 1 if it is optional but not decodable from the VIN. Information about these features was gleaned from www.safercars.gov and National Insurance Crime Bureau vehicle-identification manuals (models and subseries where standard or available) and Ward's Automotive Yearbooks (percent equipped if optional and not VIN-decodable). Note that vehicles may be coded 1 for up to three of the four side-air-bag variables, namely if they have curtain plus torso bags and the curtains deploy in rollovers. The variable on vehicle-to-vehicle compatibility was simply coded 1 (for Option 1) or 2 (for Option 2), as these features are either standard or unavailable. AWD is coded 1 for either all-wheel drive or 4-wheel drive.

AWD and 4x4 usually add substantial mass to a vehicle, relative to the same model with 2-wheel drive. However, the vast majority of 4x4 and AWD vehicles are LTVs where NHTSA's VIN decoder assigns separate make-model codes to 4x2, 4x4, and AWD – and each of these make-

[30] Kahane (2003), pp. 18-19.
[31] "Enhancing Vehicle-to-Vehicle Crash Compatibility, Commitment for Continued Progress by Leading Automakers," Docket No. NHTSA-2003-14623-0013.

models has a different curb weight. For the relatively few passenger cars and LTVs (mostly CUVs) with "car-like" make-model codes that are available with either FWD/RWD or AWD, there is initially only one "central" curb weight defined for that make-model, NHTSA analyzes the VIN; if it is an AWD vehicle, AWD=1 and the curb weight is augmented; if not, AWD=0 and the curb weight is diminished.[32]

NHTSA's databases, which are available to the public at http://www.nhtsa.gov/fuel-economy, show the curb weight, footprint, and other attributes of each crash-involved vehicle. Appendices B and C of this report are codebooks for the variables on the public databases.

2.2 Fatal crash involvements: FARS data reduction

The preparation of the database of vehicles involved in fatal crashes consists of identifying: (1) the vehicle's make-model, body style, and curb weight, based on VIN analysis as described in the preceding section; (2) the type of crash, depending on the types and curb weights of other vehicles involved and whether non-occupants were involved; (3) the dependent variable, the count of fatalities in the crash (including fatalities in other vehicles and non-occupants); (4) potential control variables, factors that correlate with both vehicle weight and fatality risk, such as driver age, urban versus rural, day versus night, and posted speed limit.

The 2005-2011 FARS files contain 85,890 records of crash-involved vehicles of model years 2003-2010 with decodable VINs that can be assigned a model year, curb weight, and footprint, and identified as passenger cars or LTVs (pickup trucks, CUVs, truck-based SUVs and vans, excluding vehicles[33] but including "300-series" pickups and vans with GVWR sometimes over 10,000 pounds). The set of FARS records in this analysis represents a decrease of around 24 percent relative to the 2012 analysis (113,248 records), due to both a general downward trend in fatalities and a decrease in new vehicle registrations beginning in 2009. The database of fatal crash involvements consists of those 85,890 records. Table 2-1 assigns the 85,890 "case" vehicle records to nine basic crash types:

[32] A review of Branham weights for 8 make-models of cars available with FWD/RWD or AWD showed that AWD added an average of 168 pounds; that the AWD models averaged 115 pounds heavier than the "central" curb weight for that make-model and the FWD/RWD models, 53 pounds lighter. Thus, 115 pounds were added to the initial, central curb weight for cars with AWD=1 (if AWD was optional, not standard for that make-model) and 53 pounds were subtracted from the initial curb weight if AWD=0 (for those make-models where AWD was optionally available). Similarly, a review of Branham weights for 8 make-models of CUVs with car-like make-model codes and optional AWD showed that AWD added an average of 195 pounds; the AWD-equipped vehicles averaged 116 pounds more than the "central" curb weight; and the non-AWD vehicles averaged 79 pounds less than the "central" curb weight.

[33] Although Branham may list curb weights for incomplete vehicles such as cab-chassis or RV cutoffs, it is unknown how much additional weight (and it may be a lot) is added during the second stage of building the vehicle – e.g., adding the RV body.

TABLE 2-1: FATAL-CRASH INVOLVEMENTS OF MY 2003-2010 CARS AND LTVs WITH KNOWN CURB WEIGHTS ON CY 2005-2011 FARS

	Passenger Cars	Truck-Based LTVs	CUVs & Minivans
1. First-event rollovers	2,154	3,652	503
2. Hit fixed object	8,162	5,176	1,421
3. Hit pedestrians/bikes/motorcycles	6,280	5,594	2,253
4. Hit heavy truck or bus	2,586	1,743	673
5. Hit car, CUV or minivan < 3,082 lbs.	3,149	3,678	1,118
6. Hit car, CUV or minivan ≥ 3,082 lbs.	4,252	3,851	1,244
7. Hit truck-based LTV < 4,150 lbs.	2,073	1,700	491
8. Hit truck-based LTV ≥ 4,150 lbs.	3,115	1,819	717
9. All other crash involvements	8,676	6,945	2,865
	40,447	34,158	11,285

The 18,486 "all other" crash involvements in Table 2-1 include:

- 15,103 in collisions that involved three or more vehicles
- 835 in single-vehicle crashes where it is difficult to tell if the first truly harmful event was a rollover or a collision with a fixed object
- 1,082 crashes involving fatalities to both occupants and non-occupants, or where it was not clear which of the two involved vehicles hit the fatally injured non-occupant
- 528 non-collisions of other types, such as 1st-event immersion or falling from a moving vehicle
- 546 two-vehicle collisions where the other vehicle was of other/unknown type or unknown mass
- 217 collisions with trains
- 175 collisions with animals, working vehicles, or on-road objects

"First-event rollovers" include single-vehicle crashes where the rollover seemed to be the first truly harmful event, even if FARS coded an apparent tripping mechanism, such as a ditch, as the "first" harmful event. "Fixed-object" collisions include single-vehicle crashes where the case vehicle first left the travel lanes and then struck a substantial fixed object (including a parked car), regardless of whether it subsequently rolled over or not.[34] The third crash type includes collisions of one car or LTV with pedestrian(s), bicyclist(s), or motorcyclist(s), where the fatalities are not in the car or LTV, plus crashes involving two vehicles and non-occupant(s) where FARS clearly specifies that the case vehicle first hit and fatally injured the non-occupant, then hit the other vehicle without any additional fatality. Crash type 4 includes collisions involving one car or LTV and one or more heavy vehicles. Types 5-8 are limited to 2-vehicle collisions where the case vehicle is a 2003-2010 car or LTV and the "other" vehicle is a car or LTV, respectively, of known curb weight but any model year, not necessarily 2003-2010. Note

[34] Rollovers preceded by collisions with devices such as guardrails, which might be solid impacts in some cases and mere tripping mechanisms in others, are classified in the "all other crashes" group.

that truck-based LTVs have relatively high proportions of 1st-event rollovers and collisions with light cars, CUVs or minivans (where most of the fatalities are in the car, CUV, or minivan).

The following driver, road, and environmental factors are control variables for "case" vehicles defined directly from FARS data:

DRVAGE – Driver age (range 14 to 96): include if AGE of the driver of the case vehicle is 14 to 96. Delete case if AGE=97 (97 or older), 99 (unknown), less than 14, or if no driver record exists.

DRVMALE – Driver male (values 0, 1): if, for the driver of the case vehicle, SEX=1 (male) then DRVMALE=1, else if SEX=2 (female) then DRVMALE=0, else delete the case

NITE – Crash happened between 7:00 P.M. and 5:59 A.M. (values 0, 1): if HOUR = 6-18 (i.e., 6:00 a.m. – 6:59 p.m.) then NITE = 0, else if HOUR = 0-5 or 19-24 then NITE = 1, else delete the case

RURAL – Crash happened in a county with population density < 250 per square mile (values 0, 1): the Department of Energy (Wenzel) proposed this approach and supplied a list of population densities for every county in the United States, compatible with FARS (FIPS) State/county codes. If population density < 250 then RURAL=1, if ≥ 250 then RURAL=0, if COUNTY is unknown, delete the case.

SPDLIM55 – Crash happened on a road with speed limit 55 or more (values 0, 1): if the accident-level variable SP_LIMIT if 55, 60, 65, 70, 75, or 80 then SPDLIM55 = 1; otherwise SPDLIM55 = 0 (includes speed limits 5-50, unknown, or stray values).

CY – Calendar year of the crash, range 2005 to 2011

VEHAGE – Age of the case vehicle, CY-MY, range 0 (for a new vehicle) to 8 (MY 2003 in CY 2011). Delete cases with CY-MY = -1.[35]

HIFAT_ST – Crash happened in a State with a higher-than-national-average fatality rate (values 0, 1): if the State had a higher-than-national-average overall fatality rate per million vehicle years, HIFAT_ST = 1, else 0. The fatality rate is the sum of 2005-2011 traffic fatalities, divided by 2011 registered vehicles, as tabulated by the Federal Highway Administration.[36] The 26 States with lower-than average rates are Alaska, California, Connecticut, Delaware, Hawaii, Illinois, Indiana, Iowa, Maryland, Massachusetts, Michigan, Minnesota, Nebraska, New Hampshire, New Jersey, New York, North Dakota, Ohio, Oregon, Pennsylvania, Rhode Island, Utah, Vermont, Virginia, Washington, and Wisconsin. The 25 jurisdictions with higher-than-average rates are Alabama, Arizona, Arkansas, Colorado, D.C., Florida, Georgia, Idaho, Kansas, Kentucky, Louisiana, Maine, Mississippi, Missouri, Montana, Nevada, New Mexico, North Carolina, Oklahoma, South Carolina, South Dakota, Tennessee, Texas, West Virginia and

[35] Because corresponding exposure data might not be available. For example, if the new model year started selling October 1, there would be zero registrations in the NVPP file as of July 1.
[36] Table MV-1, State Motor-Vehicle Registrations – 2011, https://www.fhwa.dot.gov/policyinformation/statistics/2011/mv1.cfm.

Wyoming. HIFAT_ST is essentially a geographical variable. The HIFAT_ST = 1 group is primarily a contiguous area consisting of the South, the Mountain States and the adjacent States Kansas and Missouri, characterized by substantial non-metropolitan populations and/or short winters. The HIFAT_ST = 0 group is primarily the Northeast, the Midwest (except Kansas and Missouri), and the Pacific States, characterized high urbanization, by long winters, and/or aging populations.

2.3 Vehicle registration years: IHS Automotive NVPP data reduction

IHS Automotive's *National Vehicle Population Profile* (NVPP) databases do not include the actual VIN, but their VIN-derived variables suffice to define the fundamental vehicle group, specific make-model and body style/truck type as described in Section 2.1.[37] NVPP data specify the number of vehicles registered as of July 1 of every calendar year, and provide estimates of vehicle registration years by MY, CY, vehicle group, make-model, body style/truck type and, where needed, by State. NVPP data have no information, for example, on the age or gender of the drivers, or the annual VMT, or whether the vehicles were driven by day or at night.

2.4 Annual VMT: odometer readings from IHS Automotive

Fatality rates per hundred million vehicle miles of travel (VMT), rather than per million registration years, are the most widely accepted measure of risk. Estimates of the average VMT for a vehicle of a specific make-model and MY during a specific CY were derived as follows.

For its CAFE Final Regulatory Impact Analysis[38], NHTSA created updated estimates of the number of miles that the average car or LTV was driven per year, from the day the first owner acquires the vehicle, based on data from the 2009 National Household Travel Survey. Table 2-2 shows estimates for the first 9 years (the relevant ranges to apply to the databases):

[37] But not the reverse: IHS Automotive's more detailed classification variables cannot be derived from NHTSA's fundamental vehicle group, specific make-model and body style/truck type.
[38] National Highway Traffic Safety Administration (2012). *Final Regulatory Impact Analysis, Corporate Average Fuel Economy for MY 2017-MY 2025 Passenger Cars and Light Trucks*. Docket No. NHTSA-2009-0062-0012.

TABLE 2-2: AVERAGE ANNUAL VMT BY NUMBER OF YEARS IN SERVICE

	Cars	Cumulative (Cars)	LTV	Cumulative (LTV)
1st year	14,700	14,700	15,974	15,974
2nd	14,252	28,952	15,404	31,378
3rd	14,025	42,977	14,841	46,219
4th	13,593	56,570	14,435	60,654
5th	13,324	69,894	14,038	74,692
6th	13,064	82,958	13,650	88,342
7th	12,809	95,767	12,590	100,932
8th	11,378	107,145	12,192	113,124
9th	11,087	118,232	11,810	124,934

Table 2-2 does not correspond exactly to the average mileage for vehicles of a specific MY in a particular CY, because owners may acquire their new vehicles on any day of the year. For example, one customer bought his MY 2007 car on May 1, 2007 and only drove it for 7 months during CY 2007, while another bought her MY 2007 car back on November 1, 2006 and was already into her second year of ownership after November 1, 2007.

The 2012 report provided calculations tracking the cumulative mileage of a simulated 10,000-vehicle run of a generic make-model car in model year *N*. The simulation assumed that vehicles were sold at a uniform rate from October 1 of the previous calendar year (*N*-1) through September 30 of calendar year *N*; that each individual owner, starting from the date he or she buys the vehicle, drives at a constant rate of 14,700 miles per year until one year after the purchase date, then at a constant rate of 14,252 miles per year until two years after the purchase date, and so on; and (for simplicity) that no vehicles are retired.

The simulation generated annual VMT schedules that adjust for the unknown (assumed uniformly distributed) timing of purchases for a given model year vehicle. The projected VMT schedules presented in the 2012 report served as the basis for VMT weights by vehicle age in the 2012 database. The ratios of annual VMT by vehicle age (from Table 2-3 in the 2012 report) to average VMT by year of vehicle ownership (from Table 2-2 in the 2012 report) were applied to the updated database for this analysis to generate VMT schedules and weights, as itemized in Table 2-3:

TABLE 2-3: AVERAGE VMT BY VEHICLE AGE AND CALENDAR YEAR, ADJUSTED FOR TIMING OF VEHICLE PURCHASE

From Table 2-2			From 2012 Report, Tables 2-2 and 2-3		2016 VMT Schedule		
Year of Ownership	Average Annual Car VMT by Vehicle Age	Average Annual LTV VMT by Vehicle Age	CY/Year of Ownership	Ratio of VMT in CY to Average Annual VMT	CY	Average Car VMT	Average LTV VMT
1st Year	14,700	15,974	*MY/1st Year*	0.9575	*MY*	14,075	15,295
2nd	14,252	15,404	*MY+1/2nd*	1.0048	*MY+1*	14,320	15,478
3rd	14,025	14,841	*MY+2/3rd*	1.0054	*MY+2*	14,100	14,921
4th	13,593	14,435	*MY+3/4th*	1.0060	*MY+3*	13,674	14,521
5th	13,324	14,038	*MY+4/5th*	1.0066	*MY+4*	13,412	14,130
6th	13,064	13,650	*MY+5/6th*	1.0071	*MY+5*	13,157	13,747
7th	12,809	12,590	*MY+6/7th*	1.0077	*MY+6*	12,907	12,686
8th	11,378	12,192	*MY+7/8th*	1.0082	*MY+7*	11,472	12,292
9th	11,087	11,810	*MY+8/9th*	1.0088	*MY+8*	11,184	11,913

Table 2-3 estimates the VMT of the average vehicle of a specific MY during a specific CY. But, of course, some makes and models are driven more than average and others less. IHS Automotive has recently assembled a large vehicle database, derived primarily from repair orders at dealerships and other repair facilities, that includes the vehicle's odometer reading on that day (e.g., on the day it was brought in for maintenance or repairs). In October 2014, IHS Automotive extracted records of the MY 2003-2010 cars and LTVs that appear on the database and had at least one odometer reading during the past 30 months. For each individual vehicle, IHS Automotive selected the single, most recent odometer reading for that vehicle in the database. IHS Automotive grouped the vehicles by the NVPP coding system for makes and models, indicating the number of vehicles and average odometer reading for each code. NHTSA purchased the aggregated file. The agency further aggregated the data by its 5-digit vehicle-group and make-model codes, by body type, and by MY, applying the same programs as in the NVPP data reduction.

The average odometer reading for all MY 2008 cars and LTVs on this IHS Automotive file might be, for example, 50,000 (the "typical" vehicle). The average odometer reading for a 2008 ______ 4-door sedan might be 40,000, which would be 80 percent of the reading for the typical car. Thus, in each CY, the VMT for the 2008 ______ 4-door sedan will be an estimated 80 percent of the VMT for the typical car. For example, Table 2-3 shows that the typical MY 2008 car was driven 14,320 miles in CY 2009; the 2008 ______ 4-door sedan was driven an estimated 11,456 miles in CY 2009 (80 percent of 14,320). Similarly, Table 2-3 shows 14,100 miles for the typical MY 2008 car in CY 2010; that would be 11,280 for the ______ 4-door sedan.

The estimated total VMT of a specific make-model of model year MY in calendar year CY is the number of vehicles registered for that MY and CY times the VMT of the typical vehicle of that MY in that CY, as shown in Table 2-3, times the ratio of odometer readings for that specific vehicle in that MY relative to the typical vehicle.

The file of odometer readings is not a historic database. For any vehicle, even back to MY 2003, it only specifies the most recent reading during the 30 months before October 2014, rather than a series of readings from 2003 onward. The assumption in the above estimates is that if the 2008 ______ 4-door sedan currently has 80 percent of the VMT of the typical MY 2008 car, it also accumulated VMT, year by year, at 80 percent of the typical rate. The database will not identify make-models whose lifetime VMT is concentrated more than usual in the early or the late years of their time on the road.

2.5 Induced-exposure crashes: State data reduction

The preceding data estimates the VMT accumulated by vehicles of a specific curb weight in a given MY and CY but say nothing about who was driving the vehicles, or on what type of road. Classification of the VMT by age, gender, urban/rural, etc. allow fatality rates to be adjusted for these control variables – i.e., to compare the fatality rates of cars of two different curb weights for drivers of the same age and gender on the same type of road. State data on primarily nonfatal[39] crashes, specifically, "induced-exposure"[40] crash involvements, supply this information. Induced-exposure crash involvements are the non-culpable vehicles in two-vehicle collisions. Those non-culpable vehicles did nothing to precipitate the collision, but were hit merely because "they were there." The involvements are a surrogate for exposure, because they measure how often vehicles "were there" to be hit by other vehicles. "The induced exposure concept assumes that the not-at-fault driver in a two-vehicle crash is reflective of what is 'on the road' at that point in time, and that the sample of all not-at-fault drivers can be used to predict the characteristics of all non-accident involved drivers on the roadway (i.e., exposure characteristics)."[41]

The State data represent a sample of 13 States that provide the VIN (all in common with the 2012 report):

Alabama	Florida	Kansas	Kentucky
Maryland	Michigan	Missouri	Nebraska
New Jersey	Pennsylvania	Washington State	Wisconsin
Wyoming			

[39] The file of induced-exposure crash involvements includes fatal as well as nonfatal crashes; however, over 99 percent of the crashes are nonfatal.
[40]Stutts, J. C., and Martell, C. (1992), "Older Driver Population and Crash Involvement Trends, 1974-1988," *Accident Analysis and Prevention*, Vol. 28, pp. 317-327; Haight, F.A. (1970), "A Crude Framework for Bypassing Exposure," *Journal of Safety* Research, Vol. 2, pp. 26-29; Haight, F.A. (1973). "Induced Exposure," *Accident Analysis and Prevention*, Vol. 5, pp. 111-126; Thorpe, J.D. (1964), "Calculating Relative Involvement Rates in Accidents without Determining Exposure," *Australian Road Research*, Vol. 2, pp. 25-36; Van Der Zwaag, D.D. (1971), "Induced Exposure as a Tool to Determine Passenger Car and Truck Involvement in Accidents," *HIT Lab Reports*, Vol. 1, pp. 1-8; Cerrelli, E. (1973). "Driver Exposure: The Indirect Approach for Obtaining Relative Measures," *Accident Analysis and Prevention*, Vol. 5, pp. 147-156.
[41] Stutts and Martell (1992), p. 318; however, see also Kahane (2003), pp. 34-35 for some caveats about induced-exposure data.

The State data include 2,255,398 records of induced-exposure cases, a decrease of around eight percent relative to the 2012 database (2,457,228 records), compared to a 24 percent decrease in FARS records relative to the 2012 database. The difference in sizes of the State and FARS data between the 2012 and 2016 reports indicate the presence of a larger decrease in the fatality rate than in the crash rate between the two samples.

For all 13 States, the data included crash records through CY 2011 with relatively complete data on the VINs of crash-involved vehicles. Because data were available for all 13 States through CY 2011, it was not necessary to impute induced exposure for any calendar years in the analysis; this represents an improvement in the availability of data relative to the 2012 report.

Maryland, Michigan, Nebraska, New Jersey, Pennsylvania, Washington State, and Wisconsin have lower-than-national-average fatality risk, as defined in Section 2.2, while Alabama, Florida, Kansas, Kentucky, Missouri, and Wyoming are higher than average.[42]

Records of induced-exposure crash involvements of MY 2003-2010 cars and LTVs with decodable VINs were extracted from the State data files. The sample of records was limited to vehicles that were in crashes involving exactly two vehicles and zero non-occupants. The sample was further limited to crashes where one vehicle can be classified "non-culpable" and the other "culpable." If so, the non-culpable vehicle is specified as the induced-exposure case.

The first criterion for culpability is whether the State itself notes a violation or a contributing circumstance for the driver of that vehicle. If, by that criterion, both vehicles are culpable, the case is not used. But if, by that initial criterion, neither vehicle is culpable in over 20 percent of the crashes, two additional criteria are considered, as in NHTSA's previous report:[43] (1) if one moving vehicle hit another that was standing still (where permitted), the moving vehicle is culpable; (2) for States coding the impact area, if one vehicle frontally impacts the rear of another vehicle (that was not backing up or encroaching into the first vehicle's lane), the frontally impacting vehicle is culpable. The culpable vehicle may be any type or model year; only the non-culpable vehicle has to be a MY 2003-2010 car or LTV. Furthermore, the non-culpable vehicle must have a driver age 14-96, thereby automatically excluding unoccupied, parked vehicles from the study.

Control variables are defined for induced-exposure vehicles parallel to those defined in FARS. DRVAGE, DRVMALE, RURAL (based on the county's population density), CY, and HIFAT_ST can be defined in each State just as in FARS. Many States, like FARS, have a single speed limit defined at the crash level, but some define a speed limit for each vehicle, as vehicles on different roads could collide at an intersection. In these States, for consistency with FARS and the other States, the higher speed limit of the two vehicles is used to define SPDLIM55. All States except Alabama in 2005-2006 specify the time of the crash, permitting NITE to be defined

[42] Four State files were included in NHTSA's 2003 and 2010 analyses but not here: Ohio stopped reporting VINs in the data it sends to NHTSA; North Carolina and Utah have not sent 2007 data to NHTSA; Illinois does not report speed limits in the data it sends to NHTSA and the 2003/2010 attempts to impute speed limits from other variables were not fully satisfactory. But in the meantime Michigan has resumed reporting VINs and eight additional States send files including VINs and speed limits to NHTSA: Alabama, Kansas, Kentucky, Nebraska, New Jersey, Washington, Wisconsin, and Wyoming.
[43] Kahane (2003), p. 32.

as in FARS. For 2002-2006 Alabama data (which define neither the time of day nor the month of the crash), NITE is imputed from the case number and the light condition, based on the relationship of those variables in the 2007-2011 data (which does encode time and month). For example, the crashes with case numbers near the middle of the file occurred in June and July, at which time virtually all crashes in the dark are between 7:00 P.M. and 5:59 A.M. (NITE = 1), whereas the crashes with case numbers near the end of the file occurred in December, at which time virtually all daylight crashes are between 6:00 A.M. and 6:59 P.M. (NITE = 0). This is the only imputed control variable, and only in 2005-2006 Alabama data.

Unlike the 2011 and 2012 NHTSA analysis, 2005-2011 State files were available for all 13 States in the database. Thus, it was not necessary to use a given yearly State file to classify an unavailable calendar year for a given State in the database.

The counts of induced-exposure crash involvements in 2005-2011 vary from State to State:

Alabama	207,511
Florida	309,633
Kansas	55,653
Kentucky	182,868
Maryland	106,055
Michigan	344,632
Missouri	196,525
Nebraska	46,808
New Jersey	407,730
Pennsylvania	126,003
Washington State	139,697
Wisconsin	118,825
Wyoming	13,458
	2,255,398

There are usually more crashes in the more populous States, but reporting thresholds play a role. For example, Pennsylvania has considerably fewer crashes than New Jersey because of a higher reporting threshold. The technique described in the next section, weighting the cases by VMT, will give higher weights to the cases in the States with higher reporting thresholds.

This report relies on induced-exposure data from 13 States to represent the United States. Although the absolute distributions of crashes by driver age, rural/urban, etc. differ considerably from State to State, the interactions of these variables with curb weight and footprint are remarkably consistent across States. As we shall show in Section 3.5, the use of data from just 13 States rather than all the States makes minimal-to-moderate contribution to the uncertainty of the estimated effects of mass reduction on fatality rates.

2.6 Assembling the analysis data files

The database of induced-exposure crash involvements for model year 2003-2010 vehicles in calendar years 2005-2011 consists of 2,255,398 records from 13 States, as described in the preceding section. The critical step in building the database is to allocate the right number of vehicle years and VMT to each induced-exposure crash, so that the induced-exposure crashes in 13 States represent all the vehicle years and VMT in the United States. This will apportion the nation's vehicle registration years and VMT not only by make-model, body style, model year and calendar year but also by driver age, gender, rural/urban location and the other control variables. The weighting procedure was modified somewhat from NHTSA's 2003 and 2010 reports in the 2011 and 2012 analysis (and also applied in this report) to allow greater flexibility in addressing vehicles with lower sales that might not experience induced-exposure crashes every year in each State; this approach is particularly valuable in incorporating data from States with relatively low populations and few crashes.

The first example of allocation is for a vehicle with high sales. During CY 2010, the MY 2007 Honda Accord 4-door had the following non-zero registrations (as of July 1, 2011) and non-zero counts of induced-exposure crash involvements in each of the 13 States:

MY 2007 Honda Accord in CY 2010	Registrations	Induced-Exposure Involvements
Alabama	5,860	185
Florida	23,650	160
Kansas	2,570	26
Kentucky	3,552	106
Missouri	4,365	88
Wyoming	323	4
These 6 high-fatality-rate States	40,230	
Maryland	10,486	87
Michigan	4,809	85
Nebraska	1,643	20
New Jersey	18,109	440
Pennsylvania	15,171	79
Washington State	5,736	84
Wisconsin	4,587	57
These 7 low-fatality-rate States	60,541	
All 24 high-fatality-rate States + D.C.	142,471	
All 26 low-fatality-rate States	217,258	
Entire United States	359,729	

Since there were 185 crash involvements and 5,860 registered cars in Alabama, each crash corresponds to

$$5{,}860/185 = 31.68 \text{ vehicle years within Alabama.}$$

However, since the 6 high-fatality-rate States in our sample had 40,230 registered vehicles, whereas all 24 high-fatality-rate States plus D.C. had 142,471 registered vehicles, each Alabama crash would be allocated

$$(142{,}471/40{,}230) * (5{,}860/185) = 112.18 \text{ high-fatality-rate vehicle years in the United States.}$$

Similarly, each of the 57 crash involvements in Maryland would be allocated

$$(217{,}258/60{,}541) * (10{,}486/87) = 432.53 \text{ low-fatality-rate vehicle years in the United States.}$$

The allocation of vehicle years per crash in the 13 States is:

MY 2007 Honda Accord in CY 2010	Induced-Exposure Involvements	Vehicle Years Apportioned Per Involvement
Alabama	185	112.18
Florida	160	521.47
Kansas	26	350.05
Kentucky	106	118.67
Missouri	88	175.66
Wyoming	4	285.97
Maryland	87	432.53
Michigan	85	203.03
Nebraska	20	294.80
New Jersey	440	147.70
Pennsylvania	79	689.15
Washington State	84	245.05
Wisconsin	57	288.79

Note that the sum of the products of each State's induced exposure cases and apportionment –

$$185*112.18 + 160*521.47 + 26*350.05 + 106*118.67 + 88*175.66 + 4*285.97$$

$$+ 87*432.53 + 85*203.03 + 20*294.80 + 440*147.70 + 79*689.15 + 84*245.05 + 57*288.79$$

– equals 359,729 vehicle years in the entire United States, matching the registration total for the vehicle.

In other words, these weight factors (vehicle years) allocated to each induced-exposure crash will add up, over the entire file, exactly to the number of 2007 Honda Accord 4-door cars registered in the United States during CY 2010. In general, the weight factors are higher in States such as Pennsylvania that have higher crash-reporting thresholds, and relatively fewer reported crashes per vehicle year.

The second example is the MY 2007 Volvo XC70 AWD CUV, a vehicle with lower sales that did not experience an induced-exposure crash in Florida, Kansas and Wyoming during CY 2010:

MY 2007 Volvo XC70 AWD in CY 2010	Registrations	Induced-Exposure Involvements
Alabama	43	1
Florida	283	none
Kansas	40	none
Kentucky	64	4
Missouri	89	2
Wyoming	24	none
The 3 high-fatality-rate States with registrations and crashes	196	
Maryland	310	1
Michigan	250	3
Nebraska	28	1
New Jersey	743	11
Pennsylvania	640	2
Washington State	305	1
Wisconsin	143	1
The 7 low-fatality-rate States with registrations and crashes (all)	9,235	
All 24 high-fatality-rate States + D.C.	2,476	
All 26 low-fatality-rate States	9,235	
Entire United States	11,711	

Since there was 1 crash involvement and 43 registered cars in Alabama, that crash corresponds to 43 vehicle years within Alabama.

However, since the 3 high-fatality-rate States with non-zero registrations and crashes in our sample had 196 registered vehicles, whereas all 24 high-fatality-rate States plus D.C. had 2,476 registered vehicles, each Alabama crash would be allocated

(2,476/196) * (43/1) = 543.20 high-fatality-rate vehicle years in the United States.

The allocation of vehicle years per crash in the 13 States is:

MY 2007 Volvo XC70 AWD in CY 2010	Induced-Exposure Involvements	Vehicle Years Apportioned Per Involvement
Alabama	1	543.20
Florida	none	N/A
Kansas	none	N/A
Kentucky	4	202.12
Missouri	2	562.15
Wyoming	none	N/A
Maryland	1	1183.48
Michigan	3	318.14
Nebraska	1	106.90
New Jersey	11	257.87
Pennsylvania	2	1221.66
Washington State	1	1164.40
Wisconsin	1	545.93

Again, 1*543.20 + 4*202.12 + 2*562.15 +

1*1183.48 + 3*318.14 + 1*106.90 + 11*257.87 + 2*1221.66 + 1*1164.40 + 1*545.93

= 11,711 vehicle years in the entire United States, matching the registration total for the vehicle.

This process is repeated for all other make-models of cars and LTVs, MY 2003-2010 in CY 2005-2011. It successfully allocates 99.48 percent of the registration years of MY 2003-2010 vehicles in CY 2005-2011. However, some vehicle group-make-model-body style-MY combinations had sales so low that they had zero crashes and/or zero registrations in all 6 high-fatality-rate States and/or in all 7 low-fatality-rate States in one or more CY, making it impossible to directly allocate registration years to a specific crash in that CY. For such combinations, the induced-exposure cases for the various other CY are accepted (but only the registrations for that CY are allocated among them).

If the sales are so low that none of the other CY produced candidate cases for that vehicle group-make-model-body style-MY combination, even the induced-exposure cases for the various other MY, but same vehicle group, make-model, and body style are accepted. If, even with this extension, there are still no candidate cases, this combination is deleted from the working induced-exposure file and likewise from the file of fatal crash involvements.

As a consequence, combinations totaling 0.20 percent of the registration years of MY 2003-2010 vehicles in CY 2005-2011 were deleted from the analysis. The procedure eliminates the unappealing technique in the 2003 and 2010 reports of creating single dummy records that average, over several crashes, the values of fundamentally categorical variables such as the driver's gender.[44]

VMT are also allocated to each induced-exposure case, based on the make-model, body style, MY, and CY (see Section 2.4). The average 2007Honda Accord 4-door is estimated to have traveled 13,855 miles in CY 2010. Since each Alabama crash is apportioned 87.69 vehicle years, it is also apportioned 112.18 * 13,855 = 1,554,254 vehicle miles. The average 2007 Volvo CX70 AWD (a higher-mileage vehicle) is estimated to have traveled 13,147 miles in CY 2010. Because the Alabama crash is apportioned 543.20 vehicle years, it is also apportioned 543.20 x 13,147 = 7,141,450 vehicle miles.

Here are hypothetical examples of a record from the database of fatal-crash involvements and a record from the database of induced-exposure crash involvements. The fatal-crash record is from a high-fatality-rate State and the induced-exposure record is from Alabama, a high-fatality-rate State. Both records are MY 2007 Honda Accord 4-door sedans in CY 2010:

	Record from Fatal-Crash Database	Record from Induced-Exposure Database
Crash type	Hit truck-based LTV ≥ 4,303 lbs.	-
N of fatalities in the crash	2	-
Vehicle registration years	-	112.18
VMT	-	1,554,254
Vehicle type	4-door car	4-door car
Curb weight	3,262 lbs.	3,262 lbs.
Footprint	45.8 sq. ft.	45.8 sq. ft.
Driver age	24	28
Driver male?	1	1
At night?	0	0
Rural?	1	0
Speed limit 55+?	1	0
Calendar year	2010	2010
Vehicle age	2	2
High-fatality-rate State?	1	1
ABS (4-wheel)	1	1
ESC	0	0
AWD	0	0
Curtain air bags	0	1
Rollover curtains	0	0
Torso air bags	0	1
Combination side air bags	0	0

[44] Kahane (2003), p. 37; however, changing the procedure likely had little influence on the results, because dummy records accounted for only 1% of the registration years in the previous study and cases from alternate CY/MY accounted for only 0.19% of the registration years in this report.

The 85,890 records on the database of fatal crash involvements come from all 50 States and the District of Columbia. Each of the 2,255,398 records on the database of induced-exposure crash involvements is nominally a specific crash involvement in one of 13 States, a discrete unit. But when any of these records is weighted by its allocation of vehicle years or VMT, it becomes a cohort of vehicle years or VMT in the United States. The induced-exposure records are a national census of vehicle years and VMT. Fatal-crash records are weighted by the number of fatalities in the crash. The sum of the fatalities in the crashes divided by the sum of the VMT is the national fatality rate per mile. The two databases will be combined and used for the regression analyses.

3. Results

3.0 Summary

The effects of mass reduction and footprint reduction on societal fatality rates per billion VMT are estimated by logistic regression for five classes of vehicles in nine types of crashes, controlling for other factors such as driver age and gender, urbanization and speed limit, and safety equipment such as ESC. The regressions tend to show a benefit for mass reduction in rollovers and fixed-object impacts. They tend to show a harmful effect of mass reduction in collisions with other vehicles, with the key exception of a general benefit for mass reduction in a heavy vehicle in collisions with lighter vehicles.

Averaged across crash types, mass reduction by 100 pounds in:

- Cars weighing less than 3,197 pounds is associated with a 1.49 percent societal fatality increase (statistically significant at the 90-percent confidence level);

- Cars weighing 3,197 pounds or more is associated with a 0.50 percent societal fatality increase (not statistically significant at the 90-percent confidence level);

- Truck-based LTVs weighing less than 4,947 pounds is associated with a 0.10 percent societal fatality decrease (not statistically significant at the 90-percent confidence level);

- Truck-based LTVs weighing 4,947 pounds or more is associated with a 0.72 percent societal fatality decrease (statistically significant at the 90-percent confidence level); and

- CUVs and minivans is associated with a 0.99 percent societal fatality decrease (statistically significant at the 90-percent confidence level).

The report presents computational examples of simultaneous mass reductions in all types of vehicles: (1) mass reduction by 100 pounds in every vehicle is projected to lead to an increase in fatalities of approximately 100 per year; (2) mass reductions that are proportionately somewhat greater in the heavier vehicles can be safety-neutral or better as point estimates. However, the estimated safety effects that will appear in the midterm evaluation will be based on the CAFE Compliance and Effects Modeling System (usually referred to as the “Volpe model”) and not these computational examples.

The results are generally consistent with NHTSA’s 2012 report. The estimated effects of a 100-pound mass reduction on societal fatality risk are close in magnitude for lighter cars (1.49 percent risk increase in this report versus 1.56 percent risk increase in the 2012 report) and heavier cars (0.50 percent risk increase in this report versus 0.51 percent risk increase in the 2012 report). The estimated effects of a 100-pound mass reduction on societal fatality risk are more beneficial than in the 2012 report for heavier truck-based LTVs (0.72 percent risk decrease in this report versus 0.34 percent risk decrease in the 2012 report) and CUVs and minivans (0.99 percent risk decrease in this report versus 0.37 percent risk decrease in the 2012 report).

The estimated effect of mass reduction for lighter truck-based LTVs on societal fatality risk is distinct in this report relative to the 2012 report. In this report, a 100-pound mass reduction in lighter truck-based LTVs is estimated to reduce societal fatality risk by 0.10 percent, compared to an estimated 0.52 percent societal fatality risk increase in the 2012 report. This result likely reflects at least one of two relationships:

- The relatively large increase in curb weights across LTVs in FARS (from median 4,594 pounds in the 2012 report to 4,947 pounds in this report) indicates that lighter LTVs have become heavier relative to the fleet of (generally lighter) passenger cars (consistent with heavier LTVs, for which mass reduction is also more societally beneficial in this report relative to the 2012 report); and

- Neither the 2012 nor current estimate of the sensitivity of societal fatality risk to the mass of lighter LTVs is statistically significant at the 90-percent confidence level, and hence the variability in estimates across reports reflects a weak statistical relationship between mass and fatality risk for lighter LTVs.

3.1 Regression setup

Case-vehicle categories: NHTSA's 2003 and 2010 reports analyzed two groups of MY 1991-1999 case vehicles, passenger cars and LTVs. All LTVs were included in the same analysis, with categorical variables to indicate the LTV type (SUV, MINIVAN, BIGVAN; pickup trucks being the default type). NHTSA expressed misgivings, echoed by Paul Green in his peer review of the 2010 report, that including disparate types of "niche" vehicles, each with its own pattern of crash types and of relationships between mass and footprint, might generate coefficients for mass and footprint that reflect the vehicle mix rather than the underlying relationships, within each individual type of LTV, of these parameters with fatality risk.[45] The issue is now even more critical because of the increase in CUVs, which are technically LTVs but in many ways more closely resemble cars.

Consistent with the 2012 report, this report will present regression analyses on three rather than two classes of vehicles, to help mitigate this issue:

- <u>Truck-based LTVs</u> exclude CUVs and, for that matter, minivans, which also resemble CUVs and cars in some ways. CUVs and minivans are examined separately in their own group. In order to make this class even more homogeneous, full-size vans, which account for only 1.32 percent of the vehicle registration years and 1.64 percent of the VMT in the database, are also excluded in the regression analyses. In other words, it is limited to pickup trucks and truck-based SUVs, most of which are built on pickup-truck platforms.[46]

- <u>CUVs and minivans</u>: An argument could be made for including them with cars, but they are not really cars; including CUVs and minivans with cars would just move the problem

[45] Kahane (2010), pp. 522-523.
[46] Although full-sized vans and the Chevrolet Astro/GMC Safari are not included in the regression analyses, these vehicles are included in the tabulations of baseline fatalities of truck-based LTVs and regression coefficients for truck-based LTVs are applied to those baseline fatalities.

in the 2003 and 2010 reports from one class to another. Rather, CUVs and minivans constitute a class by themselves in this analysis. However, in the regressions, minivans do not include the Chevrolet Astro and GMC Safari (which more closely resemble full-size vans than the typical minivan). Appendix A lists the SUVs that this report calls CUVs.

- Passenger cars: As in the 2012 report, 2-door and 4-door cars are included in the regressions. Two-door high-performance cars and 4-door police cars are excluded because their inclusion was found to skew the regression results in the 2010 and 2003 analyses, respectively.[47] To make this class more homogeneous and simplify the analyses, the 5.2 percent of passenger cars equipped with all-wheel-drive are also excluded (as will be discussed at the end of this section); all other 2-door and 4-door cars are included.

A sensitivity test at the end of Section 3.5 includes the full-size vans among the truck-based LTVs, and high-performance cars, police cars, and AWD-equipped cars among the passenger cars.

Formulation of the independent variables: The two principal independent variables are curb weight and footprint. Curb weight and footprint have been highly correlated across the 2010 and 2012 reports; as the 2010 report discussed at length, strong correlations between the two central independent variables in the analysis raised concerns about the accuracy of regression coefficients.[48] In the 2012 report, the correlation coefficient of curb weight with footprint was .896 in cars and .748 in LTVs. After controlling for body style, but not the other control variables, the variance inflation factors (VIF) were 7.34 in cars, 9.80 in LTVs, and 8.71 in CUVs and minivans. In logistic regressions, "there is no formal cutoff value to use with VIF for determining presence of multicollinearity. Values of VIF exceeding 10 are often regarded as indicating multicollinearity, but in weaker models, which is often the case in logistic regression, values above 2.5 may be a cause for concern."[49] Allison "begins to get concerned" when he sees VIF scores over 2.5.[50]

These statistics have changed little in the MY 2003-2010 database. The correlation coefficient of curb weight with footprint is now .882 in cars, .727 in truck-based LTVs, and .818 in CUVs and minivans. After controlling for body style and all the other control variables, the VIF is 6.27

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[47] *Ibid*., pp. 484-486; Kahane (2003), pp. 171-172; in this study, the excluded high-performance cars are Chrysler/Plymouth Prowler, Dodge Viper, Ford Mustang and GT, Chevrolet Corvette and Camaro, Pontiac GTO and Firebird, BMW Z3 and Z8, Jaguar XK, Mercedes SL and SLR, all Porsche, and Acura NSX. Excluded 4-door cars are not limited to "police" models of Ford Crown Victoria and 2006-2007 Chevrolet Impala but also all other Crown Victorias (which, if not police cars, are often taxicabs or high-mileage fleet vehicles) and 2004-2005 Impala SS, which often served as a police car before Chevrolet developed its "police" model in 2006.

[48] Kahane (2010), pp. 479-481 and 522-523.

[49] Schadler, A. *Multicollinearity in Logistic Regression*. Lexington, KY: University of Kentucky Center for Statistical Computing Support. http://www.uky.edu/ComputingCenter/SSTARS/MulticollinearityinLogisticRegression.htm.

[50] Allison, P.D. (1999), pp. 48-51.

in cars, 7.55 in truck-based LTVs, and 8.17 in CUVs and minivans.[51] VIF continues to be in the somewhat unfavorable 2.5-10 range.

Several methods to index curb weight to footprint or vice-versa were considered in response to comments by the peer reviewers on the 2010 and also the 2011 preliminary report. Analyses in the 2012 report using alternative indexing techniques indicated that the indexing techniques successfully lower VIF but do not meaningfully affect the results of the logistic regressions (see Section 4.6 of the 2012 report). NHTSA will continue to use curb weight and footprint as the two principal variables, but will check the results with a decile analysis – by a method revised in the 2012 report in response to Farmer's peer review of the 2010 report – in Section 3.4. The decile analysis produces results consistent with the basic regressions and provides at least some corroboration for the accuracy of the coefficients.

Footprint is measured in square feet, and is calculated as the wheelbase multiplied by the average of the front and rear track widths. As in the 2012 report, curb weight is entered as a 2-piece linear variable (measured in hundreds of pounds) in the analyses of cars and truck-based LTVs, to permit separate estimates of the effects of mass reduction in the lighter or in the heavier vehicles. However, because vehicles became heavier after 2000 (and because CUVs and minivans are no longer included with the truck-based LTVs), the median weight of MY 2003-2010 vehicles involved in fatal crashes, which serves as the dividing line between "lighter" and "heavier," has increased in the cars from 3,106 to 3,197 and from 4,594 to 4,947 in the LTVs.

In the analyses of passenger cars, for example, if the curb weight is less than 3,197,

UNDRWT00 = .01 (curb weight – 3,197), OVERWT00 = 0

And if it is 3,197 or more,

UNDRWT00 = 0, OVERWT00 = .01 (curb weight – 3,197)

In the regression analyses of CUVs and minivans, where the database is much smaller as shown in Table 2-1, it is futile to estimate separate effects above and below the median weight. Mass is a simple linear variable, LBS00, measured in hundreds of pounds.

Dichotomous variables indicate the vehicle's body style. In the regressions of passenger cars, TWODOOR=1 for 2-door cars, 0 for 4-door cars. In the regressions of truck-based LTVs, SUV=1 for SUVs, HD_PKP=1 for heavy-duty pickup trucks (200/300 series), and both variables are zero for 100-series and smaller pickup trucks. In the regressions of CUVs and minivans, MINIVAN=1 for minivans, 0 for CUVs.

Fatal-crash rates per VMT are higher for young and old drivers than for people age 30-50. They are higher for males than females, but the difference decreases at the higher ages. As in the 2012 report, these relationships are captured by entering driver age and gender as nine variables,

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[51] As the VIF test is based on a linear regression model with a dummy dependent variable, control variables such as driver age and calendar year are formulated as simple linear variables. By contrast, the VIF for curb weight with all the other control variables, but not footprint, is only 3.74 for cars, 3.10 for truck-based LTVs, and 3.41 for CUVs and minivans.

DRVMALE (defined in Section 2.2) and M14_30 M30_50 M50_70 M70_96, F14_30 F30_50 F50_70 F70_96, where, for example, M14_30 = 30 – DRVAGE for male drivers age 14-30, = 0 for male drivers age 31+ and all female drivers.[52] In other words, age is entered as a 4-piece linear variable, allowing separate slopes for various age groups depending on the type of crash and the driver's gender.

The control variables NITE, RURAL, SPDLIM55, and HIFAT_ST; the vehicle attributes ESC, ABS, and AWD; and the side-air-bag variables CURTAIN, ROLLCURT, TORSO, and COMBO are unchanged from Section 2.2. Information on compatibility certification is expressed as two dichotomous variables, BLOCKER1=1 if the LTV is certified to meet Option 1, BLOCKER2=1 if Option 2. As in the 2003, 2010 and 2012 reports, vehicle age is expressed by VEHAGE = CY - MY, with an additional variable BRANDNEW = 1 if VEHAGE = 0 (to allow an effect for new vehicles that differs from the trend). Calendar year is expressed by the dichotomous variables CY2005, CY2006, CY2007, CY2008, CY2010, and CY2011, all of which equal zero if CY = 2009.

Setup for a regression: As explained in Section 2.6, a regression is performed on a temporary data file that combines a subset of the records from the database of fatal crash involvements and a subset of the records from the database of induced-exposure crash involvements. For example, the analysis of 1st-event rollovers of passenger cars would combine the subset of fatal-involvement records that are passenger cars (vehicle class) and 1st-event rollovers (fatal-crash type) with the subset of induced-exposure records that are passenger cars (vehicle class).

The two databases already have many variables in common: curb weight, footprint, and the various controls such as driver age and gender that will be independent variables in the regression. One additional variable, the dependent variable FATAL, is defined on the temporary, combined data file: FATAL equals 1 for each of the records from the database of fatal-crash involvements and FATAL equals 2 for each of the records from the database of induced-exposure involvements. The other new variable is the case-weight factor for the regression, WEIGHTFA. Each record from the database of fatal-crash involvements is weighted by the number of fatalities in the crash, including occupants of other vehicles and non-occupants (WEIGHTFA equals the FARS variable FATALS).

Each record from the database of induced-exposure involvements is weighted by its allocation of the nation's VMT (WEIGHTFA equals the variable VMTWTFA on the induced-exposure database). The technique is logistic regression performed by the SAS procedure LOGISTIC. The regressions analyze rates of fatal-crash involvements (weighted by the number of fatalities in the crash); the computational models that will be presented in Section 3.6 translate the regression results into estimates of the effect of mass reduction on overall fatalities.

Exploratory analyses (variables that may be dropped): Exploratory regressions omitting some of the control variables showed that only a few variables may be dropped from any of the analyses without perceptibly affecting the results. The variables for the various types of side air bags may be dropped from the analyses of pedestrian crashes, because the air bags in the vehicle will not affect the fatality risk for the pedestrians. In rollover crashes, ROLLCURT is the only

[52] Kahane (2003), pp. 69-70.

air-bag variable; in the other non-pedestrian crash types, ROLLCURT is omitted but CURTAIN, TORSO, and COMBO are included. Consistent with the 2012 report, the air bag variables and ABS are omitted for all crash types; these variables were omitted in the 2012 truck-based LTV analyses because they are about equally available in lighter and heavier LTVs, unlike in cars (in which the heavier vehicles are more commonly equipped with side air bags and ABS). In subsequent analyses, NHTSA will explore the sensitivity of LTV model results to the inclusion of air bag variables and ABS. The blocker-beam variables, on the other hand appear only in the regressions for the truck-based LTVs.

In general, the variable for all-wheel/4-wheel drive (AWD) should not be dropped from the regression analyses, because the larger and heavier vehicles tend to be equipped somewhat more often with those technologies. However, only 5.2 percent of passenger cars were equipped with AWD in MY 2003-2010. The analyses of passenger cars are simplified by limiting them to cars without AWD and dropping the AWD control variable.

3.2 Three regression examples

There are 27 basic regressions in the central analysis in this report; the set of regressions three vehicle classes, with nine crash types for each vehicle class. Here, for example, is the regression for passenger cars' collisions with truck-based LTVs weighing 4,303 pounds or more. This regression associated large fatality increases with lower mass for passenger cars both above and below the median curb weight of 3,197 pounds. The central independent variables are the mass and footprint of passenger cars (case vehicles). The mass of the partner vehicle is not specified in the regression, only that it weighs 4,303 pounds or more. The temporary data file for the analysis consists of 1,097,593 records, including 2,555 from the fatal-crash database and 1,095,038 from the induced-exposure database. In the 3.43 trillion VMT allocated among the 1,095,038 induced-exposure crash involvements of MY 2005-2010 passenger-car case vehicles during CY 2005-2011 (see "Response Profile"), these cars experienced 2,555 fatal collisions with truck-based LTCs $\geq$ 4,303 pounds, resulting in 3,022 fatalities:

```
The LOGISTIC Procedure: Car collisions with Truck-Based LTCs ≥ 4,303 pounds

                Response Profile

Ordered                      Total            Total
  Value        FATAL     Frequency           Weight

      1            1          2555             3022
      2            2       1095038     3.4288765E12

        Model Fit Statistics

                              Intercept
              Intercept             and
Criterion          Only      Covariates

AIC           132060.85       127239.03
SC            132072.76       127608.19
-2 Log L      132058.85       127177.03
```

R-Square 0.0044 Max-rescaled R-Square 0.0391

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	4881.8295	30	<.0001
Score	6548.4005	30	<.0001
Wald	5373.5740	30	<.0001

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-21.8922	0.6920	1000.7098	<.0001
UNDRWT00	1	-0.0278	0.0132	4.4451	0.0350
OVERWT00	1	-0.0194	0.0149	1.6955	0.1929
FOOTPRNT	1	-0.0146	0.0149	0.9574	0.3279
TWODOOR	1	0.0861	0.0592	2.1188	0.1455
CURTAIN	1	-0.1123	0.0720	2.4315	0.1189
COMBO	1	-0.1225	0.0745	2.6987	0.1004
TORSO	1	-0.2115	0.0705	9.0056	0.0027
ABS	1	0.00839	0.0744	0.0127	0.9102
ESC	1	-0.3500	0.0743	22.1840	<.0001
DRVMALE	1	0.4348	0.1019	18.2258	<.0001
M14_30	1	0.0617	0.00845	53.3440	<.0001
M30_50	1	0.00603	0.00544	1.2290	0.2676
M50_70	1	0.0327	0.00587	30.9885	<.0001
M70_96	1	0.0872	0.00736	140.4203	<.0001
F14_30	1	0.0505	0.00956	27.9126	<.0001
F30_50	1	-0.00409	0.00589	0.4815	0.4877
F50_70	1	0.0556	0.00606	84.0112	<.0001
F70_96	1	0.0861	0.00851	102.3129	<.0001
NITE	1	0.7361	0.0411	320.5212	<.0001
RURAL	1	1.4812	0.0381	1511.4510	<.0001
SPDLIM55	1	1.2610	0.0372	1150.3585	<.0001
HIFAT_ST	1	0.4205	0.0374	126.4523	<.0001
VEHAGE	1	-0.00763	0.0137	0.3084	0.5787
BRANDNEW	1	-0.0671	0.0709	0.8947	0.3442
CY2005	1	-0.0371	0.0853	0.1898	0.6631
CY2006	1	-0.1121	0.0772	2.1090	0.1464
CY2007	1	-0.0394	0.0687	0.3296	0.5659
CY2008	1	-0.1501	0.0657	5.2264	0.0222
CY2010	1	0.00374	0.0612	0.0037	0.9512
CY2011	1	-0.0203	0.0647	0.0983	0.7539

Societal fatality risk was an estimated 2.78 percent higher for each 100-pound increment across the cars weighing less than 3,197 pounds (see the entry for UNDRWT00 in "Analysis of Maximum Likelihood Estimates"). The regression printouts generated by SAS indicate the effect of increasing mass by 100 pounds. However, this report, consistent with earlier NHTSA reports will show in all tables of results the effects of reducing mass by 100 pounds. In other words, the coefficients that will be shown in the tables will be the opposites of the coefficients in these regression examples.

The Wald chi-square for that coefficient would have been 4.45 if each fatality and each mile of VMT had been drawn from a simple random sample (SRS), but it was not; a higher sampling error that takes the study design into account is computed in Section 3.6. A Wald chi-square of 3.84 or more indicates statistical significance at the .05 level for SRS. If the SAS printout shows 3.84 or more, the effect may or may not be significant given the actual sample design, but if it shows less than 3.84 even for SRS, the effect will almost certainly not be significant after the sample design is taken into account. Risk increased by an estimated 1.94 percent as mass increased by 100 pounds across cars ≥ 3,197 pounds; with a chi-square of 1.70, this would not have been significant even under simple random sampling. Risk also increased by 1.46 percent as footprint increased by 1 square foot; this, too, is not statistically significant.

Two-door cars had a higher fatality rate than four-door cars, after controlling for the other variables. The three types of side air bags and ESC are associated with fatality reductions; however, only torso bags and ESC were estimated to have a statistically significant impact on fatality rates (at the 95-percent confidence level).

Fatality rates for males are not only higher than for females, but fatality rates also increase for each year that a male driver is younger or older than 50 (especially if younger than 30 or older than 70). Similarly, fatality rates are higher for each year a female driver is younger than 30 or older than 50 (especially if older than 70); consistent with male drivers, no significant effect of age was identified for female drivers between 30 and 50 years of age. Fatality rates per VMT are substantially higher at night, on rural roads, when the speed limit is 55 or above, and in high-fatality States.

The regression results also include overall “model fit statistics.” The “max-rescaled R-square,” which has approximately the same meaning as the R-square statistic for a linear regression, is a relatively low .0391. Basically, the R-square statistic indicates that it is difficult to predict from demographic and environmental variables such as driver age, urbanization, and time of day that one specific mile of travel will result in a fatal crash while another will not. On the other hand, “testing global null hypothesis” finds that the likelihood-ratio chi-square for the model is 4884.83 with 30 degrees of freedom, which is statistically significant at the .0001 level. In other words, the control variables, as a group, have strong relationships with fatality risk, even though they are insufficient to predict if a specific mile of travel will be fatal or not.

Similarly, in the other 26 regressions, max-rescaled R-square ranged from .0205 to .1111, while the likelihood-ratio chi-square was always significant at the .0001 level. Neither of these statistics sheds much light on how well the regressions are measuring the relationships between fatality risk and mass or footprint; rather, it is primarily the other control variables with much higher chi-square values, such as NITE, RURAL, and SPDLIM55 that are driving these statistics.

The following is an example of a regression where pickups and truck-based SUVs are the case vehicles, specifically their collisions with cars, CUVs or minivans weighing at least 3,157 pounds. This regression associated large fatality decreases with lower mass for truck-based LTVs both above and below the threshold curb weight of 4,947 pounds. The central independent variables are the mass and footprint of the truck-based LTVs. The mass of the car/CUV/minivan partner vehicle is not specified, only that it weighs at least 3,157 pounds:

The LOGISTIC Procedure: Pickups/truck-based SUV collisions with cars/CUVs/minivans ≥ 3,157 pounds

Response Profile

Ordered Value	FATAL	Total Frequency	Total Weight
1	1	3333	3971
2	2	584777	2.3883434E12

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	168490.32	164088.59
SC	168501.61	164438.41
-2 Log L	168488.32	164026.59

R-Square 0.0076 Max-rescaled R-Square 0.0303

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	4461.7331	30	<.0001
Score	5400.9320	30	<.0001
Wald	4644.9974	30	<.0001

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-21.4083	0.3534	3669.5846	<.0001
UNDRWT00	1	0.0123	0.00646	3.5973	0.0579
OVERWT00	1	0.0154	0.00612	6.3563	0.0117
FOOTPRNT	1	-0.00827	0.00515	2.5787	0.1083
SUV	1	0.0674	0.0675	0.9962	0.3182
HD_PKP	1	0.1477	0.0722	4.1865	0.0407
BLOCKER1	1	-0.1044	0.0392	7.0968	0.0077
BLOCKER2	1	-0.0832	0.0503	2.7299	0.0985
DRVMALE	1	0.0860	0.0864	0.9901	0.3197
M14_30	1	0.0335	0.00647	26.7160	<.0001
M30_50	1	0.0231	0.00347	44.4040	<.0001
M50_70	1	0.0277	0.00441	39.5235	<.0001
M70_96	1	0.0410	0.0121	11.5117	0.0007
F14_30	1	0.0358	0.0103	12.0681	0.0005
F30_50	1	0.0120	0.00572	4.3918	0.0361
F50_70	1	0.0313	0.00877	12.7205	0.0004
F70_96	1	0.0906	0.0243	13.9525	0.0002
ESC	1	-0.1427	0.0570	6.2766	0.0122
AWD	1	-0.1938	0.0404	22.9708	<.0001
NITE	1	0.8398	0.0354	563.6904	<.0001
RURAL	1	1.2048	0.0343	1234.4812	<.0001
SPDLIM55	1	1.3005	0.0322	1631.3767	<.0001

HIFAT_ST	1	0.2059	0.0348	34.9502	<.0001
VEHAGE	1	0.0414	0.0122	11.5783	0.0007
BRANDNEW	1	0.0334	0.0641	0.2708	0.6028
CY2005	1	0.0538	0.0752	0.5130	0.4738
CY2006	1	0.1133	0.0656	2.9817	0.0842
CY2007	1	0.1492	0.0591	6.3798	0.0115
CY2008	1	0.0208	0.0573	0.1323	0.7161
CY2010	1	-0.0849	0.0564	2.2638	0.1324
CY2011	1	-0.1084	0.0590	3.3781	0.0661

The 2.39 trillion VMT of MY 2003-2010 truck-based LTVs were allocated among the 584,777 induced-exposure records. These LTVs experienced 3,333 fatal collisions with cars, CUVs, and minivans ≥ 3,157 pounds, resulting in 3,971 fatalities. Societal fatality risk was a non-significant 1.23 percent higher for each 100-pound increment across the LTVs under 4,947 pounds. Fatality risk increased by 1.54 percent for each additional 100 pounds in the LTVs weighing 4,947 pounds or more; this would have been significant with simple random sampling (chi-square = 6.36). Footprint does not have a significant estimated effect.

As for the specific type of LTV, SUVs and heavy-duty pickips have higher fatality rates than light-duty pickups after controlling for vehicle mass and footprint, with around 7 percent higher risk and 15 percent higher risk for SUVs and heavy-duty pickups, respectively (the latter of which would be statistically significant if this were a simple random sample: $\chi^2 = 4.19$).

Option 1 and Option 2 blocker beams, ESC, and AWD/4x4 are associated with reduced fatality risk; the estimated coefficients are statistically significant at the 90-percent confidence level for Option 2 blocker beams, at the 98-percent level for ESC, and at the 99-percent level for Option 1 blocker beams and AWD/4x4. The effects of driver age and the environmental variables are similar to the preceding regression, with the key exception that increased age within the range of 30 to 50 years is also associated with a significant increase in risk for both males and females.. Older LTVs are estimated to have significantly higher fatality risks than newer LTVs. The calendar-year variables indicate that fatality risk declined consistently over time within the sample for this crash type.

The following is a regression where CUVs or minivans are the case vehicles and the partner vehicles are heavy trucks. This regression associated a large fatality increase with lower mass for CUVs and minivans. The central independent variables are the mass (as a single, linear variable LBS100 rather than the separate variables UNDRWT00 and OVERWT00 in the preceding regressions) and footprint of the CUVs or minivans. The mass of the partner trucks is not specified, but they range from pickup trucks and vans just over 10,000 pounds GVWR to the heaviest combination vehicles:

The LOGISTIC Procedure: CUV/minivan collisions with heavy trucks

Response Profile

Ordered Value	FATAL	Total Frequency	Total Weight
1	1	673	807
2	2	440882	1.4496946E12

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	36008.810	34074.412
SC	36019.808	34415.352
-2 Log L	36006.810	34012.412

R-Square 0.0045 Max-rescaled R-Square 0.0575

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	1994.3983	30	<.0001
Score	2921.3888	30	<.0001
Wald	2006.9041	30	<.0001

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-22.4446	0.6477	1200.8928	<.0001
LBS100	1	-0.0111	0.0178	0.3892	0.5327
FOOTPRNT	1	-0.0119	0.0229	0.2709	0.6027
MINIVAN	1	0.0823	0.1305	0.3975	0.5284
CURTAIN	1	0.1618	0.1432	1.2763	0.2586
COMBO	1	-0.0174	0.1282	0.0185	0.8919
TORSO	1	-0.3835	0.1233	9.6815	0.0019
ABS	1	-0.4801	0.1603	8.9686	0.0027
ESC	1	-0.1002	0.1394	0.5168	0.4722
AWD	1	-0.1140	0.1040	1.2015	0.2730
DRVMALE	1	0.5959	0.1755	11.5271	0.0007
M14_30	1	0.0362	0.0185	3.8251	0.0505
M30_50	1	0.0231	0.00980	5.5408	0.0186
M50_70	1	0.0271	0.00978	7.6661	0.0056
M70_96	1	0.1074	0.0137	61.3152	<.0001
F14_30	1	0.0453	0.0220	4.2291	0.0397
F30_50	1	0.00160	0.0108	0.0217	0.8829
F50_70	1	0.0619	0.0110	31.3517	<.0001
F70_96	1	0.0965	0.0195	24.4497	<.0001
NITE	1	0.5235	0.0876	35.7057	<.0001
RURAL	1	1.9817	0.0796	619.6208	<.0001
SPDLIM55	1	1.4918	0.0714	436.6367	<.0001
HIFAT_ST	1	0.4988	0.0736	45.8948	<.0001

VEHAGE	1	0.0669	0.0289	5.3584	0.0206
BRANDNEW	1	0.3148	0.1250	6.3367	0.0118
CY2005	1	0.1893	0.1747	1.1742	0.2785
CY2006	1	0.3074	0.1491	4.2475	0.0393
CY2007	1	0.1374	0.1379	0.9929	0.3190
CY2008	1	0.1287	0.1265	1.0359	0.3088
CY2010	1	0.0579	0.1216	0.2267	0.6340
CY2011	1	-0.1590	0.1335	1.4181	0.2337

The 1.45 trillion VMT of the CUVs and minivans were allocated among 440,882 induced-exposure records. They experienced 673 fatal collisions with truck-based LTVs weighing less than 4,303 pounds, resulting in 807 fatalities. The VMT and the counts of fatal and induced-exposure crashes are much smaller than in the two preceding regressions. Fatality risk decreased by 1.11 percent for each additional 100 pounds, and by 1.19 percent for each additional square foot of footprint in the CUVs and minivans; neither effect reaches statistical significance with the available data. In this type of crash, minivans have a statistically insignificantly higher risk than CUVs after controlling for the other variables.

ABS and torso bags are estimated to reduce fatality rates (both coefficients are statistically significant at the 99-percent confidence level); other air bags, ESC and AWD have no significant estimated effects on fatality rates. The range of estimated age-related impacts on fatality rates in CUVs and minivans is consistent with the corresponding estimates for passenger cars. The model estimates statistically significant higher risks for each year of age males and females are below 30 or above 50, with the strongest estimated effects for males and females older than 70.

Fatality risks are significantly higher in rural areas, at night, on roads with speed limit 55 or higher, and in high-fatality states, consistent with the preceding regressions. Older CUVs and minivans are estimated to have significantly higher fatality risks than newer CUVs and minivans.

3.3 Mass and footprint coefficients for the 27 basic regressions

Table 3-1 presents the effects of reducing mass (while holding footprint constant) or reducing footprint (while holding mass constant) in 27 basic regressions: three vehicle classes, with nine crash types for each vehicle class. The regressions estimate the average change in societal fatality risk for vehicles weighing *n*-100 pounds relative to vehicles weighing *n* pounds, keeping footprint and other factors constant and the change in risk for vehicles with footprint *m*-1 square feet relative to vehicles with footprint *m* square feet, keeping mass and other factors constant. Because the regressions for cars and truck-based LTVs each generate two coefficients for mass, one below and one above the median, the 27 regressions generate a total of 45 mass coefficients (but the footprint coefficient is the same for the lighter and heavier vehicles of the same class).

The reported coefficients for mass and footprint are opposites of the coefficients generated by the SAS regressions, converted to percentage values. That is, a negative number indicates that mass reduction is beneficial (or higher mass is associated with increased risk) and a positive number says mass reduction is harmful (or higher mass is associated with decreased risk). The Wald chi-square, as explained above, assumes the data are SRS and is a screening tool rather than an actual significance test: if it is less than 3.84, the coefficient is almost certainly not significant, after taking the actual sample design into account. If it exceeds 3.84, further analysis is needed to see if the coefficient is significant after accounting for the sampling design.

TABLE 3-1: EFFECTS OF MASS OR FOOTPRINT REDUCTION BY CASE-VEHICLE CLASS AND CRASH TYPE

	100-POUND MASS REDUCTION		1 SQ FT FOOTPRINT REDUCTION	
CRASH TYPE	FATALITY INCREASE (%)	WALD CHI-SQUARE	FATALITY INCREASE (%)	WALD CHI-SQUARE
	CARS < 3,197 POUNDS			
1st-EVENT ROLLOVER	- 2.96	4.04	7.75	22.11
HIT FIXED OBJECT	- .14	.03	1.03	1.40
HIT PEDESTRIAN/BIKE/MOTORCYCLE	2.26	6.24	- 1.19	1.49
HIT HEAVY VEHICLE	2.57	3.54	.98	.40
HIT CAR/CUV/MINIVAN < 3157	- 1.39	1.41	- .15	.01
HIT CAR/CUV/MINIVAN 3157+	2.44	4.99	- 1.50	1.52
HIT TRUCK-BASED LTV < 4303	1.01	.52	2.57	2.61
HIT TRUCK-BASED LTV 4303+	2.78	4.45	1.46	.96
ALL OTHERS	2.62	13.48	- .12	.02
	CARS ≥ 3,197 POUNDS			
1st-EVENT ROLLOVER	- 5.42	9.42	7.75	22.11
HIT FIXED OBJECT	- .70	.61	1.03	1.40
HIT PEDESTRIAN/BIKE/MOTORCYCLE	.96	.95	- 1.19	1.49
HIT HEAVY VEHICLE	2.94	3.63	.98	.40
HIT CAR/CUV/MINIVAN < 3157	.12	.01	- 1.54	.01
HIT CAR/CUV/MINIVAN 3157+	1.91	2.48	- 1.50	1.52
HIT TRUCK-BASED LTV < 4303	- 1.07	.46	2.57	2.61
HIT TRUCK-BASED LTV 4303+	1.94	1.70	1.46	.96
ALL OTHERS	.42	.28	- .12	.02
	PICKUPS & TRUCK-BASED SUVs < 4,947 POUNDS			
1st-EVENT ROLLOVER	- .42	.40	.89	2.67
HIT FIXED OBJECT	- 1.83	11.03	2.20	23.40
HIT PEDESTRIAN/BIKE/MOTORCYCLE	- .27	.23	.03	<.01
HIT HEAVY VEHICLE	3.85	18.82	- 1.13	2.31
HIT CAR/CUV/MINIVAN < 3157	.03	<.01	- .26	.28
HIT CAR/CUV/MINIVAN 3157+	- 1.23	3.60	.83	2.58
HIT TRUCK-BASED LTV < 4303	- 1.08	1.63	1.98	8.52
HIT TRUCK-BASED LTV 4303+	1.38	2.24	.96	1.58
ALL OTHERS	.16	.13	- .20	.31

CRASH TYPE	100-POUND MASS REDUCTION FATALITY INCREASE (%)	100-POUND MASS REDUCTION WALD CHI-SQUARE	1 SQ FT FOOTPRINT REDUCTION FATALITY INCREASE (%)	1 SQ FT FOOTPRINT REDUCTION WALD CHI-SQUARE
	PICKUPS & TRUCK-BASED SUVs ≥ 4,947 POUNDS			
1st-EVENT ROLLOVER	1.16	2.99	.89	2.67
HIT FIXED OBJECT	1.78	8.94	2.20	23.40
HIT PEDESTRIAN/BIKE/MOTORCYCLE	- .52	.88	.03	<.01
HIT HEAVY VEHICLE	1.54	2.38	- 1.13	2.31
HIT CAR/CUV/MINIVAN < 3157	- 2.19	15.23	- .26	.28
HIT CAR/CUV/MINIVAN 3157+	- 1.54	6.36	.83	2.58
HIT TRUCK-BASED LTV < 4303	- 2.45	9.13	1.98	8.52
HIT TRUCK-BASED LTV 4303+	- 1.30	1.88	.96	1.58
ALL OTHERS	- .59	1.83	- .20	.31
	CUVs & MINIVANS			
1st-EVENT ROLLOVER	- 6.97	12.73	11.29	18.85
HIT FIXED OBJECT	- 3.12	6.42	6.55	15.71
HIT PEDESTRIAN/BIKE/MOTORCYCLE	- 2.49	7.32	.93	.58
HIT HEAVY VEHICLE	1.11	.39	1.19	.27
HIT CAR/CUV/MINIVAN < 3157	- .27	.05	- .81	.24
HIT CAR/CUV/MINIVAN 3157+	.39	.09	- 1.42	.66
HIT TRUCK-BASED LTV < 4303	1.88	1.04	- 2.96	1.53
HIT TRUCK-BASED LTV 4150+	.89	.24	1.04	.19
ALL OTHERS	- 1.20	2.36	1.82	3.02

The principal findings in Table 3-1 are:

- In run-off-road crashes – first-event rollovers and impacts with fixed objects – mass reduction is usually beneficial (as evidenced by negative effects) and footprint reduction is always harmful (as evidenced by positive effects). Conversely, increased mass would tend to be harmful and added footprint protective in these crashes.
    - The mass effects for passenger cars in first-event rollovers (i.e., beneficial mass reduction) are potentially statistically significant after accounting for the sample design, as evidenced by chi-square > 3.84. Conversely, the mass effects for passenger cars in fixed-object collisions are not statistically significant.
    - Counter to (1) above, the mass effects for truck-based LTVs in first-event rollovers are not statistically significant (chi-square < 3.84). Likewise, the mass effects for truck-based LTVs in fixed-object collisions are potentially statistically significant; importantly, the estimated effects are distinct between the two vehicle classes (i.e., mass reduction is estimated to reduce risk in lighter truck-based LTVs but increase risk in heavier truck-based LTVs).
    - While mass reduction is estimated to be societally beneficial in these crashes for four out of five vehicle classes, in CUVs and minivans the estimated effects of mass reduction are strongly beneficial and of footprint reduction, exceedingly harmful: these may be possible symptoms of inaccurate estimates due to the near

multicollinearity of mass and footprint. An alternative regression in which only curb weight is included confirms the potential presence of multicollinearity effects; when footprint is excluded, mass reduction is associated with an increase in risk in one-vehicle crashes for all vehicle types (see the section below on downsizing).

- In the other seven types of crashes, most of which take place on the road, mass reduction in the lighter vehicles (i.e., passenger cars) usually creates societal harm; in the heavier vehicles (i.e., truck-based LTVs), mass reduction creates societal benefits; and in the vehicles of medium weight (i.e., CUVs, minivans), mass reduction has no consistent effect. Footprint reduction is estimated to have a variable and statistically insignificant effect across vehicle classes, with the exception of a potentially statistically significant harmful effect in truck-based LTV collisions with other truck-based LTVs weighing less than 4,303 pounds.

    - In the lighter cars (< 3,197 pounds), six of seven mass effects are positive, and three of them have chi-square > 3.84.

    - In the heavier pickup trucks and SUVs (4,947 pounds and up), both mass effects for collisions with cars, CUVs, and minivans, and the mass effect for collisions with lighter truck-based LTVs are negative with chi-square > 3.84.

    - In the lighter pickups and SUVs and the CUVs and minivans, six mass effects are negative and eight are positive. Two of these estimated effects are statistically significant: increased risk in collisions between lighter LTV and heavy trucks, and decreased risk in collisions between CUVs and minivans and pedestrians, bicyclists and motorcyclists.

    - In pickups, SUVs, CUVs, and minivans, eight footprint effects are negative and six are positive. One estimate is statistically significant: increased risk in collisions among lighter LTVs when reducing footprint.

- In collisions with pedestrians, bicyclists, and motorcyclists, the fatality rate increases as mass decreases in the lighter cars ($\chi^2 > 3.84$).

- The strongest harmful effect for mass reduction, 3.85 percent fatality increase per 100 pounds, are found in truck-based LTVs < 4,303 pounds when they collide with heavy vehicles ($\chi^2 > 3.84$).

- The strongest beneficial effects for mass reduction, 6.97 percent and 5.42 percent fatality reduction per 100 pounds, are found in first-event rollovers involving CUVs and minivans and cars ≥ 3,197 pounds, respectively ($\chi^2 > 3.84$ in both cases). However, these large coefficient estimates indicate the potential presence of multicollinearity effects due to narrow ranges of curb weight and footprint for CUVs and minivans relative to other vehicle classes.

- Footprint has a weaker estimated protective impact, in general, compared to the estimates in the 2012 report. Potentially statistically significant footprint effects were identified for: rollovers in cars, CUVs and minivans; and fixed-object collisions in truck-based LTVs, CUVs and minivans.

Discussion: In general terms, these results are consistent with the hypotheses discussed in Section 1.5 and also consistent with the regressions of NHTSA's 2012 report, which are summarized in Table 3-2 for passenger cars (excluding two-door muscle cars and four-door police cars, and all-wheel drive cars) and LTVs. Two-door muscle cars, four-door police cars, all-wheel drive cars, and full-sized vans were excluded from the analysis for consistency with the 2012 and 2010 reports, which conducted sensitivity analysis to highlight how the inclusion of "niche" vehicles may distort how the regressions allocate effects between mass and footprint.[53]

Footprint reduction is harmful and mass reduction generally beneficial in rollovers and fixed-object collisions, consistent with handling and stability considerations. In the other types of crashes, mass reduction is generally harmful in the lighter cars and beneficial in the heavier LTVs, consistent with momentum considerations.

TABLE 3-2: 2012 REPORT[54] (MY 2000-2007 VEHICLES IN CY 2002-2008) - EFFECTS OF MASS OR FOOTPRINT REDUCTION BY CASE-VEHICLE CLASS AND CRASH TYPE

	100-POUND MASS REDUCTION		1 SQ FT FOOTPRINT REDUCTION	
CRASH TYPE	FATALITY INCREASE (%)	WALD CHI-SQUARE	FATALITY INCREASE (%)	WALD CHI-SQUARE
		CARS < 3,106 POUNDS		
1st-EVENT ROLLOVER	- 1.83	2.21	8.08	31.56
HIT FIXED OBJECT	- .46	.46	4.01	26.07
HIT PEDESTRIAN/BIKE/MOTORCYCLE	2.03	5.75	.91	.92
HIT HEAVY VEHICLE	2.26	3.77	2.97	4.86
HIT CAR/CUV/MINIVAN < 3082	.76	.57	.23	.04
HIT CAR/CUV/MINIVAN 3082+	.48	.25	.49	.20
HIT TRUCK-BASED LTV < 4150	1.17	.98	3.96	8.30
HIT TRUCK-BASED LTV 4150+	6.06	29.80	1.77	1.89
ALL OTHERS	1.95	9.96	1.14	2.64

53 Kahane (2012), p. 68-70.
54 Kahane (2012), Table 3-1 on pp. 51-52.

CRASH TYPE	100-POUND MASS REDUCTION FATALITY INCREASE (%)	100-POUND MASS REDUCTION WALD CHI-SQUARE	1 SQ FT FOOTPRINT REDUCTION FATALITY INCREASE (%)	1 SQ FT FOOTPRINT REDUCTION WALD CHI-SQUARE
CARS ≥ 3,106 POUNDS				
1st-EVENT ROLLOVER	- 2.89	3.09	8.08	31.56
HIT FIXED OBJECT	- 1.29	2.34	4.01	26.07
HIT PEDESTRIAN/BIKE/MOTORCYCLE	- .14	.02	.91	.92
HIT HEAVY VEHICLE	.39	.08	2.97	4.86
HIT CAR/CUV/MINIVAN < 3082	.26	.05	.23	.04
HIT CAR/CUV/MINIVAN 3082+	1.62	2.09	.49	.20
HIT TRUCK-BASED LTV < 4150	.53	.14	3.96	8.30
HIT TRUCK-BASED LTV 4150+	2.34	3.11	1.77	1.89
ALL OTHERS	1.16	2.51	1.14	2.64
PICKUPS & TRUCK-BASED SUVs < 4,594 POUNDS				
1st-EVENT ROLLOVER	.66	1.40	1.19	7.65
HIT FIXED OBJECT	- 1.39	7.03	1.99	26.73
HIT PEDESTRIAN/BIKE/MOTORCYCLE	1.07	3.41	- 1.24	8.60
HIT HEAVY VEHICLE	1.62	3.60	.75	1.41
HIT CAR/CUV/MINIVAN < 3082	- .09	.02	- .21	.24
HIT CAR/CUV/MINIVAN 3082+	- .71	1.30	.31	.46
HIT TRUCK-BASED LTV < 4150	- .63	.56	1.01	2.81
HIT TRUCK-BASED LTV 4150+	4.46	26.58	- 1.69	6.88
ALL OTHERS	.73	2.86	- .44	1.93
PICKUPS & TRUCK-BASED SUVs ≥ 4,594 POUNDS				
1st-EVENT ROLLOVER	- 1.28	7.51	1.19	7.65
HIT FIXED OBJECT	.76	2.74	1.99	26.73
HIT PEDESTRIAN/BIKE/MOTORCYCLE	- .05	.01	- 1.24	8.60
HIT HEAVY VEHICLE	.32	.17	.75	1.41
HIT CAR/CUV/MINIVAN < 3082	- .91	3.99	- .21	.24
HIT CAR/CUV/MINIVAN 3082+	- 1.37	8.05	.31	.46
HIT TRUCK-BASED LTV < 4150	- .96	1.99	1.01	2.81
HIT TRUCK-BASED LTV 4150+	.53	.53	- 1.69	6.88
ALL OTHERS	- .11	.10	- .44	1.93

CRASH TYPE	100-POUND MASS REDUCTION FATALITY INCREASE (%)	100-POUND MASS REDUCTION WALD CHI-SQUARE	1 SQ FT FOOTPRINT REDUCTION FATALITY INCREASE (%)	1 SQ FT FOOTPRINT REDUCTION WALD CHI-SQUARE
		CUVs & MINIVANS		
1st-EVENT ROLLOVER	- 7.02	15.31	11.59	22.66
HIT FIXED OBJECT	- 3.61	7.47	7.67	18.19
HIT PEDESTRIAN/BIKE/MOTORCYCLE	- 1.57	2.19	.37	.07
HIT HEAVY VEHICLE	1.94	1.10	4.66	3.76
HIT CAR/CUV/MINIVAN < 3082	- .09	.01	- .79	.19
HIT CAR/CUV/MINIVAN 3082+	1.68	1.54	- 2.19	1.47
HIT TRUCK-BASED LTV < 4150	3.82	3.94	- 4.05	2.48
HIT TRUCK-BASED LTV 4150+	- .93	.29	3.80	2.64
ALL OTHERS	- .40	.23	2.72	5.98

The general results are similar across the 2012 and 2016 reports, but there are some important differences. Seven previously-insignificant estimated mass effects are potentially statistically significant in this report (case vehicles listed first within incident types): collisions between the lighter cars and the lighter cars, CUVs and minivans; first-event rollovers for the lighter cars; collisions between both the heavier cars and the lighter truck-based LTVs and heavy vehicles; fixed-object collisions for the heavier truck-based LTVs; collisions between the heavier LTVs and the lighter truck-based LTVs; and collisions between CUVs and minivans and pedestrians, bicycles and motorcycles.

Only two previously-significant estimated mass effects are statistically insignificant in this report. Collisions between the lighter truck-based LTVs and heavier truck-based LTVs are now statistically insignificant, but are still estimated to involve societally harmful mass reduction. Collisions between CUVs and minivans and the lighter truck-based LTVs are now statistically insignificant, but the estimated impact (societally harmful mass reduction) is larger than in the 2012 report.

Three previously-insignificant estimated footprint effects are statistically insignificant in this report, all of which correspond to cars. The estimated effects of footprint reduction in cars are now insignificant for collisions with: fixed objects, heavy vehicles, and lighter truck-based LTVs. Each of these three footprint effects were estimated to have strong significant impacts (societally harmful footprint reduction) in the 2012 report; the estimated effects are smaller in all three cases in this report, although the estimated effect for footprint reduction in cars in collisions with lighter truck-based LTVs is still large and of the same sign as in the 2012 report.

3.4 The effect of mass within deciles of footprint

In previous reports, the relatively high correlation and VIF of mass and footprint raised questions about near multicollinearity. In the updated analysis, a few of the regressions in Table 3-1 displayed possible symptoms of multicollinearity, namely a strong positive coefficient for mass and a strong negative coefficient for footprint – or vice versa. Specifically, the CUV/minivan regressions for rollovers and fixed-object crashes displayed strong positive coefficients for mass (6.97, 3.12) and strong negative coefficients for footprint (-11.29, -6.55).[55] Directionally similar, but with weaker estimated effects for mass, are the car regression for rollovers (mass coefficients 2.96 and 5.42, footprint coefficient -7.75).

Another way to avoid having mass and footprint in the same regressions is to split up the database into deciles of footprint, as implemented in the 2011 and 2012 reports and continued in this report. The logistic regressions within each decile of footprint use the same variables as in the preceding section, except footprint. Also, in the analyses of cars and truck-based LTVs, the two-piece linear curb-weight variables are replaced by the simple, linear variable LBS100, as in the basic analyses of CUVs and minivans. The objective, for each vehicle class and type of crash, is to find out in how many deciles the regression estimates a negative coefficient for LBS100 (suggesting mass reduction is harmful), and how many positive (suggesting mass reduction is beneficial); the probability of the coefficient being exactly zero is infinitesimal.

The analysis just counts the numbers of negative and positive coefficients and does not take into account whether the coefficients are statistically significant. NHTSA considers the decile analysis a relatively blunt, essentially non-parametric tool (i.e., simply counting how many negative coefficients) for just confirming the directional accuracy of the basic regressions. Although a more extensive analysis is theoretically feasible (e.g., using the mass coefficients for each decile to compute an overall effect), it is not clear what advantage it would have over the basic regressions. Furthermore, because footprint still varies to some extent within each decile, it would not be an analysis that fully controls for footprint, either.

Table 3-3 enumerates the ten deciles of footprint and specifies the range of footprint and curb weight in each decile: for passenger cars (excluding muscle cars, police cars, and cars with AWD), for pickup trucks and truck-based SUVs, and for CUVs and minivans. Within the middle deciles, footprints for cars and CUVs and minivans are generally in a range of about one square foot, while curb weights generally vary by around 1,000 pounds; footprints for pickup trucks and truck-based SUVs are in a wider range of about two to five square feet while curb weights vary by over 2,000 pounds.

[55] Table 3-1 shows the opposite sign for each regression coefficient, because it estimates the effect of reducing mass or footprint.

TABLE 3-3: TEN DECILES OF FOOTPRINT FOR MY 2003-2010 VEHICLE GROUPS

Footprint Deciles	Range of Footprint (Square Feet)	Range of Curb Weight (Pounds)
	PASSENGER CARS	
1st	26.8 to 41.2	1785 to 3312
2nd	41.3 to 42.0	2436 to 3424
3rd	42.0 to 42.4	2577 to 3303
4th	42.6 to 44.0	2712 to 4057
5th	44.0 to 45.0	2809 to 3914
6th	45.0 to 45.8	3046 to 3851
7th	45.8 to 46.8	2968 to 4024
8th	46.8 to 47.2	2627 to 4801
9th	47.3 to 47.9	3282 to 4080
10th	48.0 to 56.4	3342 to 4885
	PICKUP TRUCKS AND TRUCK-BASED SUVs	
1st	34.6 to 43.8	2690 to 4704
2nd	44.4 to 47.1	2960 to 5672
3rd	47.3 to 48.4	3140 to 5770
4th	48.4 to 49.9	3087 to 5995
5th	50.3 to 53.3	3164 to 5833
6th	54.1 to 56.1	3522 to 6070
7th	56.1 to 59.1	3736 to 6642
8th	59.2 to 64.4	3865 to 6765
9th	64.5 to 65.5	4291 to 7346
10th	66.3 to 80.9	4580 to 7710
	CUVs AND MINIVANS	
1st	40.2 to 43.1	2777 to 3699
2nd	43.4 to 43.7	3086 to 3831
3rd	43.7 to 44.6	3310 to 4365
4th	44.6 to 46.1	3205 to 4325
5th	47.0 to 49.0	3373 to 4788
6th	49.0 to 50.1	3748 to 4687
7th	50.2 to 52.0	3838 to 6493
8th	52.0 to 52.6	3765 to 4651
9th	52.6 to 54.7	4017 to 5377
10th	54.7 to 58.0	4071 to 5076

Table 3-4 shows in how many of the ten deciles the regression coefficient for curb weight (LBS100) is negative (i.e., the regression coefficient implies that mass reduction is harmful). In the remainder of the ten deciles, the coefficient is positive and implies that mass reduction is beneficial. Table 3-4 just counts how many of the 10 individual coefficients are negative; they are not necessarily statistically significant. Any inconsistencies between Table 3-4 and the basic regression results (which include the footprint variable) in Table 3-1 could indicate that the basic regression inaccurately allocates the relative contributions of mass and footprint due to their near multicollinearity. Examples of candidate inconsistencies between Tables 3-4 and Table 3-1 include:

- Mass reduction is strongly beneficial in the basic regression – as evidenced by a substantial negative "fatality increase (%)" per 100-pound mass reduction in Table 3-1, with an accompanying Wald chi-square well above 3.84[56] – but harmful in most of the deciles – as evidenced by, say, a 7 or more in Table 3-4
- Mass reduction is strongly harmful in the basic regression – as evidenced by a substantial positive "fatality increase (%)" per 100-pound mass reduction in Table 3-1, with an accompanying Wald chi-square well above 3.84 – but beneficial in most of the deciles – as evidenced by a 3 or less in Table 3-4
- A near-zero or non-significant effect in the basic regressions[57] but the decile analyses lean strongly either way, as evidenced by a 0, 1, 9, or 10 in Table 3-4.

TABLE 3-4: NUMBER OF FOOTPRINT DECILES IN WHICH MASS REDUCTION IS HARMFUL, BY CASE VEHICLE CLASS AND CRASH TYPE
(Number of deciles where mass coefficient is negative, not necessarily statistically significant)

Crash Type	Passenger Cars	Pickups & Truck-Based SUVs	CUVs & Minivans
First-event rollovers	3	7	4
Hit fixed object	5	5	5
Hit pedestrians/bikes/motorcycles	5	5	4
Hit heavy truck or bus	6	8	6
Hit car, CUV or minivan < 3,157 lbs.	3	4	7
Hit car, CUV or minivan ≥ 3,157 lbs.	6	3	7
Hit truck-based LTV < 4,303 lbs.	2	3	4
Hit truck-based LTV ≥ 4,303 lbs.	6	5	6
All other crash involvements	6	6	4

The basic regressions and decile analyses are generally consistent for passenger cars, except perhaps in collisions with lighter truck-based LTVs; in the basic regressions, mass reduction in

[56] For passenger cars and truck-based LTVs, where there are actually two mass coefficients in Table 3-1 – e.g., one for cars < 3,197 and one for cars ≥ 3,197 – these two coefficients should be in the same direction and at least one of them have Wald chi-square well above 3.84.
[57] Or effects in opposite directions for the lighter and heavier vehicles of the same type.

lighter passenger cars is estimated to be societally harmful, while only two deciles are associated with harmful mass reduction for cars in collisions with lighter LTVs. The basic regressions indicated that mass reduction was generally beneficial in first-event rollovers. Consistent with the basic regressions, mass reduction is harmful (has a negative coefficient) in only three of the 10 deciles. Thus, for first-event rollovers, the decile analysis support a conclusion that mass reduction in cars is beneficial.

The basic regressions indicate that mass reduction in cars is beneficial (but not statistically significant) in collisions with fixed objects. The decile analysis similarly offers no strong signal, with mass reduction harmful in five deciles. Mass reduction in cars is reported as generally harmful in collisions with pedestrian/bicycle/motorcycle, heavy truck, car/CUV/minivan ≥ 3,157 pounds, truck-based LTVs ≥ 4,303 pounds, and all other crashes in Table 3-1. In the decile analysis, mass reduction in cars has a muted harmful effect in 5, 6, 6, 6, and 6 of the 10 respective deciles.

For first-event rollovers in pickup trucks and truck-based SUVs, the basic regressions indicated that mass reduction was beneficial for the lighter LTVs and harmful for the heavier LTVs. Consistent with the basic regressions, mass reduction is harmful (has a negative coefficient) in seven of the 10 deciles, including all of the five highest deciles. The basic regressions indicate a strong benefit of mass reduction for collisions of lighter truck-based LTVs with fixed objects, with a weaker opposite effect for heavier LTVs. Similar to the decile analysis of passenger cars, the decile analysis of truck-based LTVs indicates a muted effect, with a harmful effect estimated in five deciles.

The basic regressions indicated that mass reduction was generally societally beneficial in collisions of truck-based LTVs with cars. The decile analysis likewise similarly indicates that mass reduction is harmful in fewer than half of the deciles in each type of collision with cars. The basic regression showed a strong benefit for mass reduction in the heavier truck-based LTVs in collisions with lighter LTVs; this is echoed by estimated harm in only three deciles. In collisions with heavy trucks, the basic regressions indicate that mass reduction in the LTVs has a harmful effect; this result is consistent with the decile analysis, which indicates a harmful effect in eight deciles.

The analyses for CUVs and minivans indicated harmful effects (negative coefficients) for mass reduction in four deciles for rollovers and in five deciles for collisions with fixed objects. Those results do not support the strong benefits found for mass reduction in the basic regressions, but they do not unequivocally contradict them, either. The basic regressions indicated a significant beneficial effect of mass reduction in CUVs and minivans for collisions with pedestrians, bicycles and motorcycles; this effect was only weakly confirmed in the decile analysis, with a harmful effect estimated in four deciles. The two basic regressions of CUVs and minivans in collisions with cars, CUVs and minivans both indicated weak effects of mass reduction. This is one component of the analysis where the decile analysis offers evidence of different results, with, in each case, harmful effects estimated in seven deciles.

Table 3-4 includes 270 individual regression coefficients for deciles, 90 each for cars, truck-based LTVs, and CUVs/minivans. Because coefficients are not statistically independent across crash types (as different crash types use the same induced-exposure data), the tallies of positive and negative coefficients cannot be statistically tested as if they were 270 independent observations. Overall, 42 of the 90 coefficients for cars, 46 of the 90 coefficients for truck-based LTVs, and 47 of the 90 coefficients for CUVs/minivans are in the direction of mass reduction being harmful. In other words, the deciles split close to 50-50 for all three groups of vehicles. The only cases where the decile analysis consistently shows mass reduction being beneficial in two-vehicle collisions is for collisions involving two truck-based LTVs. The decile analysis does not indicate a clear benefit for mass reduction across all first-event rollovers and fixed-object collisions, but the analysis does not rule it out, either.

In the big picture, the decile analyses do not raise any serious doubts about the results of the basic regressions; only one of the 27 analyses shows a strong inconsistency between the basic regression coefficients and the decile coefficients (passenger cars in collisions with lighter LTVs), based on the three criteria listed before Table 3-4. The decile analyses suggest that the basic regressions, on average, get the relative effects of mass and footprint about right; mass reduction is estimated to be societally beneficial for some ranges of vehicle mass and societally harmful for other ranges, and these relationships vary by crash type and vehicle type. There does not appear to be a systematic bias against mass and in favor of footprint, or vice-versa. However, the amount of agreement between the basic regressions and the decile analysis is only partial; relatively small sample sizes within each decile may drive some disagreement between the two analyses.

3.5 Overall effect of mass reduction by vehicle class and its confidence bounds

The John A. Volpe National Transportation Systems Center of the United States Department of Transportation has a computer model, the CAFE Compliance and Effects Modeling System (usually referred to as the "Volpe model"), that works out the impacts of CAFE standards, including safety effects, over the lifetimes of future vehicles. The Volpe model requires five basic numbers in order to predict the safety effects, if any, of foreseeable mass reductions in MY 2022+ vehicles. The five numbers are the overall percentage increases or decreases, per 100-pound mass reduction while holding footprint constant, in crash fatalities (including the occupants of other vehicles and non-occupants) involving case vehicles that are:

- Passenger cars weighing less than 3,197 pounds
- Passenger cars weighing 3,197 pounds or more
- Truck-based LTVs weighing less than 4,947 pounds
- Truck-based LTVs weighing 4,947 pounds or more
- CUVs and minivans

Table 3-5 computes these five percentages: point estimates and also upper and lower 95% sampling-error confidence bounds, which will serve as ranges for the estimates. These confidence bounds take the sample design into account and are not based on the Wald chi-square statistics in Table 3-1 (which assume SRS). For example, in passenger cars < 3,197 pounds, the point estimate is that crash fatalities would increase by 1.49 percent per 100-pound mass reduction, with 95-percent confidence bounds ranging from a 0.30 percent decrease to a 3.27 percent increase. Conversely, in truck-based LTVs ≥ 4,947 pounds, societal fatalities would decrease by 0.72 percent per 100-pound mass reduction, with 95-percent confidence bounds ranging from a 1.45 percent decrease to a 0.02 percent increase.

TABLE 3-5: ESTIMATED EFFECTS OF 100-POUND MASS REDUCTION WHILE HOLDING FOOTPRINT CONSTANT BY VEHICLE CLASS AND CRASH TYPE

		FATALITY INCREASE PER 100-POUND MASS REDUCTION			
	FATALITIES AFTER	POINT ESTIMATE		95% CONFIDENCE BOUNDS (%)	
CRASH TYPE	ESC	N	%	LOWER	UPPER
		CARS < 3,197 POUNDS			
1st-EVENT ROLLOVER	133	-4	-2.96	-6.70	.79
HIT FIXED OBJECT	791	-1	- .14	-2.47	2.19
HIT PEDESTRIAN/BIKE/MOTORCYCLE	759	17	2.26	.04	4.48
HIT HEAVY VEHICLE	332	9	2.57	-3.10	8.25
HIT CAR-CUV-MINIVAN < 3157	432	-6	-1.39	-4.86	2.08
HIT CAR-CUV-MINIVAN 3157+	510	12	2.44	- .73	5.61
HIT TRUCK-BASED LTV < 4303	298	3	1.01	-2.58	4.61
HIT TRUCK-BASED LTV 4303+	393	11	2.78	-2.23	7.80
ALL OTHERS	1,168	31	2.62	.31	4.93
OVERALL	**4,815**	**72**	**1.49**	**- .30**	**3.27**
		CARS ≥ 3,197 POUNDS			
1st-EVENT ROLLOVER	152	-8	-5.42	-5.42	-1.69
HIT FIXED OBJECT	982	-7	- .70	-3.01	1.61
HIT PEDESTRIAN/BIKE/MOTORCYCLE	1,058	10	.96	-1.62	3.55
HIT HEAVY VEHICLE	363	11	2.95	-3.32	9.21
HIT CAR-CUV-MINIVAN < 3157	621	1	.12	-3.82	4.07
HIT CAR-CUV-MINIVAN 3157+	669	13	1.91	- .87	4.70
HIT TRUCK-BASED LTV < 4303	345	-4	-1.07	-4.87	2.73
HIT TRUCK-BASED LTV 4303+	462	9	1.94	-2.42	6.30
ALL OTHERS	1,655	7	.42	- .73	1.57
OVERALL	**6,308**	**32**	**.50**	**- .59**	**1.60**
		PICKUPS & TRUCK-BASED SUVs < 4,947 POUNDS			
1st-EVENT ROLLOVER	75	0	- .42	-2.43	1.60
HIT FIXED OBJECT	300	-6	-1.83	-3.96	.30
HIT PEDESTRIAN/BIKE/MOTORCYCLE	553	-2	- .27	-2.00	1.47
HIT HEAVY VEHICLE	188	7	3.85	.90	6.80
HIT CAR-CUV-MINIVAN < 3157	339	0	.03	- .77	.84
HIT CAR-CUV-MINIVAN 3157+	326	-4	-1.23	-3.15	.70
HIT TRUCK-BASED LTV < 4303	165	-2	-1.08	-3.57	1.42
HIT TRUCK-BASED LTV 4303+	128	2	1.38	- .22	2.97
ALL OTHERS	729	1	.16	-1.67	1.99
OVERALL	**2,803**	**-3**	**- .10**	**-1.08**	**.88**

		FATALITY INCREASE PER 100-POUND MASS REDUCTION			
	FATALITIES AFTER	POINT ESTIMATE		95% CONFIDENCE BOUNDS (%)	
CRASH TYPE	ESC	N	%	LOWER	UPPER
		PICKUPS & TRUCK-BASED SUVs ≥ 4,947 POUNDS			
1st-EVENT ROLLOVER	106	1	1.16	-1.12	3.45
HIT FIXED OBJECT	389	7	1.79	- .25	3.82
HIT PEDESTRIAN/BIKE/MOTORCYCLE	718	-4	- .52	-2.22	1.18
HIT HEAVY VEHICLE	229	4	1.54	-1.09	4.17
HIT CAR-CUV-MINIVAN < 3157	575	-13	-2.19	-3.70	- .68
HIT CAR-CUV-MINIVAN 3157+	556	-9	-1.54	-3.37	.28
HIT TRUCK-BASED LTV < 4303	285	-7	-2.46	-4.26	- .65
HIT TRUCK-BASED LTV 4303+	259	-3	-1.30	-4.08	1.48
ALL OTHERS	1,033	-6	- .59	-1.47	.29
OVERALL	**4,150**	**-30**	**- .72**	**-1.45**	**.02**
		CUVs & MINIVANS			
1st-EVENT ROLLOVER	40	-3	-6.97	-12.78	-1.16
HIT FIXED OBJECT	277	-9	-3.12	-7.42	1.18
HIT PEDESTRIAN/BIKE/MOTORCYCLE	654	-16	-2.49	-4.43	- .55
HIT HEAVY VEHICLE	189	2	1.11	-1.62	3.84
HIT CAR-CUV-MINIVAN < 3157	365	-1	- .27	-3.23	2.68
HIT CAR-CUV-MINIVAN 3157+	360	1	.39	-3.09	3.86
HIT TRUCK-BASED LTV < 4303	161	3	1.88	-16.14	19.90
HIT TRUCK-BASED LTV 4303+	210	2	.89	-5.88	7.67
ALL OTHERS	970	-12	-1.20	-3.19	.80
OVERALL	**3,224**	**-32**	**- .99**	**-2.17**	**.19**

The principal findings in Table 3-5 include estimates of both positive and negative impacts on societal fatalities per 100-pound mass reduction, across vehicle classes. Table 3-5 indicates that that crash fatalities would increase by 1.49 percent per 100-pound mass reduction in passenger cars < 3,197 pounds (with 95-percent confidence bounds ranging from a 0.30 percent decrease to a 2.59 percent increase). Conversely, Table 3-5 indicates that crash fatalities would decrease when reducing mass in truck-based LTVs ≥ 4,947 pounds and CUVs and minivans. For each 100-pound mass reduction in truck-based LTVs ≥ 4,947 pounds, crash fatalities are estimated to decrease by 0.72 percent (95-percent confidence bounds ranging from a 1.45 percent decrease to a 0.02 percent increase). For each 100-pound mass reduction in CUVs and minivans, crash fatalities are estimated to decrease by 0.99 percent (95-percent confidence bounds ranging from a 2.17 percent decrease to a 0.19 percent increase). The confidence bounds at Table 3-5 are generated by the jackknife approach, as described later in this section.

The point estimates for passenger cars < 3,197 pounds, truck-based LTVs ≥ 4,947 pounds, and CUVs and minivans are statistically significant at the 90-percent confidence level (critical *t*-statistic value of 1.833), but statistically insignificant at the 95-percent confidence level (critical *t*-statistic value of 2.262); the point estimate for truck-based LTVs ≥ 4,947 pounds falls just short of significance at the 95-percent confidence level.

In the other two vehicle classes, one point estimate indicates an increase in societal fatality rates (0.50 percent in cars ≥ 3,197 pounds, and one point estimate indicates a decrease in societal fatality rates (0.10 percent in truck-based LTVs < 4,947 pounds). Neither of these two point estimates is statistically significant at the 95- or 90-percent confidence level, as evidenced by confidence bounds spanning zero by large margins relative to the point estimates. Combined effects of simultaneously reducing mass in all five vehicle classes are estimated in the next section.

The point estimates in Table 3-5 are expressed as percentages (the middle column of numbers) for the individual crash types are copied from the left column of numbers in Table 3-1, and are based on the actual regression results. In order to obtain an overall effect across crash types, it is necessary to gauge the relative incidence of each type of crash: the "baseline" fatalities. As in NHTSA's 2012 report, the baseline is derived from a subset of the more recent fatalities in the FARS analysis database, namely the last four MY in the last five CY (MY 2007-2010 vehicles in CY 2007-2011 crashes).[58] The choice of the last four MY and last five CY has no special meaning but just represents one possible trade-off between the two conflicting goals of using the latest-possible vehicles and having enough cases in each cell to get a precise distribution; this choice retains approximately one-third of the original FARS cases.

Furthermore, because all new vehicles are now equipped with ESC, the original baseline fatalities are adjusted downward to what they would have been if all vehicles had been equipped with ESC (as they will be in MY 2022-2025). NHTSA's most recent statistical evaluation (updated since the 2012 report) estimates[59] that ESC reduces fatal 1st-event rollovers by 60 percent in cars and 74 percent in LTVs (including CUVs and minivans); fixed-object impacts by 31 percent in cars and 45 percent in LTVs; and other non-pedestrian crashes by 7 percent in cars and 6 percent in LTVs. For example, if the database has 200 records of cars in fatal 1st-event rollovers and 100 of these cars were ESC-equipped, 100 not equipped, the baseline fatalities would be adjusted downward from 200 to 140 to reflect that the 100 fatalities in the non-equipped cars would have dropped by 60 percent, to 40, if they had been ESC-equipped (whereas the 100 fatalities in the already ESC-equipped cars would have stayed the same). Baseline fatalities have not been adjusted for other upcoming technologies, specifically curtain air bags, because they will not radically change the distribution of fatalities by crash type, only reduce the overall absolute number; they will not substantially change the relative weights of the nine crash types.

The baseline fatalities after ESC are the left column of numbers in Table 3-5. These are not annual fatality counts but are based simply on the actual counts of fatal-crash involvements for MY 2007-2010 vehicles in CY 2007-2011, for the purpose of averaging the effects of mass reduction across crash types (i.e., they are vehicle-based societal counts). For example, the 393 baseline fatalities for cars < 3,197 pounds in collisions with LTVs ≥ 4,303 pounds indicates that cars were involved in a number of fatal collisions that resulted in a total of 393 fatalities in the

[58] Kahane (2003), p. 104; also, the vehicles not included in the regressions, namely 2-door muscle cars, 4-door police cars, and full-size vans are included in tabulating baseline fatalities.

[59] Kahane, C. J. (2014). *Updated Estimates of Fatality Reduction by Electronic Stability Control.*,(Evaluation Note. Report No. DOT HS 812 020). Washington, DC: National Highway Traffic Safety Administration. http://www-nrd.nhtsa.dot.gov/Pubs/812020.pdf.

cars or in the partner LTVs. If some of those partner LTVs were MY 2007-2010, the same crash would also appear in one of the baseline counts for LTVs hitting cars/CUVs/minivans. The double-counting is not an issue here (where separate effects are estimated for each class of vehicles) but needs to be addressed in Section 3.6 (where effects will be combined across vehicle classes). Section 3.6 will also index the fatality counts to annual totals to allow estimation of the effects of mass reduction on annual fatalities.

For each type of crash, the regression coefficient is applied to the baseline fatalities to estimate the numerical increase or decrease in fatalities for that crash type (the second column of numbers in Table 3-5). Within each vehicle class, the sum of the nine numerical increases or decreases divided by the sum of the baseline fatalities yields the overall percentage effect of a 100-pound mass reduction for that class of vehicles. For example, in cars < 3,197 pounds, the increase of 72 fatalities is 1.49 percent of the baseline, 4,815.

Confidence bounds: Two sources of sampling error are considered:

- The relatively small numbers (hundreds or thousands, not hundreds-of-thousands or millions) of fatal-crash cases included in the regression analyses. Of course, FARS is technically a census, not a sample, but NHTSA analyses usually treat FARS data as if it were a sample and apply customary statistical tests such as chi-square. The crashes that actually occur in the course of a year are construed as a sample of the crashes that would have occurred if more-or-less the same national crash environment of that year had been repeated over and over, each year resulting in a somewhat different number and distribution of fatal crashes.

- The fact that induced-exposure data from only 13 States, rather than from all 50 States plus DC are used to allocate the registration years and VMT by the various control variables. With other States, the allocation might have been somewhat different. Technically, these 13 States were not selected by simple random sampling but are the States whose files are available to NHTSA and include the VIN and the other necessary control variables. But to the extent that the availability of these States' files rather than other States' does not appear to have been influenced by any criterion directly relevant to this study, these 13 States may be considered a quasi-random sample, at least for the purpose of assessing sampling error.

The first source of error ("FARS-based sampling error") far exceeds the "State-based sampling error" in the estimates of the individual regression coefficients. But as the results are averaged across crash types (in Table 3-5), the State-based errors, which have high covariance across crash types (because all regressions use the same exposure data), come closer to the FARS-based error, which has little covariance across crash types (because each regression uses a different set of FARS cases).

Both sources of error are estimated by a jackknife technique, because of the complexity of the estimator (a logistic regression coefficient) and the need for ample data to drive the regression. For the FARS-based error, the FARS cases are subdivided into 10 systematic random subsamples of equal size, based on the last digit of the case number, ST_CASE (i.e., at the accident, not the vehicle or person level); as Paul Green pointed out, the fatality cases are essentially "clustered" at the accident level.

Under the jackknife technique, ten regressions are performed, each using the 9/10 of the FARS data that remain after one of the subsamples is removed and using all the induced-exposure data. (The subsample is then replaced before the next subsample is removed.) The 10 regressions yield 10 estimates of the regression coefficients – specifically those for the mass variables (UNDRWT00, OVERWT00, or LBS100, depending on the vehicle class) – each of which is slightly different from the original coefficient based on the full FARS data.

If, for example, the original coefficient is x and the coefficient is $x + h$ when all FARS cases are used except those with ST_CASE ending in zero, a "pseudo-estimate" $x – 9h$ is generated for the subsample including only the FARS cases with ST_CASE ending in zero (because if a regression could have been run using only these cases, it would have had to produce a coefficient $x – 9h$ in order for it and the $x + h$ generated from the other 9/10 of the data to average out to x). The standard error of these 10 pseudo-estimates serves as the FARS-based component of the standard deviation of the original coefficient and it can be treated as a t-distribution with 9 degrees of freedom (df). This FARS-based error is typically a little bit more than the error implied by the Wald chi-square statistics in Table 3-1; the slight increase may be due to FARS clustering at the accident level (more than one person may be a fatality in the same crash) whereas the Wald chi-square treats each fatally injured person as a separate, independent case.

For the State-based error, the induced-exposure data is construed as a cluster sample, each State plus DC constituting a primary sampling unit (PSU); 13 of the 51 available PSUs are in the sample. Unlike the FARS data, the PSUs cannot be partitioned into subsamples of equal size, because the States vary considerably in size (i.e., cumulative VMT). But if the three least populous States – Kansas, Nebraska, and Wyoming – are combined, there are 11 subsamples, each containing at least 3.8 percent of the cumulative VMT. Eleven regressions are performed, each using all of the FARS data, but using only the induced-exposure data from the remaining States, after the State(s) in that subsample are removed, to allocate the VMT by driver age, gender, and the other control variables, as explained in Section 2.6.

In each of the regressions, the VMT still add up to the national totals; they are just allocated differently. The subsample is then replaced before the next subsample is removed. The 11 regressions yield 11 estimates of the regression coefficients for UNDRWT00, OVERWT00, and/or LBS100, each slightly different from the original coefficients based on using the induced-exposure data from all 13 States to allocate the VMT. If, for example, the original coefficient is x and the coefficient is $x + h$ when all States except Alabama are used to allocate the VMT and if the Alabama records were allocated a share w of the nation's VMT in the original file, a "pseudo-estimate" $x - h(w/(1-w))$ is generated for the subsample including only the Alabama cases (because if a regression could have been run using only Alabama induced-exposure cases to allocate the VMT, it would have had to produce a coefficient $x - h(w/(1-w))$ in order for it and the $x + h$ coefficient generated by using all the States except Alabama, which account for a 1-w share of the data, to have the share-weighted average be x). The share-weighted standard error of these 11 pseudo-estimates is multiplied by a finite population correction (FPC) of $.8718 = \sqrt{(51-13)/(51-1)}$, because the sample included 13 of the 51 available PSUs. This serves as the State-based component of the standard deviation of the original coefficient and it can be treated as a *t*-distribution with 10 degrees of freedom (df).

The standard deviation of the original coefficient is the root-sum-of-squares of the FARS- and State-based components. The two-sided 95% confidence bounds for the regression coefficients for the individual crash types are the point estimate of the coefficient (as derived from the basic regression analysis) ±2.262 standard deviations, where 2.262 is the 97.5th percentile of a *t*-distribution with 9 df (the lesser df of the FARS- and State-based components – i.e., the wider confidence bound). These are the confidence bounds shown for the individual crash types in Table 3-5. The *t*-test with 9 df can also be applied to test if the point estimate is statistically significant at the 95% confidence level (i.e., whether the magnitude of the *t*-statistic of the coefficient is greater than 2.262). Two-sided 90% confidence bounds for the regression coefficients can be identified as the point estimates of the coefficients ±1.833 standard deviations, where 1.833 is the 95th percentile of a *t*-distribution with 9 df. The *t*-test with 9 df can be applied to test if the point estimate is statistically significant at the 90% confidence level in the same manner as the significance test at 95% confidence, using a critical *t*-value of 1.833 rather than 2.262.

The same sets of pseudo-estimates for the individual regression coefficients can be used to compute confidence bounds for any linear combination of point estimates for these coefficients. For example, the point estimate of the overall effect of a 100-pound mass reduction in cars < 3,197 pounds, a 1.49 percent fatality increase according to Table 3-5, is the weighted average of the nine coefficients above it in the table, the “annual fatalities after ESC,” two columns to the left, being the weighting factor. The overall effect is recomputed using, for each of the nine crash types, the pseudo-estimate coefficient for the FARS cases with ST_CASE ending in 0 substituted for the point-estimate coefficient (but the same weighting factor); again recomputed using the pseudo-estimates for the FARS cases with ST_CASE ending in 1; and so on.

The standard error of the 10 resulting pseudo-estimates of the overall effect serves as the FARS-based component of its sampling error. The overall effect is likewise recomputed 11 times using the pseudo-estimate coefficients for the various State files to estimate the State-based component of its sampling error. The confidence bounds for the overall effects of 100-pound mass reduction in the five classes of vehicles, the “Volpe model coefficients,” are also shown in Table 3-5.

None of the point estimates are statistically significant at the 95-percent confidence level (critical *t*-statistic value of ±2.262 with 9 df), but three of the coefficients are statistically significant at the 90-percent confidence level (critical *t*-statistic value of ±1.833 with 9 df). The overall 1.49 percent fatality increase per 100-pound mass reduction in the cars < 3,197 is statistically significant at the 90-percent confidence level (t = 1.88, df = 9). Likewise, the overall 0.69 percent fatality decrease per 100-pound mass reduction in the truck-based LTVs ≥ 4,947 and the overall 0.99 percent fatality decrease per 100-pound mass reduction in CUVs and minivans are statistically significant at the 90-percent confidence level (t = -2.23 and -1.90, respectively, df = 9).

The Volpe coefficients for the other two vehicle groups, .50 and -.10 are not statistically significant at the 95- or 90-percent confidence levels (t = 1.04 and -.23, respectively). Because the confidence bounds and the significance test are based on similar *t*-statistics, the 95-percent confidence bounds will exclude zero when and if the *t*-test with 9 df is significant ($|t| > 2.262$). Likewise, the 90-percent confidence bounds will exclude zero when and if the *t*-test with 9 df is significant ($|t| > 1.833$).

Discussion of results: The implications of the results with the new database are consistent with the implications in NHTSA's 2012 report. The paramount implications are that:

(1) Mass reduction in the lighter cars is associated with societal harm;

(2) Mass reduction in the heavier LTVs, CUVs and minivans is associated with societal benefits; and

(3) Mass reduction in the heavier cars and lighter LTVs is associated with little societal effect in either direction.

The analytical results continue to be consistent with the idea, based on momentum considerations, that it does more harm than good to make the lightest vehicles even lighter but that it does more good than harm to make the heaviest vehicles lighter.

The point estimates for the effects of mass reduction are nearly unchanged across the 2012 report and this report for both the lighter cars and heavier cars. In the 2012 report, societal fatality risk was estimated to increase by 1.56 percent increase per 100-pound reduction in cars < 3,106 pounds; in this report, societal fatality risk is estimated to increase by 1.49 percent per 100-pound reduction in cars < 3,197 pounds. A similar analytical outcome was observed for the heavier cars (0.47 percent increase in fatality risk per 100-pound reduction in cars ≥ 3,106 pounds in the 2012 report, versus 0.50 percent increase in fatality risk per 100-pound reduction in cars ≥ 3,197 pounds in this report).

The point estimates for the effects of mass reduction have increased in magnitude from the 2012 report to this report for both the heavier truck-based LTVs, and CUVs and minivans. In the 2012 report, societal fatality risk was estimated to decrease by 0.34 percent per 100-pound reduction in LTVs ≥ 4,594 pounds; in this report, societal fatality risk is estimated to decrease by 0.72 percent per 100-pound reduction in LTVs ≥ 4,947 pounds. A similar increase in estimated impacts was observed for CUVs and minivans (0.37 percent decrease in fatality risk per 100-pound reduction in CUVs and minivans in the 2012 report, versus 0.99 percent increase in fatality risk per 100-pound reduction in CUVs and minivans in this report).

A notable difference between the two reports is contained within the point estimate for the lighter truck-based LTVs. The 2012 report indicated a (statistically insignificant) increase in risk from mass reduction in LTVs < 4,594 pounds that was equivalent to the corresponding estimate for the heavier passenger cars. In this report, the point estimate for LTVs < 4,947 pounds is slightly negative (also statistically insignificant). The difference in point estimates for the lighter LTVs across reports may simply reflect uncertainty in the estimates (i.e., the 95-percent and 90-percent confidence intervals for the lighter-LTV mass effect cross zero in both reports). However, the movement of the point estimate toward zero is also consistent with changes in the relative masses of vehicles across vehicle types. In particular, the heavier LTVs gained mass at a greater rate than the lighter LTVs.

In the 2012 report, the overall effect in the lighter cars was the only estimated effect that was statistically significant at the 95- and 90-percent confidence levels. As noted above, in this report three estimated mass effects were significant at the 90-percent confidence level (for the lighter cars, the heavier LTVs, and CUVs and minivans). Only six of the 45 coefficients for individual crash types in Table 3-5 are statistically significant at the 95-percent confidence level (compared to five in the 2012 report), as evidenced by upper and lower bounds with the same sign:

- The fatality increase for mass reduction for cars < 3,197 pounds in collisions with pedestrians;
- The fatality increase for mass reduction for cars < 3,197 pounds in crashes not otherwise classified;
- The fatality decrease for mass reduction in cars ≥ 3,197 pounds in first-event rollovers;
- The fatality increase for mass reduction in LTVs < 4,947 pounds in collisions with heavy vehicles;
- The fatality decrease for mass reduction in LTVs ≥ 4,947 pounds in collisions with cars, CUVs and minivans < 3,157 pounds; and
- The fatality decrease for mass reduction in LTVs ≥ 4,947 pounds in collisions with LTVs < 4,303 pounds.

3.6 Combined annual effect of mass reduction in several classes of vehicles

Charles Farmer asks in his peer review of NHTSA's 2010 report about the effect of removing 100 pounds from every car and LTV while holding footprint constant; indeed, this is not estimated in the 2010 report (although the 2003 report did estimate the annual effect of removing 100 pounds with commensurate footprint reductions). It is useful to make the question more general: What would be the annual effect on fatalities of removing *x* pounds from the heavier LTVs, *y* pounds from the lighter cars, and so on? The issues involved are adjusting the baseline fatality counts to annual levels and addressing the issue of double-counting (namely, when a FARS crash involves two or more MY 2003-2010 vehicles, it will appear multiple times in the vehicle-oriented database).

As in NHTSA's 2012 report, the starting point is FARS for the last five CY in the database – in this case, 2007-2011. There were 178,043 fatalities in crashes during that 5-year period, an average of 35,609 per year. However, quite a few involved only motorcycles, heavy trucks, or other vehicles that are not cars or LTVs; 156,184 of the fatalities occurred in crashes involving at least one car or LTV, an average of 31,237 per year. But these crashes involve an on-road fleet including vehicles of any model year, sometimes long before 2003, and most of the on-road fleet was not yet ESC-equipped. If all the cars and LTVs on the road had already been equipped with

ESC, NHTSA estimates that there would have been only 24,791 fatalities per year, not 31,237.[60] This number, 24,791 will serve as the baseline annual fatalities in the post-ESC environment. Furthermore, 15,885 of these 24,791 fatalities would have occurred in crashes involving exactly one light vehicle (i.e., a car or LTV), 7,452 in crashes involving exactly two light vehicles, and 1,454 in crashes involving three or more light vehicles.

Again paralleling the 2012 report, the vehicle sales mix of the four most recent model years in the database, in this case MY 2007-2010 is postulated to continue into the indefinite future until it becomes the entire on-road fleet, having replaced all earlier vehicles. The 24,791 annual fatalities are allocated to vehicle types and crash types based on the experience of MY 2007-2010 vehicles in CY 2007-2011, adjusted for ESC. The 15,885 fatalities in crashes involving one light vehicle would have included, for example, 239 fatalities of cars < 3,197 pounds in 1st-event rollovers, 275 fatalities of cars ≥ 3,197 pounds in 1st-event rollovers, and so on.[61] For these 15,885 fatalities, there is no issue of double-counting, as only one light vehicle was involved in the crash.

The case-vehicle involvements in crashes involving exactly two light vehicles and where the case vehicle and the "other" vehicle are both MY 2007-2010 are subdivided into cells by the type of case vehicle (car < 3,197, car ≥ 3,197, truck-based LTV < 4,947, truck-based LTV ≥ 4,947, CUV/minivan) and the type of crash (predominantly: hit car/CUV/minivan < 3,157, hit car/CUV/minivan ≥ 3,157, hit truck-based LTV < 4,303, and hit truck-based LTV ≥ 4,303; but also some other types, such as when the crash involved a heavy truck, pedestrian, or motorcycle in addition to the two light vehicles). Each crash will appear twice in the tabulation, once with vehicle no. 1 as the case vehicle, once with vehicle no. 2 as the case vehicle. However, all the cell counts are then multiplied by the same constant so they will add up to 7,482, the annual number of fatalities in such crashes. That addresses the issue of double-counting, for even though the crashes appear twice, the cell counts add up only to 7,452 the number of annual fatalities in the crashes.

However, for the subset of these crashes that involved only the two light vehicles and no other units, the computational model intentionally double-counts because the effects of mass reduction in each of the two light vehicles are additive. These effects are tallied separately and eventually summed. For example, when a car ≥ 3,197 pounds collides with a truck-based LTV ≥ 4,303 pounds, according to the regressions (Table 3-1), removing 100 pounds from the car would have increased societal risk by 1.94 percent whereas removing 100 pounds from the LTV would have reduced societal risk by 1.54 percent; thus, removing 100 pounds from both would have increased risk by an estimated net 0.40 percent.

The case-vehicle involvements in crashes involving three or more MY 2007-2010 light vehicles are likewise subdivided by the type of case vehicle and the type of crash. Almost all of these are

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[60] Kahane (2014) estimates that ESC reduces fatal 1st-event rollovers by 60 percent in cars and 74 percent in LTVs; fixed-object impacts by 31 percent in cars and 45 percent in LTVs; and other non-pedestrian crashes by 7 percent in cars and by 6 percent in LTVs.

[61] The actual fatalities on the database in crashes involving one car or LTV – and that car or LTV is MY 2007-2010 – are tabulated by vehicle class and crash type. The actual fatality counts for the non-ESC-equipped vehicles are adjusted downward for ESC effectiveness. Each cell in the table is then multiplied by the same constant so that the cells sum up to 15,885.

the last type of crash ("all others") and none are of the crash types that involve two light vehicles and nothing else. All the cell counts are then multiplied by the same constant so they will add up to 1,458, the annual number of fatalities in such crashes. Even though some crashes may appear multiple times, the cell counts add up only to 1,454, essentially pro-rating the cases and avoiding double-counting.

Table 3-8 shows how the computational model works to estimate the annual effect of removing 100 pounds from every vehicle. It tabulates a year's crash fatalities by crash type and case-vehicle type. The first column of numbers, "annual crash fatalities after ESC" adds up to exactly 24,791. In the first four crash types and the last one, these are the sums of the FARS variable FATALS for the vehicle records on the database, adjusted downward for ESC effectiveness and multiplied by constants, as described above, in order that the fatalities in crashes involving one light vehicle add up to 15,885 and the fatalities in crashes involving three or more light vehicles add up to 1,454.

Table 3-8 shows two counts for the four types of crashes that involve two light vehicles and no other traffic units. The smaller number on the left only counts a crash the first time it appears on the database (i.e., it does not count subsequent vehicle records with the same CY and ST_CASE) to assure that the entire left column adds up to 24,791. The larger number on the right counts the crash both times it appears (most often in two different rows) to allow tallying the effects of mass reduction in either vehicle. The next column is the percent societal fatality increase per 100-pound mass reduction while holding footprint constant: the same numbers as in Tables 3-1 and 3-5, based on the regression coefficients.

The next column is the amount of mass reduction in each vehicle class. In Table 3-8 it is 100 pounds for all vehicle classes. The final column is the annual societal fatality increase associated with the mass reduction in that class of vehicle in that type of crash. It is the product of the annual crash fatalities (the only number shown for the first four and the last crash type, the larger number on the right for the four crash types involving two light vehicles and no other units), the percent effect per 100 pounds, and the amount of mass reduction (which in Table 3-8 is always 100 pounds).

The last column adds up to an estimated annual increase of 91 fatalities if all vehicles became 100 pounds lighter without changing footprint: an increase of 0.37 percent over the 24,791 annual baseline fatalities after ESC.

TABLE 3-7: ESTIMATED ANNUAL EFFECT OF 100-POUND MASS REDUCTION IN ALL VEHICLES HOLDING FOOTPRINT CONSTANT

CRASH TYPE	VEHICLE TYPE	ANNUAL CRASH FATALS AFTER ESC		FATALITY INCREASE PER 100 LB RED (%)	MASS RED	FATALITY INCREASE
1st-EVENT ROLLOVER	CAR < 3197	239		-2.96	100	- 7.1
	CAR 3197+	275		-5.42	100	-14.9
	TRUCK-BASED LTV < 4947	134		-0.42	100	- .6
	TRUCK-BASED LTV 4947+	191		1.16	100	2.2
	CUV OR MINIVAN	72		-6.97	100	- 5.0
HIT FIXED OBJECT	CAR < 3197	1427		- .14	100	- 2.0
	CAR 3197+	1770		- .70	100	-12.3
	TRUCK-BASED LTV < 4947	541		-1.83	100	- 9.9
	TRUCK-BASED LTV 4947+	701		1.79	100	12.5
	CUV OR MINIVAN	499		-3.12	100	-15.6
HIT PEDESTRIAN/BIKE/MOTORCYCLE	CAR < 3197	1358		2.26	100	30.7
	CAR 3197+	1873		.96	100	18.1
	TRUCK-BASED LTV < 4947	983		-0.27	100	- 2.6
	TRUCK-BASED LTV 4947+	1291		- .52	100	- 6.7
	CUV OR MINIVAN	1184		-2.49	100	-29.5
HIT HEAVY VEHICLE	CAR < 3197	613		2.57	100	15.8
	CAR 3197+	634		2.95	100	18.7
	TRUCK-BASED LTV < 4947	330		3.85	100	12.7
	TRUCK-BASED LTV 4947+	404		1.54	100	6.2
	CUV OR MINIVAN	328		1.11	100	3.6
HIT CAR-CUV-MINIVAN < 3157	CAR < 3197	321*	654**	-1.39	100	- 9.1
	CAR 3197+	433*	1037**	.12	100	1.3
	TRUCK-BASED LTV < 4947	138*	368**	.03	100	.1
	TRUCK-BASED LTV 4947+	254*	877**	-2.19	100	-19.2
	CUV OR MINIVAN	151*	491**	- .27	100	- 1.3
HIT CAR-CUV-MINIVAN 3157+	CAR < 3197	901*	1456**	2.44	100	35.5
	CAR 3197+	865*	1643**	1.91	100	31.4
	TRUCK-BASED LTV < 4947	314*	625**	-1.23	100	- 7.7
	TRUCK-BASED LTV 4947+	510*	1035**	-1.54	100	-16.0
	CUV OR MINIVAN	369*	821**	.39	100	3.2
HIT TRUCK-BASED LTV < 4303	CAR < 3197	111*	189**	1.01	100	1.9
	CAR 3197+	100*	123**	-1.07	100	- 1.3
	TRUCK-BASED LTV < 4947	23*	34**	-1.08	100	- .4
	TRUCK-BASED LTV 4947+	92*	138**	-2.46	100	- 3.4
	CUV OR MINIVAN	73*	84**	1.88	100	1.6
HIT TRUCK-BASED LTV 4303+	CAR < 3197	632*	940**	2.78	100	26.1
	CAR 3197+	446*	946**	1.94	100	18.3
	TRUCK-BASED LTV < 4947	172*	369**	1.38	100	5.1
	TRUCK-BASED LTV 4947+	282*	556**	-1.30	100	- 7.2
	CUV OR MINIVAN	234*	465**	.89	100	4.2
ALL OTHERS	CAR < 3197	728		2.62	100	19.1
	CAR 3197+	1017		.42	100	4.3
	TRUCK-BASED LTV < 4947	519		.16	100	.8
	TRUCK-BASED LTV 4947+	643		- .59	100	- 3.8
	CUV OR MINIVAN	616		-1.20	100	- 7.4
		======				=======
ALL CRASH TYPES AND ALL VEHICLE TYPES		**24791**				**90.5**

* Including each crash only the first time it appears in the database: for tallying annual crash fatalities
** Including each crash both times it appears: for computing effects of mass reduction in each vehicle

The scenario of removing 100 pounds from every vehicle, while useful for illustrative purposes is not likely to happen. A hundred pounds is twice the proportion of the mass of a 2,500-pound car as a 5,000-pound pickup truck or CUV; most scenarios contemplate proportionately greater or at least equal mass reduction from the heavier vehicles. The computational model applied to Table 3-7 allows mass reduction to vary among the vehicle classes. Continuing methods from the previous reports, here are three hypothetical scenarios that involve removing different but relatively small amounts of mass:

Proportionate reduction: The average curb weight of MY 2007-2010 vehicles involved in fatal incidents was 3,922 pounds; 100 pounds is 2.55 percent of 3,922. The average weights of the five vehicle classes are 2,777; 3,522; 4,268; 5,622; and 3,918 pounds, respectively; 2.55 percent of these averages are 71, 90, 109, 143, and 100 pounds. Rather than 100 pounds apiece, 71 pounds are removed from cars < 3,197, 90 pounds from cars ≥ 3,197, and so on. In this scenario, annual fatalities are projected to increase by an estimated 36.6, which is less than half the magnitude of the estimated effect of reducing 100 pounds from every vehicle (an increase of 90.5 fatalities per year).

More reduction in heavy LTVs and no reduction in the lighter cars: In this scenario, the mass reduction in the heavier truck-based LTVs is doubled relative to the previous scenario, from 143 to 286 pounds; no mass is reduced in the cars < 3,197; and the same reductions are taken as in the proportionate-reduction scenario for the other three groups. In this scenario, annual fatalities are expected to decrease by an estimated 92.6, which is an approximately opposite result to reducing 100 pounds from every vehicle.

More reduction in heavy LTVs and at least some reduction in all groups: Reduce mass by: 50 pounds in the lighter cars (a 1.78 percent reduction in mass); 93 pounds in the heavier cars (2.63 percent); by 114 pounds in the lighter truck-based LTVs (2.67 percent); by 180 pounds in the heavier truck-based LTVs (3.23 percent); and by 104 pounds in CUVs and minivans (2.61 percent). This scenario is safety-neutral for a fleet-average reduction of 100 pounds per vehicle – i.e., the point estimate is zero change in fatalities. There are infinite safety-neutral scenarios that could be identified in which at least some mass is removed from all vehicles; the central characteristic of this scenario is the removal of a greater share of mass in heavier vehicles.

Each of these scenarios involves relatively small amounts of initial mass reduction in the immediate post-ESC environment. These estimates are not intended as substitutes for the Volpe model, which will track the longer-term effects of more extensive mass reduction in stages and by different amounts depending on the make-model. An important feature of the Volpe model absent here is that after successive mass reductions, cars that originally exceeded 3,197 pounds will eventually fall under 3,197 pounds and then each additional pound of mass reduction would have a more harmful effect (namely, the coefficients for the cars < 3,197 pounds); likewise for truck-based LTVs and their 4,947 pound threshold. Instead, the point of these scenarios is to illustrate the ranges of point estimates that can be obtained for initial mass reduction. There could in fact be many safety-neutral combinations.

3.7 Effect of reducing mass and footprint (downsizing)

All of the analyses so far estimated the effect of mass reduction while holding footprint constant, which NHTSA assumes is most likely in the future given the disincentive to shrink footprint due to the footprint-based CAFE standards; but as was done in the previous reports, it is also possible to estimate the effect of downsizing, namely, reducing mass with historically commensurate reductions in footprint (size) – more exactly, comparing the societal fatality rates of groups of vehicles of the same type (e.g., cars) but different mass and footprint, the heavier vehicles having typically larger footprints than the lighter vehicles. This can be accomplished by simply running the 27 basic regressions without the footprint variable, but all other variables unchanged: The effect of historically commensurate footprint reduction will be an implicit component of the regression coefficient for mass.

Table 3-8 lists the 45 coefficients for curb weight in the regressions that omit the footprint variable, by vehicle type and crash type; the overall effects (point estimates and their confidence bounds) of downsizing by 100 pounds in each of the five classes of vehicles, computed using the same post-ESC baseline fatalities as in Table 3-5; and the composite point estimate for downsizing all vehicles by 100 pounds, computed as in Table 3-7.

Downsizing by 100 pounds (which, by definition, includes a historically commensurate reduction in footprint) is associated with substantial fatality increases in passenger cars for many crash types, especially in cars < 3,197 pounds. The most notable effect of excluding footprint from the basic regressions is an estimated increase in fatality risk for single-vehicle crashes for all vehicle classes; in the basic regressions, the estimated societal effect of mass reduction in single-vehicle crashes is beneficial for all but one vehicle class. Collisions with lighter passenger cars, CUVs and minivans represent a key exception in the analysis: For these collisions, mass reduction in passenger cars is associated with beneficial (for cars < 3,197 pounds) or neutral (for cars ≥ 3,197 pounds) societal impacts.

For truck-based LTVs < 4,303 pounds, mass reduction is associated with relatively small net impacts across most crash types. However, consistent with all other vehicle types except for larger LTVs, mass reduction in lighter LTVs is associated with large increases in societal fatality risk in collisions with heavy vehicles and heavier LTVs. For truck-based LTVs ≥ 4,303 pounds, mass reduction is associated with large reductions in societal fatality risk for all collisions with passenger cars, CUVs, minivans and LTVs; mass reduction in heavier LTVs is also associated with a large reduction in societal fatality risk for collisions with pedestrians, bicycles and motorcycles. However, mass reduction in heavier LTVs is associated with large increases in societal fatality risk for single-vehicle incidents (i.e., first-event rollovers and collisions with fixed objects).

TABLE 3-8: ESTIMATED EFFECTS OF 100-POUND MASS REDUCTION <u>WITHOUT</u> HOLDING FOOTPRINT CONSTANT BY VEHICLE CLASS AND CRASH TYPE (DOWNSIZING)

	FATALITY INCREASE PER 100-POUND DOWNSIZING (%)				
	CARS		TRUCK-BASED LTVs		CUVs & MINIVANS
	< 3,197	≥ 3,197	< 4,947	≥ 4,947	
1st-EVENT ROLLOVER	2.08	.10	.47	1.55	.31
HIT FIXED OBJECT	.53	.05	.36	2.72	1.04
HIT PEDESTRIAN/BIKE/MOTORCYCLE	1.46	.11	- .24	- .51	-1.91
HIT HEAVY VEHICLE	3.24	3.66	2.75	1.02	1.88
HIT CAR-CUV-MINIVAN < 3157	-1.50	.01	- .22	-2.31	- .77
HIT CAR-CUV-MINIVAN 3157+	1.44	.82	- .42	-1.18	- .50
HIT TRUCK-BASED LTV < 4303	2.74	.79	.86	-1.61	.04
HIT TRUCK-BASED LTV 4303+	3.77	3.00	2.30	- .87	1.54
ALL OTHERS	2.54	.34	- .03	- .68	- .07
OVERALL - POINT ESTIMATE	**1.71**	**.68**	**.26**	**- .54**	**- .25**

100-POUND DOWNSIZING IN ALL VEHICLES: FATALITIES INCREASE BY 0.48 PERCENT (119 PER YEAR)

Across crash types, societal fatality risk increases by 1.71 percent per 100-pound downsizing of cars < 3,197 pounds, and by 0.68 percent for cars ≥ 3,197 pounds. The fatality increase in truck-based LTVs < 4,947 pounds is smaller, at 0.26 percent. Societal fatality risk is estimated to decrease by 0.54 percent when downsizing truck-based LTVs ≥ 4,947 pounds. The effect of downsizing in CUVs and minivans is an estimated 0.25 percent decrease. Overall, the point estimates are generally consistent in magnitude for passenger cars and LTVs compared to the analyses in which footprint is held constant; the major exception is a smaller estimated reduction in societal risk associated with downsizing CUVs and minivans.

The estimated effect of downsizing all vehicles by 100 pounds is an annual fatality increase of 119, or 0.48 percent (under an all-ESC fleet). This estimated effect is around 30 percent larger than the estimated effect of a 100-pound mass reduction while maintaining footprint (90.5 per year).

3.8 Effect of mass reduction for drivers with BAC < .08 or with BAC = 0

The principal goal of NHTSA evaluations of vehicle safety is to estimate the societal effect on the entire public without excluding behavior-defined groups. However, analyses limited to drivers with blood alcohol concentration (BAC) < .08 (not impaired) or, alternatively, BAC = 0 could be considered sensitivity tests. Specifically, for these analysis, crash involvements on FARS where the driver's actual BAC or median of the ten imputed values of BAC was .08 or higher (or alternatively: .01 or higher) were deleted; the actual and imputed BAC values were obtained from FARS Alcohol Multiple Imputation Person (MIPER) files. No cases were deleted from the induced-exposure file, where BAC would usually be unreported for these mostly nonfatal crashes. For the same reason, BAC would also be an unsatisfactory control variable in regression analyses: BAC is usually unreported or said to be zero for the induced-exposure cases.

One effect may readily be predicted: Drinking drivers account for a large proportion of rollovers and impacts with fixed objects, where mass reduction is usually beneficial; excluding them should reduce the share of rollovers and fixed-object impacts in the baseline fatalities, and in turn the overall average effect of mass reduction should become more harmful. On the other hand, there are no obvious reasons why excluding the drinking drivers should affect the coefficients for the individual crash types. Table 3-11 compares the individual and overall mass effects for all drivers (on the left, copied from Table 3-5), for drivers with BAC < .08 (in the middle), and for drivers with BAC = 0 (on the right).

The "fatals after ESC" columns (i.e., the numbers of baseline fatalities that would have occurred if all vehicles had been ESC-equipped) indicate that close to half the rollovers and fixed-object impacts involved drivers with BAC ≥ .08. That is, the baseline fatalities for the drivers with BAC < .08 is about half as large as the "all drivers" baseline for these crash types. In all the other crash types, only about 10 percent of the drivers had BAC ≥ .08. Because rollover and fixed-object are generally associated with beneficial mass reduction across vehicle types, the overall effect of 100-pound mass reduction is generally more harmful for the drivers with BAC < .08 (e.g., a 2.17 percent fatality increase in cars < 3,197 pounds, as compared to a 1.49 percent increase for all drivers).

The estimated overall impacts of 100-pound mass reduction are notably larger for lighter passenger cars and heavier passenger cars when limiting the data to drivers with BAC < .08 or .01, versus applying the full dataset. For cars < 3,197 pounds, the estimated overall impact ranges from a 1.49 percent increase in fatalities under the full dataset to a 2.23 percent increase when restricting the analysis to drivers with BAC < .01. Similarly, for cars ≥ 3,197 pounds, the estimated overall impact ranges from a 0.50 percent increase under the full dataset to a 1.36 percent increase when limiting the analysis to drivers with BAC < .01.

The estimated overall impacts of 100-pound mass reduction are similar across the full dataset, the BAC < .08 dataset, and the BAC < .01 dataset for lighter LTVs (ranging from a 0.10 percent reduction in fatalities to a 0.30 percent increase), heavier LTVs (0.72 percent decrease to 0.91 percent decrease), and CUVs and minivans (0.93 percent decrease to 0.99 percent decrease).

The coefficients for individual crash types demonstrate limited directional change across the two alternative data sets. Of the 45 coefficients, 15 went in the direction of more harm (or less benefit) for mass reduction when the data were limited to drivers with BAC < .08. Among these coefficients, six changed from indicating societally beneficial mass reduction to societally harmful mass reduction between the base regressions and the corresponding regressions where the data were limited to drivers with BAC < .08 (first-event rollovers in the lighter passenger cars, lighter and heavier truck-based LTVs, collisions between the lighter cars, fixed-object collisions for the heavier cars, and collisions between CUVs and minivans and heavy vehicles).

Conversely, 10 coefficients went in the direction of more benefit (or less harm). Among these coefficients, two changed from indicating societally harmful mass reduction to societally beneficial mass reduction between the base regressions and the corresponding regressions where the data were limited to drivers with BAC < .08 (for collisions between the lighter LTVs, collisions between the heavier LTVs, and collisions between lighter LTVs and heavier LTVs). Restricting the analysis to cases where drivers with BAC < .01 resulted in stronger coefficients for first-event rollovers in the lighter passenger cars and lighter LTVs, and fixed-object collisions for the heavier cars and lighter LTVs.

The drivers with BAC < .08, whose crashes are relatively less often preceded by loss of control, may exhibit more strongly the trends associated with momentum considerations. This hypothesis is confirmed across changes in coefficients for: collisions between lighter cars and heavy vehicles; lighter LTVs and heavier cars; heavier LTVs and lighter cars and lighter LTVs; and CUVs and minivans and heavier LTVs. The crashes of drivers with BAC ≥ .08 are probably more often preceded by loss of control, even when they hit other vehicles rather than fixed objects; the benefit of the lighter vehicle being somewhat easier to control might, in these cases, be relatively more important than the momentum considerations.

TABLE 3-10: ALL DRIVERS VERSUS DRIVERS WITH BAC < .08 OR BAC = 0
ESTIMATED EFFECTS OF 100-POUND MASS REDUCTION WHILE HOLDING FOOTPRINT CONSTANT, BY VEHICLE CLASS AND CRASH TYPE

	ALL DRIVERS			DRIVERS WITH BAC < .08			DRIVERS WITH BAC = 0		
	FATALS AFTER	FATALITY INCREASE		FATALS AFTER	FATALITY INCREASE		FATALS AFTER	FATALITY INCREASE	
CRASH TYPE	ESC	N	%	ESC	N	%	ESC	N	%
				CARS < 3,197 POUNDS					
1st-EVENT ROLLOVER	133	-4	-2.96	66	-1	-1.61	56	-1	- .92
HIT FIXED OBJECT	791	-1	- .14	489	4	.80	424	4	1.06
HIT PEDESTRIAN/BIKE/MOTORCYCLE	759	17	2.26	702	21	3.01	674	19	2.82
HIT HEAVY VEHICLE	332	9	2.57	289	10	3.46	278	10	3.66
HIT CAR-CUV-MINIVAN < 3157	432	-6	-1.39	380	1	.17	361	1	.41
HIT CAR-CUV-MINIVAN 3157+	510	12	2.44	438	10	2.37	417	10	2.29
HIT TRUCK-BASED LTV < 4303	298	3	1.01	263	3	1.07	253	2	.85
HIT TRUCK-BASED LTV 4303+	393	11	2.78	351	10	2.72	338	9	2.63
ALL OTHERS	1,168	31	2.62	1,085	30	2.78	1,056	31	2.89
OVERALL	**4,815**	**72**	**1.49**	**4,063**	**88**	**2.17**	**3,857**	**86**	**2.23**
				CARS ≥ 3,197 POUNDS					
1st-EVENT ROLLOVER	152	-8	-5.42	80	-6	-6.89	65	-4	-6.10
HIT FIXED OBJECT	982	-7	- .70	551	5	.90	487	10	2.10
HIT PEDESTRIAN/BIKE/MOTORCYCLE	1,058	10	.97	960	15	1.59	924	12	1.27
HIT HEAVY VEHICLE	363	11	2.94	306	8	2.61	289	7	2.32
HIT CAR-CUV-MINIVAN < 3157	621	1	.12	548	5	.89	534	7	1.25
HIT CAR-CUV-MINIVAN 3157+	669	13	1.91	594	17	2.80	566	17	2.99
HIT TRUCK-BASED LTV < 4303	345	-4	-1.07	309	-5	-1.74	297	-5	-1.64
HIT TRUCK-BASED LTV 4303+	462	9	1.94	423	8	1.87	405	10	2.59
ALL OTHERS	1,665	7	.42	1,535	10	.62	1,490	15	1.02
OVERALL	**6,308**	**32**	**.50**	**5,306**	**56**	**1.05**	**5,057**	**69**	**1.36**

CRASH TYPE	ALL DRIVERS FATALS AFTER ESC	ALL DRIVERS FATALITY INCREASE N	ALL DRIVERS FATALITY INCREASE %	DRIVERS WITH BAC < .08 FATALS AFTER ESC	DRIVERS WITH BAC < .08 FATALITY INCREASE N	DRIVERS WITH BAC < .08 FATALITY INCREASE %	DRIVERS WITH BAC = 0 FATALS AFTER ESC	DRIVERS WITH BAC = 0 FATALITY INCREASE N	DRIVERS WITH BAC = 0 FATALITY INCREASE %
PICKUPS & TRUCK-BASED SUVs < 4,947 POUNDS									
1st-EVENT ROLLOVER	75	0	- .42	42	0	.54	38	1	1.58
HIT FIXED OBJECT	300	-6	-1.83	244	-3	-1.36	155	-1	- .84
HIT PEDESTRIAN/BIKE/MOTORCYCLE	553	-2	- .27	524	0	- .03	509	0	.06
HIT HEAVY VEHICLE	188	7	3.85	172	7	4.15	163	7	4.33
HIT CAR-CUV-MINIVAN < 3157	339	0	.03	306	0	.11	295	1	.25
HIT CAR-CUV-MINIVAN 3157+	326	-4	-1.23	288	-2	- .70	274	-2	- .62
HIT TRUCK-BASED LTV < 4303	165	-2	1.08	151	-2	-1.38	142	-2	-1.54
HIT TRUCK-BASED LTV 4303+	128	2	1.38	122	2	1.25	117	2	1.61
ALL OTHERS	729	1	.16	703	1	.13	679	2	.24
OVERALL	**2,803**	**-3**	**- .10**	**2,552**	**3**	**.10**	**2,372**	**7**	**.30**
PICKUPS & TRUCK-BASED SUVs ≥ 4,947 POUNDS									
1st-EVENT ROLLOVER	106	1	-1.36	60	0	.09	54	0	.22
HIT FIXED OBJECT	389	7	.69	213	2	.73	191	1	.62
HIT PEDESTRIAN/BIKE/MOTORCYCLE	718	-4	- .11	661	-2	- .32	637	-2	- .39
HIT HEAVY VEHICLE	229	4	.24	206	4	1.77	199	3	1.71
HIT CAR-CUV-MINIVAN < 3157	575	-13	- .96	520	-13	-2.46	509	-12	-2.26
HIT CAR-CUV-MINIVAN 3157+	556	-9	-1.43	509	-9	-1.74	499	-9	-1.75
HIT TRUCK-BASED LTV < 4303	285	-7	-1.02	255	-6	-2.32	250	-6	-2.42
HIT TRUCK-BASED LTV 4303+	259	-3	.48	234	-1	- .63	229	-1	- .52
ALL OTHERS	1,033	-6	- .16	959	-5	- .53	935	-7	- .72
OVERALL	**4,150**	**-30**	**- .72**	**3,617**	**-31**	**- .86**	**3,504**	**-32**	**- .91**

CRASH TYPE	ALL DRIVERS FATALS AFTER ESC	ALL DRIVERS FATALITY INCREASE N	ALL DRIVERS FATALITY INCREASE %	DRIVERS WITH BAC < .08 FATALS AFTER ESC	DRIVERS WITH BAC < .08 FATALITY INCREASE N	DRIVERS WITH BAC < .08 FATALITY INCREASE %	DRIVERS WITH BAC = 0 FATALS AFTER ESC	DRIVERS WITH BAC = 0 FATALITY INCREASE N	DRIVERS WITH BAC = 0 FATALITY INCREASE %
CUVs & MINIVANS									
1st-EVENT ROLLOVER	40	-3	-6.92	32	-2	-6.17	32	-2	-6.50
HIT FIXED OBJECT	277	-9	-3.70	192	-8	-3.95	177	-6	-3.58
HIT PEDESTRIAN/BIKE/MOTORCYCLE	654	-16	-1.64	621	-18	-2.91	606	-18	-2.92
HIT HEAVY VEHICLE	189	2	1.81	165	3	1.92	159	3	1.81
HIT CAR-CUV-MINIVAN < 3157	365	-1	- .17	354	0	- .14	347	-1	- .41
HIT CAR-CUV-MINIVAN 3157+	360	1	1.57	338	0	.07	333	0	- .02
HIT TRUCK-BASED LTV < 4303	161	3	3.76	143	4	2.61	142	4	2.62
HIT TRUCK-BASED LTV 4303+	210	2	-1.03	190	1	.51	187	1	.44
ALL OTHERS	970	-12	- .49	935	-9	-1.00	929	-6	- .71
OVERALL	**3,224**	**-32**	**- .99**	**2,970**	**-29**	**- .98**	**2,899**	**-27**	**- .93**

4. Sensitivity Analysis

4.0 Summary

NHTSA's baseline analysis, in addition to sampling error, has another source of uncertainty: the baseline statistical model can be varied by choosing different control variables or redefining the vehicle classes or crash types. That is, alternative models could produce different point estimates. To conclude the analysis in this report, NHTSA applied the set of 11 plausible alternative techniques (i.e., sensitivity analyses) that appeared in the 2012 report, which were developed based on peer-, public, and government reviews of the 2011 preliminary report.

The sensitivity analyses illustrate both the fragility and the robustness of the baseline estimates. On the one hand, the variation among the Volpe coefficients is large relative to the baseline estimate: a range of point estimates similar to the sampling-error confidence bounds of the baseline estimate. On the other hand, the variations are not large in absolute terms. In the alternative models, as in the baseline models, mass reduction tends to be relatively more harmful in the lighter vehicles, more beneficial in the heavier vehicles.

The societal effect of mass reduction remains small across the sensitivity analyses; a judicious combination of mass reductions that maintain footprint and are proportionately higher in the heavier vehicles is unlikely to have a societal effect large enough to be detected by statistical analyses of crash data.

4.1 Sensitivity analysis results

Chapter 3 of this report provides sampling-error confidence bounds for the baseline statistical model's point estimates of mass reduction: the statistical uncertainty that is a consequence of having less than a census of data. A further source of uncertainty in model estimates is that the baseline statistical model can be varied through alternative model specifications such as including different independent variables, redefining the vehicle classes or crash types, restricting the set of fatal incidents to meet preferred criteria or selecting alternative vehicle exposure data. Ultimately, alternative models produce different point estimates.

In the analysis reported in this section, NHTSA applied 11 techniques that appeared in the 2012 report. Each of the 11 techniques could be construed as sensitivity analyses of the baseline model, in that they share many features of the baseline model but differ in one or more terms or assumptions. The shared features are:

- Use of NHTSA's fatal-crash and induced-exposure databases, or subsets thereof.
- Regression analyses of societal fatalities per billion VMT, by case-vehicle mass, size (usually footprint but possibly track width and wheelbase), and control variables.
- Separate regressions for different types of case vehicles in different types of crashes (not necessarily the same definitions as baseline), and a weighted average of the effects in a post-ESC vehicle fleet.
- They generate five point estimates, one for each vehicle type, across all crash types after accounting for a vehicle fleet with complete adoption of ESC.

NHTSA has applied each of these 11 techniques to the updated databases created for this report to generate alternative point estimates as well as estimates of the annual effect on fatalities of removing 100 pounds from every vehicle, or removing different amounts of mass from the various vehicle types. The range of estimates produced by the sensitivity analyses gives an idea of the uncertainty inherent in the formulation of the models. The impact of various assumptions on specific results for certain vehicle or crash types provides insight on relationships between mass or size and fatality risk and on strengths and weaknesses of the modeling approach. However, in presenting this range, NHTSA adds the following caveats:

- The 11 alternatives are, of course, not an exhaustive list of conceivable alternatives. For example, Wenzel's sensitivity analysis includes a model in which the independent variables include the vehicle's purchase price and another model with the median owner income for each make and model.[62] Yet other techniques may be devised and they could extend the range in either direction.
- The 11 alternatives are inspired by the work of commenters on the 2011 preliminary report, but NHTSA's approach and detailed SAS code are not necessarily identical to theirs. For example, the tests that exclude drinking drivers originated with Wenzel, but NHTSA excludes all drivers with imputed BAC > 0, whereas Wenzel does not necessarily exclude them.
- The range of results is not to be interpreted like a histogram of a normal distribution, where each result has known probability of occurrence, with peak likelihood for the middle result and tailing off to both sides. Rather, the range of alternative models is presented to explore (through inspection) the sensitivity of the baseline regression results to changes in data used.
- The tables will show only point estimates for the alternative models. In fact, they too, like the baseline estimates, have sampling error (not computed – and not necessarily the same as the baseline). NHTSA has not attempted to define a "composite" of the sampling error and the variation of the point estimates.
- As stated above, the sensitivity analysis is limited to models that at least keep the framework of the baseline model (e.g., NHTSA's data, regression, fatalities per VMT).

Table 4-1 estimates the five Volpe coefficients for the baseline model (point estimates and confidence bounds) and the 11 alternative models (point estimates only) – ordered from the lowest to the highest estimated increase in societal risk per 100-pound reduction for cars weighing less than 3,197 pounds. The sources and definitions of the 11 alternative models are as follows:

1. Track width/wheelbase/stopped vehicles: Combines both analysis techniques recommended by Van Auken (2012d) – see next 2 alternative models.
2. With stopped-vehicle State data: Recommended by Van Auken (2012d); induced-exposure cases limited to vehicles that were standing still before the crash, allocating all the registration years and VMT only among these stopped-vehicle cases. NHTSA created a separate database limited to stopped-vehicle induced-exposure cases, ran the

[62] Wenzel (2012), Table ES.2, p. ix.

sensitivity analyses, and also made the data available to the public at http://www.nhtsa.gov/fuel-economy.

3. By track width and wheelbase: Recommended by Van Auken (2012d); with track width and wheelbase (and curb weight) as independent variables, but not footprint.
4. Without CY control variables: Wenzel (2011), pp. 39-46; baseline regressions but excluding all the CY control variables.
5. CUVs and minivans weighted according to 2010 sales: Recommended by Green in his peer review; CUV and minivan fatality cases and VMT reweighted to reflect relative market shares of CUVs and minivans sold in MY 2010 (i.e., more CUVs, fewer minivans than MY 2003-2010); only CUV/minivan result affected; other results, same as FRIA baseline, shown in *Italics*.
6. Without non-significant control variables: Recommended by Farmer in his peer review; for each of the 27 basic regression analyses, start with the baseline model and delete non-significant ($p > .05$) control variables one-by-one by backward selection.
7. Including muscle/police/AWD cars and full-size vans: Wenzel (2011), p. 48; car regressions include muscle, police, and AWD cars (which were excluded from the PRIA baseline regressions); LTV regressions include full-size vans; *CUV analysis not affected*.
8. Control for vehicle manufacturer: Wenzel (2011), pp. 38-39, modified as recommended by Chen and Kockelman in EPA (2012); baseline regressions with 15 additional control variables denoting the various manufacturers.

TABLE 4-1: BASELINE RESULTS, CONFIDENCE BOUNDS, AND 11 ALTERNATIVE MODELS
Based on Regressions of Societal Fatality Risk per VMT - MY 2003-2010 Cars and LTVs in CY 2005-2011
Fatality Increase (%) Per 100-Pound Mass Reduction While Holding Footprint* Constant

		Cars < 3,197 lbs	Cars ≥ 3,197 lbs	CUVs & Minivans	LTVs† < 4,947 lbs	LTVs† ≥ 4,947 lbs
TAR baseline estimate‡		**1.49**	**.50**	**- .99**	**- .10**	**- .72**
95% confidence bounds	Lower:	- .30	- .59	- 2.17	- 1.08	- 1.45
(sampling error)	Upper:	3.27	1.60	.19	.88	.02
ELEVEN ALTERNATIVE MODELS						
1. W/O CY control variables		.53	.10	- 1.13	- *.10*	- .53
2. Track width/wheelbase/stopped veh		.88	- .43	- .66	- .85	- 2.14
3. By track width & wheelbase		.92	.48	- 1.15	- .66	- .97
4. Incl. muscle/police/AWD/big van		1.44	.63	- *.99*	- .05	- .94
5. W/O non-significant control vars		1.47	.54	- .84	- .13	- .70
6. CUVs/minivans weighted 2010 sales		*1.49*	*.50*	- .27	- *.10*	- *.72*
7. With stopped-vehicle State data		1.58	- .43	- .61	- .07	- 1.80
8. Limited to drivers with BAC=0		2.22	1.38	- .92	.31	- .91
9. Control for vehicle manufacturer		2.39	1.37	zero	.32	- .09
10. Control for veh manuf/nameplate		2.65	2.96	- .43	.30	zero
11. Limited to good drivers		2.82	1.86	- .97	.37	- .62

*While holding track width and wheelbase constant in alternative model nos. 2 and 3.
†Excluding CUVs and minivans.
‡Point estimates and confidence bounds from Table 3-5.

9. Control for vehicle manufacturer and nameplate: Wenzel (2011), pp. 38-39, modified as recommended by Chen and Kockelman in EPA (2012); baseline regressions with 20 additional control variables denoting the various manufacturers (treating 5 luxury nameplates as if they were separate "manufacturers").
10. Limited to drivers with BAC=0: Recommended by Green in his peer review of the 2010 report, also Table 3-14 of this report; fatal crash cases limited to case-vehicle drivers with tested or imputed BAC < .01; VMT data same as baseline.
11. Limited to good drivers: Wenzel (2011), pp. 46-47, modified by also excluding imputed BAC ≥ .01; see also Kahane (2003), p. 94; excludes fatal crash cases with BAC > 0, drugs, non-valid license, reckless driving in this crash, and/or history of

multiple crashes or multiple violations during the past 3 years; VMT data same as baseline.

For cars < 3,197 pounds, there are an equal number of models with estimated effects of 100-pound mass reduction above and below the baseline value, a 1.49 percent increase in societal fatalities. The estimates range from a relatively small increase of 0.53 percent in the first alternative model up to a 2.82 percent increase in the last model, nearly double the baseline effect. Each of the 11 alternative point estimates for cars < 3,197 pounds is within the range of the 95% sampling-error confidence bounds for the baseline estimate: -0.30 to 3.27 percent.

As a general rule, in the alternative models, as in the baseline models, mass reduction tends to be relatively more harmful in the lighter vehicles, more beneficial in the heavier vehicles. Thus, in all models, the point estimate is positive for cars < 3,197 pounds, and in all models except one, it is negative for LTVs ≥ 4,947 pounds.

The models were listed, as stated above, in the order of their point estimates for cars < 3,197 pounds, from least positive to most positive. As a general rule, within each of the other four vehicle classes, there is also a tendency for the more negative (or less positive) coefficients to be near the top of Table 4-1 and the more positive (or less negative) to be lower in the table.

But here are some exceptions to the general rules of "more positive down the table" and "more negative towards the right of the table." Section 4.3 will discuss them as part of a more in-depth look at the various analysis techniques:

- Using stopped-vehicle instead of induced-exposure cases along with splitting footprint into track width and wheelbase (model 2) lowers the Volpe coefficients for all vehicle classes relative to the baseline model, with the largest effects for cars ≥ 3,197 pounds (reduction of 0.97 percentage point), truck-based LTVs < 4,947 pounds (reduction of 0.75 percentage point) and LTVs ≥ 4,947 pounds (reduction of 1.42 percentage points).
- Using induced-exposure cases while splitting footprint into track width and wheelbase (model 3) lowers the Volpe coefficients for truck-based LTVs < 4,947 pounds by 0.56 percentage point and LTVs ≥ 4,947 pounds by 0.25 percentage point, without the effect on heavier passenger cars observed in model 2.
- Using stopped-vehicle cases with footprint (model 7) lowers the Volpe coefficients for cars ≥ 3,197 pounds by 0.97 percentage point and LTVs ≥ 4,947 pounds by 1.08 percentage point, with a smaller effect on CUVs and minivans (reduction of 0.38 percentage point) and minimal effects on lighter passenger cars and lighter LTVs.
- The results for CUVs and minivans are generally less sensitive than other vehicle classes, with the exceptions of re-weighting by CUV sales (model 6), including manufacturer and nameplate variables (models 9 and 10), and using stopped-vehicle cases (models 2 and 7).

TABLE 4-2: ESTIMATED ANNUAL EFFECT OF MASS REDUCTION IN ALL VEHICLES (Average: 100 Pounds)
Baseline Results, Confidence Bounds, and 11 Alternative Models
Based on Regressions of Societal Fatality Risk per VMT - MY 2003-2010 Cars and LTVs in CY 2005-2011
Fatality Increase (N and % of annual fatalities) While Holding Footprint* Constant

MASS REDUCTION SCENARIO (Pounds Removed From Each Vehicle Class)

	Scenario 1 (Safety-Neutral)	Scenario 2 (Proportional)	Scenario 3 (100 Pounds)
Cars < 3,197 lbs	50	71	100
Cars ≥ 3,197 lbs	93	90	100
CUVs & Minivans	104	100	100
LTVs† < 4,947 lbs	114	109	100
LTVs† ≥ 4,947 lbs	180	143	100
Fleet-wide average	100	100	100

ANNUAL FATALITY INCREASE (N and % of 24,791 Baseline Fatalities‡)

	N	%	N	%	N	%
TAR baseline estimate	**Z E R O**		**37**	**.15**	**91**	**.37**
ELEVEN ALTERNATIVE MODELS						
1. W/O CY control variables	- 45	- .18	- 22	- .09	9	.04
2. Track width/wheelbase/stopped veh	- 291	- 1.17	- 229	- .92	- 160	- .65
3. By track width & wheelbase	- 88	- .35	- 55	- .22	- 7	- .03
4. Incl. muscle/police/AWD/big van	- 20	- .08	20	.08	80	.32
5. W/O non-significant control vars	5	.02	41	.17	96	.39
6. CUVs/minivans weighted 2010 sales	47	.19	81	.33	135	.54
7. With stopped-vehicle State data	- 184	- .74	- 120	- .48	- 44	- .18
8. Limited to drivers with BAC=0	64	.40	90	.56	134	.84
9. Control for vehicle manufacturer	231	.93	266	1.07	334	1.35
10. Control for vehicle manuf/nameplate	359	1.45	392	1.58	477	1.92
11. Limited to good drivers	78	.61	100	.78	138	1.08

*While holding track width and wheelbase constant in alternative model nos. 2 and 3.
†Excluding CUVs and minivans.
‡There is an average of 24,791 annual fatalities in 2007-2011 in crashes involving at least one car or LTV, adjusted downward for a future all-ESC fleet; different baselines are used for computing percentages in alternative model nos. 8 and 11, namely 16,030 in model 8 (annual fatalities in crashes involving drivers with BAC = 0) and 12,816 in model 11 (annual fatalities in crashes involving good drivers).

Table 4-2 estimates the net annual effect on fatalities for the baseline model and the 11 alternative models for three scenarios that remove an average of 100 pounds from vehicles while holding footprint constant. The alternative models are listed in the same order as in Table 4-1.

The three scenarios are described in Section 3.6. Scenario 1 is exactly safety-neutral, as a point estimate, in the baseline model: some mass is removed in all vehicles, but disproportionately more in the heavier vehicles. Scenario 2 is a proportional 2.55% mass reduction, averaging out to 100 pounds over all vehicles, but in absolute terms somewhat higher in the heavier vehicles. Scenario 3 consists of simply removing 100 pounds from all vehicles while holding footprint constant.

Scenario 1 – judicious mass reduction (more in the heavier vehicles) that is exactly safety-neutral as a point estimate with the baseline model – generates estimates ranging from an annual savings of 291 lives to an increase of 359 fatalities with the 11 alternative models. Even these extremes are less than two percent of annual fatalities in crashes involving cars and LTVs (estimated to be 24,791 per year for an all-ESC fleet); the estimates are absolute numbers that would be difficult to detect by statistical methods, as annual fatalities in the United States typically vary by several hundred or more from year to year.[63] In other words, the sensitivity analyses supplement the estimates of sampling error (Section 3.5) in demonstrating that the statistical analyses cannot estimate the effect of mass reduction exactly.

At the same time, the relatively narrow range of the sensitivity analyses is quite compatible with this report's conclusion that "the societal effect of mass reduction while maintaining footprint, if any, is small." Specifically, the range, at least in these sensitivity analyses, is much smaller than the range of some estimates in analyses of earlier databases, such as a reduction of 1,518 fatalities[64] or an increase of 1,118.[65]

Under Scenario 1, five sensitivity analyses generate point estimates of a societal benefit for judicious mass reduction, two analyses show a negligible increase (0.19% or less) and the baseline analysis is safety-neutral. Only two analyses estimate a net increase of 100 or more fatalities under Scenario 1: controlling for manufacturer and controlling for nameplate, both of which affect all five Volpe coefficients in the direction of more harm/less benefit for mass reduction.

4.2 Discussion of individual sensitivity analyses

NHTSA believes each of the 11 sensitivity analyses in Tables 4-1 and 4-2 is plausible enough to serve as an alternative estimate for the purpose of assessing the uncertainty of the baseline results and to shed additional light on the relationships between societal fatality risk, vehicle mass, and size. However, the agency does not see a compelling reason that any of them should supersede the technique of Chapter 3 as the baseline analysis and the principal estimate. A discussion of

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[63] NHTSA (2016). *Traffic Safety Facts 2014.* Report No. DOT HS 812 261. Washington, DC: National Highway Traffic Safety Administration, Table 1, p. 16, http://www-nrd.nhtsa.dot.gov/Pubs/812261.pdf.

[64] Van Auken and Zellner (2005b), for a 100-pound mass reduction while holding track width and wheelbase constant, sum of 836 for passenger cars (Table 2, p. 27) and 682 for LTVs (Table 5, p. 36).

[65] Kahane (2003), for 100-pound downsizing, sum of 71 and 234 on p. ix, 216 and 597 on p. xi.

the salient features, strengths, and disadvantages of the alternative models, reprising some background from the 2012 report for reader convenience, follows.

Without CY control variables:

	Cars < 3,197 lbs	Cars ≥ 3,197 lbs	CUVs & Minivans	LTVs < 4,947 lbs	LTVs ≥ 4,947 lbs
Baseline	1.49	.50	- .99	- .10	- .72
W/O CY control variables	.53	.10	- 1.13	- .10	- 1.45

Alert to opportunities to reduce the number of independent variables in the models, Wenzel sensitivity-tested and discussed a model without the six CY control variables.[66] There is little to add here, except to perform the same analysis with the latest data. The CY variables will have a statistically meaningful impact if structural changes in relationships not represented directly by the data exist across years in the sample (e.g., variations in annual fatality risk due to transient shocks to travel demand. Examples of factors leading to variation in fatality risk over time include:

- General improvement in road safety unrelated to changes in vehicle characteristics
- Exceptional year-to-year changes in overall fatality risk due to transient phenomena, such as energy crises, fuel-price increases and economic slowdowns
- A change in the fleet of potential partner vehicle for crashes, such as an increase in the mass of light trucks that are crash partners for case vehicles in the sample
- A gradual secular change in annual VMT per vehicle that is, however, not reflected in the unchanging annual-VMT estimates (Table 2-3).

Both conditions are present: as discussed in Section 1.3, four out of five vehicle classes gained mass and footprint from MY 2003 to 2010, with increases in average mass of up to nine percent and increases in average footprint of up to seven percent. Fatality rates per VMT generally dropped from CY 2005 to 2011 due to a variety of driver, environmental, and vehicle factors not explicitly included as control variables in the model. Critically, annual fatalities decreased by around nine percent from 2007 to 2008 (from 37,435 to 34,172) and by around ten percent from 2008 to 2009 (to 30,862) before holding steady at around 30,000-31,000 per year from 2009-2011[67]. The decrease in annual fatalities over that period corresponded with decreases in both new vehicle registrations (i.e., registrations of MY *t* vehicles in CYs *t* and *t+1*)[68] and national VMT[69] that represented distinct outcomes to all previous years in the database. Thus, omitting CY variables would force changes in fatality rates during CY 2008 and later to influence the coefficients of the remaining independent variables under an erroneous assumption that all

[66] Wenzel (2011), pp. 39-46.
[67] Fatality Analysis Reporting System, National Statistics, http://www-fars.nhtsa.dot.gov/Main/index.aspx.
[68] NVPP vehicle registration data (represented in the induced exposure database as the registration weight *REGWTFA*).
[69] St. Louis Federal Reserve Bank, Moving 12-Month Average of Total Vehicle Miles Traveled, https://research.stlouisfed.org/fred2/series/M12MTVUSM227NFWA.

unobserved factors had constant effects across the entire sample. Ultimately, the impacts of the economic downturn on travel demand were considerable enough that CY variables for 2008 and later are likely to capture meaningful structural shocks that make an alternative model without CY variables difficult to prefer to the baseline model.

Table 4-1 (model 1) shows that the Volpe coefficients changed the most for vehicles with curb weights away from the overall median (i.e., cars and heavier LTVs). This indicates that the presence of CY variables mitigates the potential of the regression to allocate the effects of broader trends in fatality risk to the coefficients on curb weight and footprint. Although the results are interesting from the perspective of a sensitivity analysis, the removal of CY variables decreases the explanatory power of the model by ignoring known general vehicle safety relationships. Thus, omitting the CY variables leads to downward trends in fatality risk appearing in either the central policy variables or the unobserved effects in the model (i.e., the error term).

Induced-exposure crashes limited to stopped vehicles; track width and wheelbase rather than footprint; or both:

	Cars < 3,197 lbs	Cars ≥ 3,197 lbs	CUVs & Minivans	LTVs < 4,947 lbs	LTVs ≥ 4,947 lbs
Baseline	1.49	.50	- .99	- .10	- .72
Track width/wheelbase/ stopped-vehicle	.88	- .43	- .66	- .85	- 2.14
By track width & wheelbase	.92	.48	- 1.15	- .66	- .97
Stopped-vehicle	1.58	- .43	- .61	- .07	- 1.80

The sensitivity analyses include three related models that incorporate one or both of the following proposed alternative specifications: restricting the set of induced-exposure cases to those where the case vehicle was not moving at the time of the incident, and separating footprint into its component parts of track width and wheelbase. NHTSA's 1997 report on vehicle size and fatality risk defined induced-exposure crash involvements as "vehicles that had been standing still for some time, for a legitimate reason, and got hit by somebody else. The vehicle should have done nothing to precipitate or contribute to the collision."[70] That is a subset of the involvements more commonly defined as induced exposure, namely all non-culpable vehicles in two-vehicle collisions, regardless of whether they were standing still or moving.

There had been early studies that limited induced exposure to standing vehicles, but it was no longer the usual technique.[71] The NAS peer review panel, including D.W. Reinfurt, exposure-data expert, criticized NHTSA's approach: "The [1997] Kahane report does not provide sufficient evidence that the induced exposure group of stopped-vehicle crashes is a suitable

[70] Kahane (1997), p. 20.
[71] Haight, F.A. (1973). "Induced Exposure," *Accident Analysis and Prevention*, Vol. 5, pp. 111-126.

surrogate for the vehicle fleet and driving population on the same highways as the fatal crashes."[72]

Van Auken and Zellner's earlier analyses also limited induced exposure to stopped vehicles.[73] However, NHTSA in its 2003 report returned to the "customary approach" of non-culpable vehicles, "whose efficacy is well established."[74] Reinfurt, again a peer reviewer, noted in 2003 that "Induced exposure using the traditional approach of utilizing non-culpable vehicles (drivers) in two vehicle crashes is a large improvement over the 1997 study."[75]

Van Auken subsequently used both methods and found that, given otherwise identical techniques, the regressions on the databases with stopped-vehicle induced exposure usually estimated less harm/more benefit for mass reduction than the other method.[76] Van Auken and Zellner acknowledge disadvantages of limiting to stopped vehicles, namely: losing approximately ¾ of the crash cases, even more on high-speed roads and in rural areas, and less acceptance by experts than the other method. However, Van Auken and Zellner argue that limiting to stopped vehicles may have a special offsetting benefit in studies of vehicle size and fatality risk:

> "Non-culpable vehicle induced-exposure data can include crashes where the non-culpable vehicle was moving prior to the crash. Therefore, some drivers may be more likely to be involved in these crashes than other drivers, even if the driver is not culpable in the crash. This is because some drivers may be able to avoid a crash in which they are not culpable…due to driver skill, driver alertness and/or ability to properly react in time to avoid a collision…This under-representation in the non-culpable induced-exposure data of good drivers, and over-representation of bad drivers is undesirable…A potential advantage of the stopped-vehicle induced exposure is that it is assumed to be not sensitive to the ability of the driver or vehicle to avoid the crash. This is because the vehicle is stopped and presumably would not have been able to avoid the crash. Therefore this data captures a representative sample of drivers for a given make-model-year vehicle."[77]

Note that the aggregate denominator for societal fatality rates – vehicle registration years and VMT – will not be affected by the choice of induced exposure. A nimble vehicle with low rates of non-culpable crashes will still have the same vehicle years and VMT; it will just allocate these VMT among a smaller number of induced-exposure crash cases. In a regression model without any control variables derived from induced exposure (such as driver age or urbanization), point estimates for the effects of curb weight and footprint will be exactly the same with non-culpable or stopped-vehicle induced exposure. Results will differ only to the extent that the choice of induced exposure changes the distribution of control variables – and then, only if the changes are

[72] NAS (1996). Peer-review letter from D. Warner North to Ricardo Martinez, NHTSA, July 12, 1996, Appendix B. Washington, DC: National Research Council.
[73] Van Auken & Zellner (2003); Van Auken & Zellner (2005a); Van Auken & Zellner (2005b).
[74] Kahane (2003), p. 31.
[75] NHTSA (2003). *Memorandum: Drs. James H. Hedlund, Adrian K. Lund and Donald W. Reinfurt's Reviews and Comments of the Draft Technical Report*. (Docket No. NHTSA-2003-16318-0004). Washington, DC: National Highway Traffic Safety Administration.
[76] Van Auken and Zellner (2012a).
[77] Van Auken and Zellner (2012d), pp. 20-21.

different for some makes and models than others. That said, there is evidence to support Van Auken's argument: Specifically, the stopped-vehicle subset has a higher proportion of drivers in the 30-50 age range (the most skilled group) and lower proportions of young (inexperienced) and old (often less skilled) drivers than the full non-culpable set.

Van Auken and Zellner's earlier analyses include three size-mass variables: curb weight, track width, and wheelbase.[78] Van Auken's analyses of the MY 2000-2007 database used both sets of size-mass variables and found that, given otherwise identical techniques, the regressions with track width and wheelbase usually estimated less harm/more benefit for mass reduction than regressions with footprint.[79] Van Auken suggests that track width and wheelbase are meaningful as separate variables because each has its own natural, physical relationships with certain aspects of crash-proneness and crashworthiness.[80] Some of these natural, cause-and-effect interactions could be lost to the analysis with the more synthetic variable, footprint. Furthermore, if VIF is no greater with the three mass-size variables than with just mass and footprint, there is little added risk of multicollinearity issues.

NHTSA finds that argument sufficiently convincing, at least in theory, to include analyses with track width and wheelbase in this report. It is also true that VIF (measured as the maximum for any of the independent variables in the basic regressions, when curb weight, driver age and CY are entered as simple linear variables) is about the same for track width-wheelbase as for footprint.

The sensitivity analyses in models 2, 3 and 7 examined the stopped vehicle and split footprint alternatives to re-evaluate the limitations of the alternatives that were raised in the 2012 report, to confirm whether the limitations still apply. The primary limitations of the stopped vehicle model raised in the 2012 report that apply to the data in this report are:

- Restricting the analysis to stopped vehicles results in a serious loss of sample size;
- There is uncertainty with respect to the degree to which the distribution of exposure by driver age in the stopped vehicle cases is consistent with the actual distribution of exposure by driver age;
- The stopped vehicle cases underrepresent exposure: on roads with speed limits 55 miles per hour or above; and on rural roads; and
- Comments from previous (1999 and 2003) peer review support the use of the baseline model over the stopped vehicle model.

Restricting the analysis to stopped vehicles results in a loss of approximately three-fourths of observations in the sample; estimates calibrated with respect to a restricted sample size are subject to greater uncertainty (i.e., larger confidence bounds) than those calibrated with respect to a larger set of data. The stopped vehicle database includes 670,230 observations, which is a

[78] Van Auken & Zellner (2003); Van Auken & Zellner (2005a); Van Auken & Zellner (2005b).
[79] Van Auken and Zellner (2012d), pp. 7-18.
[80] Van Auken and Zellner (2005b), pp. 10-21.

large dataset by general standards. However, driver-, crash- and vehicle-specific factors explain such a large share of variability in fatality rates that it is preferable to preserve sample size in an effort to estimate effects specific to curb weight and vehicle size, all else being equal.

Consistent with the 2012 report, the stopped vehicle data in the 2016 report represent drivers with ages associated with lower risk (i.e., drivers between 30 and 60 years of age) at a higher rate than the non-culpable data, and conversely represent drivers with ages associated with higher risk (chiefly, drivers below the age of 30) at a lower rate than the non-culpable data. There is no single definitive dataset that is capable of confirming the actual distribution of vehicle travel by driver age, but Kahane's (2012) analysis of the two most recent National Household Transportation Surveys (NHTS) offers important insight.

Table 4-3 displays the share of VMT for each of five age groups defined in the NHTS of 2001 and 2009. The NHTS asks drivers how many miles they drive in a year and averages this by age group. These annual-VMT rates are multiplied by the number of licensed drivers to find the total VMT for that age group. The 2001 NHTS rates are multiplied by the 2000 N of licensed drivers, while the 2009 NHTS rates are multiplied by the 2009 N of licensed drivers; the two sets of totals are averaged to obtain an average for the 2000-2009 decade.[81] Table 4-3 also shows the age-group distribution of VMT for MY 2003-2010 cars and LTVs in CY 2005-2011, when the VMT are allocated according to the non-culpable- and according to the stopped-vehicle induced-exposure cases:

TABLE 4-3: VMT DISTRIBUTION (%) BY DRIVER AGE GROUP
NHTS VERSUS TWO ESTIMATES BASED ON INDUCED EXPOSURE

Age Group	2000-2009 Average NHTS VMT/Year x N of Drivers	Induced Exposure (MY 2003-10 in CY 2005-11) Non-Culpable	Stopped-Vehicle
19 or younger	2.54	4.57	3.80
20-34	29.35	30.47	29.27
35-54	45.63	42.32	44.80
55-64	13.42	13.58	13.93
65 or older	9.05	9.06	8.10

The 2001 and 2009 NHTS, which roughly cover the temporal interval contained in the databases, indicate travel volumes for older drivers (from 55 to 64, and 65 or older) that are very close to the corresponding volumes in the baseline data, but are at least somewhat distinct to the corresponding values in the stopped vehicle data. Conversely, the NHTS data indicate travel volumes for younger drivers (from 20 to 34, and from 35 to 54) that are closer to the corresponding volumes in the stopped vehicle data. Lastly, both the baseline data and the

[81] 2001 and 2009 NHTS average miles per licensed driver, by age group: http://nhts.ornl.gov/2009/pub/stt.pdf, Table 23, p. 43; N of licensed drivers by age group in 2000: http://www.fhwa.dot.gov/ohim/onh00/bar7.htm; N of licensed drivers by age group in 2009: http://www.fhwa.dot.gov/policyinformation/statistics/2009/dl20.cfm.

stopped vehicle data indicate larger shares of the youngest drivers than the NHTS. Ultimately, the comparison with the NHTS data does not confirm a tendency for either the baseline or the stopped vehicle data to represent vehicle exposure by driver age more closely to external estimates of vehicle exposure by driver age.

Similarly, as in the 2012 report, the stopped vehicle data include a smaller share of exposure: on roads with speed limits of 55 miles per hour or above; and on rural roads. FHWA's *Highway Statistics 2012* indicates that travel on interstates and other freeways and expressways (i.e., roadways with speed limits generally 55 miles per hour or above) comprised 24.7 percent of national VMT in 2012[82]; this estimate does not include any additional high-speed-limit roads categorized as principal arterials. Both the baseline and stopped vehicle databases yield smaller shares of VMT on roads with speed limits of 55 or above relative to the share VMT on interstates and other freeways and expressways, but the baseline data include a much higher share of VMT on roads with speed limits of 55 or above (17.5 percent versus 12.7 percent). Similarly, rural VMT comprised 31.2 percent of national VMT in 2011[83]. Both the baseline and stopped vehicle databases understate the share of rural VMT, but the baseline data include a higher share of rural VMT than the stopped vehicle data (21.4 percent versus 19.8 percent).

However, the non-culpable data are constrained by the relative accuracy of police identification of at-fault drivers or of factors that can help classify drivers as at-fault. If the non-culpable cases actually include a sufficient share of culpable cases, the data would not meaningfully represent baseline risk. Hence, the findings of analysis calibrated with respect to the non-culpable data are strictly conditional on the validity of the assignment of culpability. Peer review of the preliminary version of the 2012 report indicated two conflicting views: (1) that stopped vehicle data under-represent risky drivers because risky drivers do not stay stopped long enough to be involved in collisions; and (2) that non-culpable vehicle data over-represent drivers because safe drivers avoid incidents more frequently. It is not clear whether the non-culpable vehicle sample or the stopped vehicle sample better represents the overall distribution of drivers and vehicles on the nation's roadways, and therefore which sample is more appropriate to use to create the induced exposure records. Peer review comments also suggested that a suitable representation of induced exposure would involve distributions of VMT by vehicle-, crash- and driver-specific factors that represent the population of drivers and vehicles on the road at any given time.

Ultimately, NHTSA chose to apply the peer-reviewed approach from the 2011 and 2012 reports in this update. As additional evidence is reviewed, NHTSA will continue to assess its approach to the use of induced exposure data in future analyses.

[82] Federal Highway Administration (ND). Table VM-2, Functional System Travel – 2012: Annual Vehicle-Miles, http://www.fhwa.dot.gov/policyinformation/statistics/2012/pdf/vm2.pdf.
[83] Federal Highway Administration (ND). Table VM-1, Annual Vehicle Distance Traveled in Miles and Related Data – 2012: By Highway Category and Vehicle Type, http://www.fhwa.dot.gov/policyinformation/statistics/2012/pdf/vm1.pdf.

The limitations of the split footprint model raised in the 2012 report that apply to the data in the 2016 report are:

- Track width and wheelbase are generally highly correlated with one another and with curb weight for the range of vehicles in the analysis, raising the threat of multicollinearity;

- The CAFE model is footprint-based, and hence working directly with footprint is preferable to decomposing it; and

- While the estimated relationship between track width and fatality risk in certain types of crashes is consistent with crash physics, the relationship between wheelbase and fatality risk is not.

The threat of multicollinearity can be evaluated in a direct manner by comparing correlations among model inputs. Multicollinearity is a significant concern even in the baseline model, through strong correlations between curb weight and footprint; correlations within vehicle classes range from around 0.73 to 0.89, (with the exceptions of correlations of around 0.24 for large pickups and 0.49 for minivans when examined separately from other LTVs and CUVs, respectively).

Critically, for all vehicle classes in the analysis, curb weight is correlated either nearly as high or higher with track width as with footprint. Track width and wheelbase are also highly correlated with one another (ranging from around 0.64 to 0.80, with the exceptions of smaller correlations for large pickups and minivans). Viewed from another angle, wheelbase is almost perfectly correlated with footprint (with correlations ranging from around 0.95 to 0.97).

Considered in concert, the split footprint model essentially incorporates the full correlation issues from the baseline model (curb weight highly correlated with another independent variable) and adds a further correlation issue (the variable that is highly correlated with curb weight is also highly correlated with a separate independent variable).

Table 4-1 shows that regression with track width and wheelbase (model 3) reduces the Volpe coefficients for all vehicle classes. The coefficients for heavier LTVs and cars reveal the largest impacts (reductions of 1.42 percentage points and 0.93 percentage point, respectively); lighter LTVs and cars also reveal strong impacts (reductions of 0.75 and 0.61 percentage point, respectively).

Conversely, Table 4-1 indicates that the impact of limiting induced exposure to stopped vehicles (model 7) is chiefly limited to heavier LTVs and cars. The Volpe coefficients in model 7 are 1.08 percentage points and 0.93 percentage point lower in model 7 than in the baseline model. The corresponding impact on the coefficient for CUVs and minivans is a 0.38 percentage point reduction, while the coefficients for lighter cars and LTVs differ from the baseline by less than 0.10 percentage point.

Combining the use of stopped-vehicle cases and separating footprint into track width and wheelbase (model 3) yields a unique set of effects. The coefficients for lighter cars and LTVs yield similar implications as in model 2, with reductions greater than one-half percentage point. The effects on coefficients for the other three vehicle classes are unique relative to models 2 and 7, however. In model 3, the coefficient for heavier cars is essentially unchanged from the baseline model, while the coefficient for CUVs and minivans decreases by 0.16 percentage point (one of only two alternative models in which this coefficient decreases relative to the baseline). Similarly, the coefficient for heavier LTVs is much closer to the baseline than in models 2 and 7 (reduction of 0.25 percentage point).

NHTSA considers the stopped-vehicle and separated footprint approaches to be plausible alternative models, useful for illustrating the uncertainty of the baseline results. However, given the obvious problems with stopped vehicles (loss of ¾ of the cases, even more on high-speed roads, and lack of endorsement from researchers), NHTSA does not believe they should supersede the baseline analysis. The database of stopped vehicles as well as a corresponding set of fatal crashes is available to the public at http://www.nhtsa.gov/fuel-economy. Likewise, NHTSA does not support the preference of a model with two correlated independent variables representing vehicle size when a single variable (footprint) tracks the two variables closely. The ability of the model to tease out separate, representative effects for three highly correlated variables is questionable; what may appear to be a distinct effect once two dimensions of vehicle size are accounted for may in fact be an artifact of unfortunate statistical properties.

Including muscle/police/AWD cars and full-size vans:

	Cars < 3,197 lbs	Cars ≥ 3,197 lbs	CUVs & Minivans	LTVs < 4,947 lbs	LTVs ≥ 4,947 lbs
Baseline	1.49	.50	- .99	- .10	- .72
W. muscle/police/AWD/big van	1.44	.63		- .05	- .94

Wenzel tested a model whose regressions include every vehicle in the database, rather than excluding certain niche vehicles, as in the baseline model: muscle cars, police, and AWD cars and full-size vans.[84] The CUV/minivan regressions stay the same. Categorical variables are added to the car and LTV regressions to denote the niche vehicles: police car and muscle car in the car regressions, as well as the AWD variable; cargo van and passenger van in the LTV regressions.

Table 4-1 (model 4) indicates relatively small deviations from the baseline. The largest impact in model 4 is for the Volpe coefficient for LTVs ≥ 4,947 pounds (reduction of 0.22 percentage point). The Volpe coefficients for cars < 3,197 pounds and LTVs < 4,947 pounds only differ by 0.05 percentage point relative to the baseline model, while the coefficient for cars ≥ 3,197 pounds is 0.13 percentage point larger than in the baseline model.

This alternative model, with its plus of using every vehicle case in the databases, may be one of the most viable substitutes for the baseline model. Furthermore, the absolute impact across the set of model coefficients is relatively small. Nevertheless, NHTSA believes including small

84 Wenzel (2011), p. 48.

groups of vehicles that have distinct pattern of crash types and of relationships with mass and footprint may distort how the regression allocates effects between mass and footprint. This approach may generate coefficients for mass and footprint that, at least to some extent, reflect how the vehicle mix varies for different mass-footprint combinations rather than the underlying relationships of mass and footprint with fatality risk. There is a trade-off between inclusiveness and uniformity in the data. NHTSA's 2010 report, for example, considered various subsets of cars and found that economy- and sporty 2-door cars could be included with 4-door cars without much change in the coefficients for curb weight and footprint (or curb weight, track width, and wheelbase), but that including muscle cars substantially altered the coefficients.[85]

Without non-significant control variables:

	Cars < 3,197 lbs	Cars ≥ 3,197 lbs	CUVs & Minivans	LTVs < 4,947 lbs	LTVs ≥ 4,947 lbs
Baseline	1.49	.50	- .99	- .10	- .72
W/O non-sig control vars	1.47	.54	- .84	- .13	- .70

In his peer review, Farmer worries that the baseline model may be "overspecified" by having too many covariates (i.e., control variables, namely independent variables other than curb weight and footprint). Farmer recommends examining the sensitivity of the model to deleting some control variables.[86] A possible approach is to delete non-significant ($p > .05$) control variables one-by-one by backward selection. In other words, for each of the 27 basic regression analyses, start with the baseline model and allow the LOGISTIC procedure in SAS to identify the control variable with the smallest Wald chi-square, run a new regression excluding that variable, and repeat the procedure until all control variables have Wald chi-square ≥ 3.84. Throughout the procedure, the curb-weight and footprint variables are not candidates for deletion and stay in every regression.

The nine baseline regressions for passenger cars usually include 27 control variables (but only 25 for rollovers and 24 for pedestrian crashes, as some or all side-air-bag variables are dropped). The procedure deletes as few as 5 or as many as 13 of these variables from the various regressions. The LTV regressions all begin with 27 control variables; between 5 and 13 drop out. The CUV/minivan regressions begin with 25 to 28 control variables and delete 8 to 18. In many cases, the procedure deletes some of the six CY variables or the eight driver-age variables, while retaining others.

Table 4-1 (model 5) shows that deleting non-significant control variables has negligible impact on the Volpe coefficients. Only the coefficient for CUVs and minivans changes by more than 0.04 percentage point. This test helps to show that logistic regression estimates for central policy variables are not perturbed by large numbers of basically orthogonal control variables. If covariates are of little importance, the regression essentially ignores them by assigning them small coefficients, with minimal impact on the coefficients for the other variables. This

[85] Kahane (2010), p. 482-490.
[86] Docket No. NHTSA-2010-0152-0036.

relationship is in stark contrast to the general concern over the inclusion of two or more nearly collinear variables such as curb weight, footprint, track width, or wheelbase. An advantage of deleting independent variables is that it shrinks standard errors of the regression coefficients for mass and footprint.

Model 4 offers a justifiable alternative to the baseline model, but, in a sense, it fixes something that is not broken. The baseline analysis has the advantage of applying the same, uniform set of control variables in each regression.

CUVs and minivans weighted according to 2010 sales:

	Cars < 3,197 lbs	Cars ≥ 3,197 lbs	CUVs & Minivans	LTVs < 4,947 lbs	LTVs ≥ 4,947 lbs
Baseline	1.49	.50	- .99	- .10	- .72
CUVs/minivans weighted by 2010 sales			- .27		

In his peer review, Green asks, "Does it make any difference when minivans are deleted from the CUV and minivan group? Compared to the other vehicle types, minivans likely represent a small percentage of vehicles, but also may be quite different from CUVs."[87] Minivans represent a small percentage of vehicles in recent model years. The market share of minivans steadily decreased after MY 2000, while the share for CUVs greatly increased. For example, Table 1-4 shows that minivans accounted for no more than 7.54 percent of new vehicle sales for MY 2003 through MY 2010, while the share for CUVs increased from 8.90 for MY 2003 (and from 1.59 for MY 2000) to 17.17 percent by MY 2008. In NHTSA's MY 2003-2010 database, the ratio of CUV to minivan registration years is 69.34 to 30.66, but this understates the ratio of sales in a more recent year. In this alternative model, the MY 2003-2010 database is adjusted to mimic MY 2010 sales by multiplying the original weight factor for each CUV case (fatal and induced-exposure) by 85.28/55.99, while multiplying the weight factor for each minivan case by 14.72/44.01, as applied in the 2012 report.

Table 4-1 (model 6) shows that the Volpe coefficient for CUVs and minivans changed from a 0.99 percent fatality reduction to a 0.27 percent reduction. The other Volpe coefficients are unchanged, because the baseline analysis carries over for cars and truck-based LTVs.

For the individual crash types, giving lower weight to the minivan cases reveals four cases of strong increases in the estimated fatality risk associated with mass reduction in CUVs and minivans. For fixed-object collisions, a baseline benefit of 3.12 percent per 100-pound mass reduction is replaced by a benefit of 1.11 percent in model 6. Similarly, for pedestrian/bicyclist/motorcyclist collisions, a baseline benefit of 2.49 percent is replaced by a benefit of 1.03 percent.

[87] Docket No. NHTSA-2010-0152-0037, p. 12.

For collisions with cars < 3,157 pounds, a baseline benefit of 0.27 percent is replaced by an estimated increase in fatality risk of 2.02 percent per 100-pound mass reduction in CUVs and minivans in model 6. Likewise, for collisions with LTVs ≥ 4,947 pounds, a baseline increase in fatality risk of 0.89 percent is replaced by an increase in fatality risk of 4.47 percent.

This sensitivity analysis is useful for illustrating the fragility of the CUV/minivan analysis, and indicates that the benefit for mass reduction estimated in the baseline analysis is influenced by structural differences in fatality risks for CUVs versus minivans that may not be adequately accounted for through the inclusion of an indicator variable for minivan status. In the 2012 report, NHTSA did not choose this model to supersede the baseline analysis, because of the added complexity of re-weighting the data. This concern remains, as well as uncertainty about the extent to which re-weighting CUV sales to a recent year is more representative of factors governing fatality risk than maintaining the relative sales weights in the baseline data. In future updates of the databases, less recent calendar years with high shares of minivan sales will be replaced with recent calendar years with lower shares of minivan sales. The replacement is expected to yield weighted shares of CUVs and minivans that are more representative of the current vehicle fleet.

Limited to drivers with BAC=0:

	Cars < 3,197 lbs	Cars ≥ 3,197 lbs	CUVs & Minivans	LTVs < 4,947 lbs	LTVs ≥ 4,947 lbs
Baseline	1.49	.50	- .99	- .10	- .72
Limited to BAC=0	2.22	1.38	- .92	.31	- .91

In his peer review of NHTSA's 2010 report, Green asks, "Would deleting alcohol-related crashes from the FARS data change any of the results?"[88] Table 3-10 of this report updates that analysis with the current databases. Specifically, crash involvements on FARS where either the driver's recorded BAC or the median of the driver's ten imputed values of BAC was .01 or higher were deleted. No cases were deleted from the induced-exposure file, where BAC would usually be unreported for these mostly nonfatal crashes. However, even the FARS data suggests such deletions would have been few. Whereas 23.76 percent of all drivers of MY 2003-2010 cars and LTVs on CY 2005-2011 FARS had reported or imputed BAC ≥ .01, only 8.65 percent of the non-culpable drivers in multi-vehicle crashes had BAC ≥ .01, and only 2.73 percent of the non-culpable drivers of the vehicles with VEH_NO ≥ 3 (who are often bystanders; the principal collision typically is vehicle no. 1 with vehicle no. 2, and one of them may then ricochet into vehicle no. 3). In nonfatal non-culpable induced-exposure involvements, the proportion of drivers with BAC ≥ .01 may be similarly low.

As shown in Table 3-10 and discussed in Section 3.9, the Volpe coefficient is computed by weighting each of the nine crash types by the number of fatalities involving case-vehicle drivers with BAC < .01 (adjusted for ESC). About half the rollovers and fixed-object impacts involved drivers with BAC ≥ .01, versus only about 10 percent of the drivers in the other crash types. In

[88] Docket No. NHTSA-2010-0152-0022, p. 32.

other words, rollovers and impacts with fixed objects, where mass reduction is beneficial for cars and CUVs/minivans, make a smaller contribution to the Volpe coefficient than in the baseline analysis. That pushes the Volpe coefficients for cars and CUVs/minivans in the direction of more harm/less benefit for mass reduction. Table 4-1 (model 8) shows a fatality increase of 2.22 percent for cars < 3,197 pounds and 1.38 percent for cars ≥ 3,197 pounds (versus 1.49% and 0.50% in the baseline analysis).

Section 3.9 suggests that limiting the data to sober drivers may have eliminated many of the crashes preceded by loss of control. Having a lighter vehicle might have helped the driver keep control of it and avoid the crash, but when two vehicles slam into one another without prior loss of control, momentum considerations are paramount: net harm for removing mass from the lighter vehicle, net benefit from the heavier vehicle. Thus, in the heavier LTVs, limiting to sober drivers pushes the Volpe coefficient in the opposite direction, up to a 0.91 percent societal benefit (from 0.72% in the baseline analysis).

NHTSA would not contemplate making this the primary analysis. To the agency, the estimated effect on "societal" fatality risk means all of society, not just the sober part of it. Nevertheless, it is an interesting sensitivity analysis because it shows how controlling for one aspect of driver "quality," in this case, sobriety intensifies rather than weakens the Volpe coefficients for passenger cars. That is consistent with the results of the two ensuing analyses controlling for manufacturer and/or nameplate.

Control for vehicle manufacturer and control for manufacturer and/or nameplate:

	Cars < 3,197 lbs	Cars ≥ 3,197 lbs	CUVs & Minivans	LTVs < 4,947 lbs	LTVs ≥ 4,947 lbs
Baseline	1.49	.50	- .99	- .10	- .72
Control for veh manuf	2.39	1.37	zero	.32	- .09
for manuf/nameplate	2.65	2.96	- .43	.30	zero

Wenzel tested a model with NHTSA's preliminary database that included 18 categorical variables denoting a manufacturer and/or nameplate, plus the other baseline control variables.[89] Chen and Kockelman, in their review of Wenzel's 2011 report, recommend splitting this into two analyses.[90] The first adds 15 variables denoting manufacturers only (e.g., Ford, Toyota). The second adds a total of 20 variables by treating five luxury nameplates as if they were separate manufacturers; for example, separate variables are included for Lincoln and Ford (which now means Ford excluding Lincoln), and for Lexus and Toyota (which now means Toyota excluding Lexus). Both techniques are applied here to NHTSA's updated database.

Table 4-1 (model 9) shows controlling for manufacturer impacts all five Volpe coefficients in the direction of more harm/less benefit for mass reduction. The impact is large for all cars, and CUVs and minivans, with estimated coefficients between 0.87 and 0.99 percentage point larger

89 Wenzel (2011), pp. 38-39.
90 EPA (2012).

than in the baseline model. The impact is less severe for trucks; the coefficients for LTVs < 4,947 pounds and ≥ 4,947 pounds are 0.42 and 0.63 percentage point larger than in the baseline model, respectively.

Table 4-1 (model 10) shows that controlling for luxury nameplate in addition to manufacturer has a large impact on cars ≥ 3,197 pounds. A high proportion of the vehicles with the five luxury nameplates are cars ≥ 3,197 pounds. The Volpe coefficient for these cars in model 10 is a 2.96 percent fatality increase per 100-pound mass reduction, which *exceeds* the coefficient for cars < 3,197 (2.65%). The impact on the coefficient for CUVs and minivans is weaker than in model 9, but still relatively large (reduction of 0.56 percentage point).

In their review of Wenzel's 2011 reports, Chen and Kockelman comment that "the type of car is very much a proxy for driver type…Simply including gender and age variables cannot account for important covariates such as education, risk aversion, driving ability, wealth, etc…These variables…are not readily available in data sets."[91]

In fact, Wenzel's strategy of controlling for manufacturer and/or nameplate is an excellent step toward finding a "proxy for driver type," to the extent that each nameplate has its own brand image and customer following. At the same time, controlling for manufacturer and/or nameplate controls for differences in vehicle design, at least to the extent of differences at the manufacturer level. Furthermore, in the baseline regression analyses without the manufacturer variables, curb weight and/or footprint may be acting to some extent as surrogates for manufacturer (i.e., some nameplates attract good drivers and also tend to have higher curb weights or larger footprint) by capturing manufacturer-related effects that are independent of curb weight and footprint. Without knowing the nameplate, the regression attributes the low fatality risk to the higher curb weight or larger footprint; controlling for manufacturer avoids that.

NHTSA believes that controlling for manufacturer and/or nameplate makes sense intuitively. Nevertheless, the agency is unwilling to make it the primary analysis, because it adds so many variables. Also, it is not so clear whether the baseline analysis erroneously attributed effects of manufacturer to footprint or, on the contrary, the new analysis might be erroneously attributing effects of footprint to manufacturer.

Conceptually, even better control for vehicle design could be achieved by adding a categorical variable for every make and model, not just for every manufacturer. NHTSA has performed logistic regressions controlling for make and model when the database was limited to a small number of makes and models (e.g., 15 models in an evaluation of side impact protection).[92] However, in this analysis it could add hundreds of variables to the analysis and result in an overspecified model.

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[91] EPA (2012).

[92] Kahane, C. J. (2007). *An Evaluation of Side Impact Protection – FMVSS 214 TTI(d) Improvements and Side Air Bags*, NHTSA Technical Report No. DOT HS 810 748. Washington, DC: National Highway Traffic Safety Administration, http://www-nrd.nhtsa.dot.gov/Pubs/810748.PDF, pp. 57-59.

Limited to good drivers:

	Cars < 3,197 lbs	Cars ≥ 3,197 lbs	CUVs & Minivans	LTVs < 4,947 lbs	LTVs ≥ 4,947 lbs
Baseline	1.49	.50	- .99	- .10	- .72
Limited to good drivers	2.82	1.86	- .97	.37	- .62

Wenzel tested another model with NHTSA's preliminary database that excluded drinking drivers and, furthermore, several other groups of drivers exhibiting imprudent behavior in the crash or on previous occasions, as defined in NHTSA's 2003 report.[93] Wenzel's analysis is modified here by excluding not only reported but also imputed BAC ≥ .01 (i.e., every drinking driver excluded in the preceding test). Fatal-crash cases were also excluded if the driver exhibited any one (or more) of these symptoms of imprudent driving behavior:

- Drug involvement on this crash (DRUGS = 1)
- Driving without a valid license at the time of this crash (L_STATUS = 0-4)
- This crash involves driving on a suspended/revoked license, reckless/erratic/negligent driving, being pursued by police, racing, hit & run, or vehicular homicide (any of DR_CF1, DR_CF2, DR_CF3 or DR_CF4 = 19,36[94],37,46,90,91)
- 2 or more reported crashes during the past 3 years (PREV_ACC = 2-75)
- 1 or more DWI convictions during the past 3 years (PREV_DWI = 1-75)
- 2 or more speeding convictions during the past 3 years (PREV_SPD = 2-75)
- 2 or more license suspensions or revocations during the past 3 years (PREV_SUS = 2-75)
- 2 or more other harmful moving violations during the past 3 years (PREV_OTH = 2-75)

As in the preceding test, only fatal crash involvements were deleted. No cases were deleted from the induced-exposure file, where BAC and driver history would usually be unreported for these mostly nonfatal crashes. Unlike the preceding test, the FARS data suggests such deletions might not have been so few. Whereas 41.3 percent of all drivers of MY 2003-2010 cars and LTVs on CY 2005-2011 FARS exhibited one or more symptoms of imprudent driving, so did 24.3 percent of the non-culpable drivers in multi-vehicle crashes and even 15.6 percent of the non-culpable drivers of the vehicles with VEH_NO ≥ 3 ("bystanders"). The proportions of imprudent drivers may vary across makes and models, as well.

A caveat on the analysis is that the results might be different if it had been possible to exclude corresponding cases from the induced-exposure database. Wenzel suggests controlling for driver characteristics that are already available in the State data or from other sources.[95] Another possibility in future research would be to obtain driver-history information for the induced-exposure cases by the same method as FARS analysts obtain if for fatality cases, namely by linking crash data to driver-history files.

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93 Wenzel (2011), pp. 46-47; Kahane (2003), p. 94.

94 In Florida, Kansas, North Carolina, Ohio, and Utah, do not include if DR_CF2, DR_CF3 or DR_CF4 = 36, since that code is applied frequently in those States and does not necessarily mean reckless driving.

95 Wenzel (2012), pp. 78-79.

Table 4-1 (model 11) shows that limiting to good drivers strengthens the Volpe coefficient for cars < 3,197 pounds to 2.82 percent, nearly double the baseline (1.49%), and 0.60 percentage point higher than when limiting the analysis to sober drivers (model 8). Similarly, the coefficient for cars ≥ 3,197 pounds rises to 1.86 percent, versus 0.50 percent in the baseline and 1.38 percent in model 8.

Conversely, the coefficient for LTVs ≥ 4,947 pounds is only 0.10 percentage point larger than in the baseline model (0.29 percentage point larger than in model 8). The coefficients for CUVs and minivans and LTVs < 4,947 pounds are within 0.06 percentage point of the corresponding values from model 8 (0.02 percentage point larger than in the baseline for CUVs and minivans, and 0.47 percentage point larger than in the baseline for LTVs < 4,947 pounds).

The Volpe coefficient is computed by weighting each of the nine crash types by the number of fatalities involving good drivers only. That eliminates 71 percent of the rollovers and fixed-object impacts, versus 44 percent of the drivers in the other crash types. In other words, rollovers and impacts with fixed objects, where mass reduction is most beneficial for cars and CUVs/minivans, make a considerably smaller contribution to the Volpe coefficient than in the baseline analysis. Furthermore, for these good drivers of passenger cars, mass reduction is less beneficial or not beneficial at all in rollovers and fixed-object impacts, and more harmful than in the baseline analysis in the other collision types. It is the same pattern as in the analysis of sober drivers, but stronger. This test, even more than the three preceding ones, shows how controlling for driver "quality" can intensify the Volpe coefficients for passenger cars.

Perhaps a take-home message from this sensitivity analysis and the sensitivity analysis restricting the sample to sober drivers is that impaired or incautious drivers, on the relatively frequent occasions when they find their vehicles out of control or pointed in the wrong direction, initiate emergency maneuvers; under those circumstances, any extra mass makes it even more difficult for them to regain directional control. A vehicle combining small footprint and high mass may be toxic for these drivers. By contrast, good, cautious drivers rarely need such maneuvers. For them, the paramount effect of mass is conservation of momentum. For them, mass reduction is especially harmful in the lightest cars, while continuing to be societally beneficial in the heavier LTVs – exactly as shown in the two sensitivity analyses.

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Appendix A

MY 2003-2010 SUVs Considered Crossover Utility Vehicles (CUVs) in this Report

Ward's Automotive Yearbooks began to list certain makes and models as "CUVs" in MY 2002 in its "Light-Duty Truck Specifications" and its narrative descriptions of the new vehicles.[96] In general, the list of vehicles considered CUVs in this report includes all those called CUVs by Ward's but also some other vehicles (among them, any CUVs of designs discontinued before 2002, since Ward's was not yet using the term), based on sources or criteria documented in the footnotes.[97]

	First MY[98]	Last MY in Database[99]	LTV Groups Included (NHTSA 5-Digit Codes)
Chrysler PT Cruiser	2001	2010	6304
Chrysler Pacifica	2004	2008	6307
Dodge Magnum	2005	2008	6310
Jeep Compass/Patriot	2007	2010	6312
Ford Escape/Merc Mariner/Mazda Tribute	2001	2010	12309
Ford Freestyle	2005	2009	12312
Ford Taurus X	2008	2009	12312
Ford Edge/Lincoln MKX	2007	2010	12314
Pontiac Aztec	2001	2005	18313
Buick Rendezvous	2002	2007	18315
Saturn Vue	2002	2010	18317
Cadillac SRX	2004	2009	18319
Chevrolet HHR	2006	2010	18321
GMC Acadia/Saturn Outlook	2007	2010	18323
Buick Enclave	2008	2010	18323
Chevrolet Traverse	2009	2010	18323
VW Touareg/Porsche Cayenne	2004	2010	30301
Audi Allroad	2001	2005	32301
Audi Q7	2007	2010	32302
BMW X5/X6	2000	2010	34301, 34303
BMW X3	2004	2010	34302
Nissan Murano	2003	2010	35304

[96] Southfield, MI: Penton Media, Inc.
[97] Ward's does not call the Jeep Liberty a CUV, nor the Dodge Nitro (a related design with a longer wheelbase, according to cars.com). Although these vehicles are of unibody design, they have additional structure for the front and rear suspension to provide better off-road and towing capabilities and for that reason it is probably more appropriate to consider them truck-based SUVs.
[98] But only the vehicles of MY 2003 and onward are included in the analyses of this report.
[99] 2010 is the last model year in this report; however, most of these vehicles continued as CUVs beyond MY 2010.

Infiniti FX35/45	2003	2008	35305
	First MY[100]	Last MY in Database[101]	LTV Groups Included (NHTSA 5-Digit Codes)
Honda CR-V	1997	2010	37301, 37303, 37307
Acura MDX	2001	2010	37302, 37305
Acura ZDX	2010	2010	37305
Honda Pilot	2003	2010	37302, 37308
Honda Element	2003	2010	37304
Acura RDX	2007	2010	37306
Mazda CX-7	2007	2010	41301
Mazda CX-9	2007	2010	41302
Mercedes ML[102]	2006	2010	42303
Mercedes R[103]	2006	2010	42304
Mercedes GL	2007	2010	42305
Subaru Forester	1998	2010	48301, 48304
Subaru Outback[104]	2005	2010	48302, 48303
Subaru Tribeca	2006	2010	48303
Subaru Baja	2003	2006	48702
Toyota RAV4[105]	1996	2010	49305, 49306, 49309, 49313
Lexus RX300	1999	2003	49308
Toyota Highlander	2001	2010	49310, 49315
Lexus RX330/350	2004	2010	49310, 49317
Volvo XC70	2001	2010	51301, 51303
Volvo XC90	2003	2010	51302
Mitsubishi Outlander[106]	2003	2010	52305, 52307
Mitsubishi Endeavor[107]	2004	2010	52306. 52308
Chevrolet Equinox/Pontiac Torrent	2005	2010	53307
Suzuki XL-7[108]	2007	2009	53307
Hyundai Santa Fe	2001	2010	55301, 55304

[100] But only the vehicles of MY 2000 and onward are included in the analyses of this report.
[101] 2010 is the last model year in this report; however, most of these vehicles continued as CUVs beyond MY 2010.
[102] But not the 1998-2005 Mercedes ML (LTV group 42301). Mercedes ML was redesigned in 2006 as a unibody and it is a crossover according to http://en.wikipedia.org/wiki/Crossover_(automobile), (even though Ward's does not call it a CUV).
[103] Mercedes R was built on the same platform as ML starting in 2006 and it is a crossover according to msn.auto, http://editorial.autos.msn.com/article.aspx?cp-documentid=435375, (even though Ward's does not call it a CUV).
[104] But not the 2003-2004 Subaru Outback (car group 48013), which is a passenger car by NHTSA's definitions for FMVSS and CAFE purposes. In 2005, Subaru Outback was reclassified an LTV and became a CUV (even though Ward's still calls it a car).
[105] http://en.wikipedia.org/wiki/Toyota_RAV4 says RAV4 was the first crossover SUV, based on Corolla.
[106] Ward's does not call it a CUV until 2007, but http://en.wikipedia.org/wiki/Mitsubishi_Outlander calls it a CUV from the start.
[107] Ward's does not call it a CUV until 2007, but cars.com calls it a CUV from the start.
[108] Ward's states that the 2007 XL-7 (LTV group 53309) was redesigned as a CUV, whereas the 2001-2006 XL-7 (LTV group 53306) was truck-based.

Hyundai Tucson/Kia Sportage[109]	2005	2010	55302, 53305
Hyundai Veracruz	2007	2010	55303
Land Rover Freelander	2002	2005	62307

[109] Ward's does not call them CUVs, but http://en.wikipedia.org/wiki/Kia_Sportage calls them CUVs based on the Elantra platform (whereas the 1995-2002 Sportage, LTV groups 63301/63302, was based on the Mazda Bongo van and was not a CUV).

Appendix B

Codebook for the Database of Fatal Crash Involvements

Observations: 85,890
Variables: 81

Alphabetic List of Variables

ABS – Antilock brake system (4-wheel) Type: Numeric8

0	Not ABS-equipped
.01-.99	proportion of vehicles with ABS (optional but cannot be identified for an individual vehicle from the 1st 12 digits of its VIN)
1	ABS-equipped

AWD – All-wheel-drive or 4-wheel-drive Type: Numeric8

0	FWD or RWD – i.e., not equipped with AWD or 4-wheel-drive
.01-.99	proportion of vehicles with AWD or 4-wheel-drive (optional but cannot be identified from 1st 12 digits of VIN)
1	equipped with AWD or 4-wheel-drive

BLOCKER – Voluntary vehicle-to-vehicle compatibility certification Type: Numeric8

0	Not certified (or not a pickup truck or SUV)
1	Certified, Option 1 (bumper height overlap with passenger cars)
2	Certified, Option 2 ("blocker beam" or other secondary energy-absorbing structure)

BOD2 – Passenger car body type Type: Numeric8

0	Not a passenger car
1	2-door convertible
2	2-door coupe or sedan
3	3-door hatchback
4	4-door sedan
5	5-door hatchback
6	Station wagon

CARS – Number of passenger cars in the crash Type: Numeric8

0 – 44	Number of passenger cars in transport involved in the crash

CG – Car group Type: Numeric8

1306-65001	Download 10Formats2011.sas, CarGroup2011.docx, or LTVGroup2011.docx for valid codes

CGP – Car group codes for merging with IHS Automotive data   Type: Numeric8

1306-65001	Download 10Formats2011.sas, CarGroup2011.docx, or LTVGroup2011.docx for valid codes

COMBO – Side air bag with torso/head protection ("combination" bag)   Type: Numeric8

0	Not equipped with combo bags
.01-.99	proportion of vehicles with combo bags (optional but cannot be identified from 1st 12 digits of VIN)
.75	Combo bag for driver only
1	Combo bags for driver and RF passenger (Note: a combo bag is a single bag that protects the head and torso; separate curtains and torso bags are coded CURTAIN=1, TORSO=1, COMBO=0)

COUNTY – County FIPS code   Type: Numeric3

1 – 840	3-digit FIPS code for the county (unmodified FARS variable)

CRSH – Crash type   Type: Numeric8

1	1st-event rollover
2	Hit fixed object
3	Hit pedestrian/bike/motorcycle
4	Hit heavy vehicle (i.e., GVWR ≥ 10,000 pounds)
5	Hit passenger car of known mass
6	Hit LTV of known mass and GVWR < 10,000 pounds
11	Other non-collision (fire, immersion, fell from vehicle,…)
12	Hit train
13	Hit animal, working vehicle, or on-road object
14	Single-vehicle crash, no non-occupants: other/unclear type
15	Single-vehicle crash involving non-occupants: other/unclear type
16	Single vehicle: fatal to multiple or other traffic units
21	Hit car of unknown mass
22	Hit LTV of unknown mass
23	Hit "other" type of vehicle (snowmobile, farm equipment, construction machinery,…)
24	Hit unknown type of vehicle
25	2-vehicle crash: fatal to non-occupants or parked-vehicle-occupants in addition to, possibly, occupants of vehicles in transport
31	3+ vehicle crash: fatal only to occupants of vehicles in transport
32	3+ vehicle crash: fatal to non-occupants or parked-vehicle-occupants in addition to, possibly, occupants of vehicles in transport

CURBWT – Curb weight (pounds)   Type: Numeric8

1807 – 7710	Curb weight in pounds

CURTAIN – Head curtain air bags for front-seat occupants Type: Numeric8

0	Not equipped with head curtain bags
.01-.99	proportion of vehicles with curtain bags (optional but cannot be identified from 1st 12 digits of VIN)
1	Head curtains for driver and RF passenger

CY – Calendar year Type: Numeric8

2005 – 2011	Calendar year in which the crash occurred

DEATHS – Case vehicle occupant fatalities Type: Numeric3

0 – 9	Number of occupant fatalities in the case vehicle (unmodified FARS variable)

DENS3 – County population density Type: Numeric8

0.1-66951	Inhabitants per square mile in the county where the crash occurred, based on 2000 census

DRVAGE – Driver age Type: Numeric8

14 – 96	Age of the driver (unknown or out-of-range excluded)

DRVMALE – Male driver Type: Numeric8

0	Female driver
1	Male driver (non-reported gender excluded)

ESC – Electronic stability control Type: Numeric8

0	Not ESC-equipped
.01-.99	proportion of vehicles with ESC (optional but cannot be identified for an individual vehicle from the 1st 12 digits of its VIN)
1	ESC-equipped

FATALS – Fatalities in the crash Type: Numeric3

1 – 12	Total number of fatalities in the crash, including occupants of any vehicles (in transport or not-in-transport) and non-occupants (unmodified FARS variable)

FOOTPRNT – Footprint (square feet) Type: Numeric8

26.8 – 80.9	Footprint in square feet (TRAKWDTH X WB_MIN converted to square feet)

GE10 – GVWR ≥ 10,000 pounds Type: Numeric8

0	GVWR (gross vehicle weight rating) < 10,000 pounds
1	GVWR ≥ 10,000 pounds

HARM_EV – First harmful event Type: Numeric3

1 – 99	First harmful event in the crash (unmodified FARS variable)

HIFAT_ST – High-fatality-rate State Type: Numeric8

0	One of the 26 States with < 160 crash fatalities per million vehicle registration years in 2005-2011
1	One of the 24 States with > 160 crash fatalities per million vehicle registration years in 2005-2011

HOUR – Hour when the crash occurred Type: Numeric3

0 – 24	Hour when the crash occurred, military time (unmodified FARS variable)

HVYTRKS – Number of heavy vehicles in the crash Type: Numeric8

0 – 13	Number of heavy vehicles in transport involved in the crash

LTVS – Number of LTVs in the crash Type: Numeric8

0 – 51	Number of LTVs in transport involved in the crash

MAK2 – Vehicle Make Type: Numeric8

2	Jeep
3	Hummer
6	Chrysler
7	Dodge
11	Sprinter
12	Ford
13	Lincoln
14	Mercury
18	Buick
19	Cadillac
20	Chevrolet
21	Oldsmobile
22	Pontiac
23	GMC
24	Saturn
30	Volkswagen
32	Audi
33	Mini-Cooper
34	BMW
35	Nissan
37	Honda
38	Isuzu
39	Jaguar
41	Mazda
42	Mercedes-Benz
45	Porsche
47	Saab
48	Subaru
49	Toyota (including Scion)
51	Volvo

52 Mitsubishi
53 Suzuki
54 Acura
55 Hyundai
58 Infiniti
59 Lexus
62 Land-Rover
63 Kia
65 Smart

MAXVEHNO – Highest VEH_NO of vehicles hitting non-occupants Type: Numeric8
1 – 99 Highest VEH_NO of the vehicles that struck and fatally injured a non-occupant

MCYCLES – number of motorcycles in the crash Type: Numeric8
0 – 25 Number of motorcycles in transport involved in the crash

MINVEHNO – Lowest VEH_NO of vehicles hitting non-occupants Type: Numeric8
1 – 99 Lowest VEH_NO of the vehicles that struck and fatally injured a non-occupant

MM2 – Make-model Type: Numeric8
2001-65031 Download 10Formats2011.sas, CarGroup2011.docx, or LTVGroup2011.docx for valid codes

MMP – Make-model codes for merging with IHS Automotive data Type: Numeric8
2001-65031 Download 10Formats2011.sas, CarGroup2011.docx, or LTVGroup2011.docx for valid codes

MY – Model year Type: Numeric8
2003 – 2010 Model year of the case vehicle

M_HARM – Most harmful event Type: Numeric3
1 – 99 Most harmful event for the case vehicle (unmodified FARS variable)

NITE – Time of day when the crash occurred Type: Numeric8
0 6:00 a.m. to 6:59 p.m.
1 7:00 p.m. to 5:59 a.m.

NONOCC – Number of non-occupant fatalities in the crash Type: Numeric8
0 – 5 Number of non-occupant fatalities in the crash

OBODY – Body type of the other vehicle Type: Numeric8
1 – 99 Body type of the other vehicle in a 2-vehicle crash (unmodified FARS variable BODY_TYP for the other vehicle)

OCC – Number of occupant fatalities in the crash Type: Numeric8

0 – 12 Number of occupant fatalities in the crash (including occupants of other vehicles in transport)

OCG2 – Car group (or LTV group) of the other vehicle Type: Numeric8

1203-99999 5-digit VIN-derived vehicle group (CG) of the other vehicle in a 2-vehicle crash (Download 10Formats2011.sas, CarGroup2011.docx, or LTVGroup2011.docx for valid codes)

OCURBWT – Curb weight (pounds) of the other vehicle Type: Numeric8

190 – 7710 Curb weight in pounds of the other vehicle in a 2-vehicle crash

OMAKMOD – FARS make and model of the other vehicle Type: Numeric8

2001-99999 Make and model of the other vehicle in a 2-vehicle crash (unmodified FARS variable MAK_MOD for the other vehicle)

OMM2 – Make and model of the other vehicle Type: Numeric8

2001-99999 5-digit VIN-derived make-model (MM2) of the other vehicle in a 2-vehicle crash (Download 10Formats2011.sas, CarGroup2011.docx, or LTVGroup2011.docx for valid codes)

OMOD_YR – Model year of the other vehicle Type: Numeric8

1924 – 9999 Model year of the other vehicle in a 2-vehicle crash (unmodified FARS variable MOD_YEAR for the other vehicle)

OTHVEH – Number of other-type vehicles in the crash Type: Numeric8

0 – 1 Number of other-type vehicles (snowmobiles, farm equipment, …) in transport involved in the crash

OVIN – VIN of the other vehicle Type: Character12

12-character VIN of the other vehicle in a 2-vehicle crash (unmodified FARS variable VIN for the other vehicle)

OVINA –VINA_MOD of the other vehicle Type: Character3

VINA_MOD of the other vehicle in a 2-vehicle crash (unmodified FARS variable VINA_MOD for the other vehicle)

OVTYP – Type of the other vehicle in a 2-vehicle crash Type: Numeric8

1 Passenger car
2 LTV
3 Heavy vehicle
4 Motorcycle
5 Other (snowmobile, farm equipment, construction machinery,…)
9 Unknown

OVTYP2 – Type (detailed) of the other vehicle in a 2-vehicle crash Type: Numeric8

1	Passenger car
2.1	CUV
2.2	Minivan
2.3	Astro/Safari/Aerostar
2.4	Truck-based LTV
3	Heavy vehicle
4	Motorcycle
5	Other (snowmobile, farm equipment, construction machinery,…)
9	Unknown

OWTFLAG – Source of curb weight for the other vehicle Type: Numeric8

0	Good VIN, MY 1985-2007, weight in database
1	Good VIN, filled in some gaps in MY 1985-1999 database
2	MM2 not defined, but FARS supplies a VIN_WGT
3	MY 1981-1984 car with MM2 decoded, use FARS VIN_WGT
4	Weights in database for RV cutaways, etc. excluded body; reset to 5000
5	Good VIN, MY 1981-1984 or 2008-2009, use 1985 or 2007 weights
6	Filled in approximate weight based on MAK_MOD
7	Car or LTV, could not define a weight
9	Not a car or LTV

PARK – Number of non-transport-vehicle-occupant fatalities Type: Numeric8

0 – 4	Number of non- transport-vehicle-occupant fatalities in the crash

PASSIVE – Frontal air bags Type: Numeric8

0	Not equipped with frontal air bags
2	Dual frontal air bags
3	Dual frontal air bags with a manual on-off switch for the RF passenger
9	Unknown if equipped and/or what type

RDSUR – Road surface condition Type: Numeric8

0	Dry
1	Wet, muddy, or oily
2	Snow, ice, or slush
9	Unknown

ROAD_FNC – Roadway function class Type: Numeric3

1 –99	Roadway function class (unmodified FARS variable)

ROLLCURT – Head curtain air bags designed to deploy in rollovers Type: Numeric8

0	Not equipped with rollover curtain bags
.01-.99	proportion of vehicles with rollover curtain bags (optional but cannot be identified from 1st 12 digits of VIN)
1	Rollover curtains for driver and RF passenger (Note: CURTAIN should also be coded 1)

RURAL – County population density Type: Numeric8

0	Crash occurred in a county with ≥ 250 inhabitants per square mile in the 2000 census
1	Crash occurred in a county with < 250 inhabitants per square mile

SPDLIM55 – Speed limit 55+ Type: Numeric8

0	Speed limit < 55 mph or not reported, for all roadways involved in the crash
1	Speed limit ≥ 55 mph for at least one roadway involved in the crash

SP_LIMIT – Speed limit Type: Numeric3

0 – 99	Highest speed limit of roadways involved in the crash (unmodified FARS variable)

SQUADCAR – Police model Type: Numeric8

0	Not a Ford Crown Victoria or Chevrolet Impala "police" model and not a 2004-2005 Chevrolet Impala SS
1	Ford Crown Victoria or Chevrolet Impala "police" model or 2004-2005 Chevrolet Impala SS

STATE – State FIPS code Type: Numeric3

1 – 56	2-digit FIPS code for the State (unmodified FARS variable)

ST_CASE – State-case ID number Type: Numeric4

10001–560168	State-case ID number (unmodified FARS variable)

SUR_COND – Roadway surface condition Type: Numeric3

1 –9	Roadway surface condtition (unmodified FARS variable)

TORSO – Side air bag with torso protection Type: Numeric8

0	Not equipped with torso bags
.01-.99	proportion of vehicles with torso bags (optional but cannot be identified from 1st 12 digits of VIN)
.25	Torso bag for RF passenger only
1	Torso bags for driver and RF passenger

TRAKWDTH – Track width (inches, average of front and rear wheels) Type: Numeric8

45.2 – 72.65	Average of front and rear track width, in inches

TRKTYP – LTV type (case vehicle) Type: Numeric8

0	Passenger car
1	Compact pickup truck (download LTVGroup2011.docx for more information)
2	Full-sized pickup truck with GVWR < 10,000 pounds
3	Compact SUV
4	Full-sized SUV
5	Minivan
6	Full-sized van with GVWR < 10,000 pounds
7	Pickup-car (e.g., Subaru Baja)
12	300-series pickup truck with GVWR ≥ 10,000 pounds
16	300-series van with GVWR ≥ 10,000 pounds

UNKVEH – Number of unknown-type vehicles in the crash Type: Numeric8

0 – 5	Number of unknown-type vehicles in transport involved in the crash

V1 – 1st character of the VIN Type: Character1
V2 – 2nd character of the VIN Type: Character1
V3 – 3rd character of the VIN Type: Character1
V4 – 4th character of the VIN Type: Character1
V5 – 5th character of the VIN Type: Character1
V6 – 6th character of the VIN Type: Character1
V7 – 7th character of the VIN Type: Character1
V8 – 8th character of the VIN Type: Character1
V11 – 11th character of the VIN Type: Character1
V12 – 12th character of the VIN Type: Character1

VEHAGE – Vehicle age in years (CY – MY) Type: Numeric8

0 – 8	Age of the case vehicle (years)

VEH_NO –Vehicle ID number Type: Numeric3

1 – 89	Vehicle ID number (unmodified FARS variable)

VE_FORMS – Number of vehicle forms submitted Type: Numeric3

1 – 92	Number of vehicle-in-transport forms submitted for this crash (unmodified FARS variable)

VINA_MOD Type: Character3

3-character make-model code (unmodified FARS variable)

VTYP – Case vehicle type Type: Numeric8

1	Passenger car, 2 doors
2	Passenger car, 4 doors
3	Pickup truck, light duty (compact or 150-series)
4	Pickup truck, heavy duty (250- or 350-series)
5	SUV, truck-based
6	CUV (crossover SUV)

7	Minivan, except Chevrolet Astro or GMC Safari
7.1	Chevrolet Astro or GMC Safari
8	Full-sized van

WHEELB – Wheelbase (inches) Type: Numeric8

73.0 – 170.3	Wheelbase

Appendix C

Codebook for the Database of Induced-Exposure Crash Involvements

(Crashes from 13 State files, with national weights)

Observations: 2,255,398
Variables: 46

Alphabetic List of Variables

ABS – Antilock brake system (4-wheel) Type: Numeric8

0	Not ABS-equipped
.01-.99	proportion of vehicles with ABS (optional but cannot be identified for an individual vehicle from the 1st 12 digits of its VIN)
1	ABS-equipped

AWD – All-wheel-drive or 4-wheel-drive Type: Numeric8

0	FWD or RWD – i.e., not equipped with AWD or 4-wheel-drive
.01-.99	proportion of vehicles with AWD or 4-wheel-drive (optional but cannot be identified from 1st 12 digits of VIN)
1	equipped with AWD or 4-wheel-drive

BLOCKER – Voluntary vehicle-to-vehicle compatibility certification Type: Numeric8

0	Not certified (or not a pickup truck or SUV)
1	Certified, Option 1 (bumper height overlap with passenger cars)
2	Certified, Option 2 ("blocker beam" or other secondary energy-absorbing structure)

BOD2 – Passenger car body type Type: Numeric8

0	Not a passenger car
1	2-door convertible
2	2-door coupe or sedan
3	3-door hatchback
4	4-door sedan
5	5-door hatchback
6	Station wagon

CG – Car group Type: Numeric8

1306-65001	Download 10Formats2011.sas, CarGroup2011.docx, or LTVGroup2011.docx for valid codes

CGP – Car group codes for merging with IHS Automotive data Type: Numeric8

1306-65001	Download 10Formats2011.sas, CarGroup2011.docx, or LTVGroup2011.docx for valid codes

COMBO – Side air bag with torso/head protection ("combination" bag) Type: Numeric8

0	Not equipped with combo bags
.01-.99	proportion of vehicles with combo bags (optional but cannot be identified from 1st 12 digits of VIN)
.75	Combo bag for driver only
1	Combo bags for driver and RF passenger (Note: a combo bag is a single bag that protects the head and torso; separate curtains and torso bags are coded CURTAIN=1, TORSO=1, COMBO=0)

CURBWT – Curb weight (pounds) Type: Numeric8

1787 – 7710	Curb weight in pounds

CURTAIN – Head curtain air bags for front-seat occupants Type: Numeric8

0	Not equipped with head curtain bags
.01-.99	proportion of vehicles with curtain bags (optional but cannot be identified from 1st 12 digits of VIN)
1	Head curtains for driver and RF passenger

CY – Calendar year Type: Numeric8

2005 – 2011	Calendar year in which the crash occurred

DRVAGE – Driver age Type: Numeric8

14 – 96	Age of the driver (unknown or out-of-range excluded)

DRVMALE – Male driver Type: Numeric8

0	Female driver
1	Male driver (non-reported gender excluded)

DUMMY – "Dummy" induced-exposure case Type: Numeric8

0	Original induced-exposure case, same MY and CY as the case vehicle
1	No original case available, used a case of the same make-model and MY, but different CY
2	No original case available, used a case of the same make-model, but different MY and CY

ESC – Electronic stability control Type: Numeric8

0	Not ESC-equipped
.01-.99	proportion of vehicles with ESC (optional but cannot be identified for an individual vehicle from the 1st 12 digits of its VIN)
1	ESC-equipped

FOOTPRNT – Footprint (square feet) Type: Numeric8

26.8 – 80.9	Footprint in square feet (TRAKWDTH X WB_MIN converted to square feet)

GE10 – GVWR ≥ 10,000 pounds Type: Numeric8

0	GVWR (gross vehicle weight rating) < 10,000 pounds
1	GVWR ≥ 10,000 pounds

HIFAT_ST – High-fatality-rate State Type: Numeric8

0	One of the 26 States with < 160 crash fatalities per million vehicle registration years in 2005-2011
1	One of the 24 States with > 160 crash fatalities per million vehicle registration years in 2005-2011

MAK2 – Vehicle Make Type: Numeric8

2	Jeep
3	Hummer
6	Chrysler
7	Dodge
11	Sprinter
12	Ford
13	Lincoln
14	Mercury
18	Buick
19	Cadillac
20	Chevrolet
21	Oldsmobile
22	Pontiac
23	GMC
24	Saturn
30	Volkswagen
32	Audi
33	Mini-Cooper
34	BMW
35	Nissan
37	Honda
38	Isuzu
39	Jaguar
41	Mazda
42	Mercedes-Benz
45	Porsche
47	Saab
48	Subaru
49	Toyota (including Scion)
51	Volvo
52	Mitsubishi
53	Suzuki
54	Acura
55	Hyundai
58	Infiniti

59	Lexus
62	Land-Rover
63	Kia
65	Smart

MM2 – Make-model Type: Numeric8

2001-65031	Download 10Formats2011.sas, CarGroup2011.docx, or LTVGroup2011.docx for valid codes

MMP – Make-model codes for merging with IHS Automotive data Type: Numeric8

2001-65031	Download 10Formats2011.sas, CarGroup2011.docx, or LTVGroup2011.docx for valid codes

MY – Model year Type: Numeric8

2003 – 2010	Model year of the case vehicle

NITE – Time of day when the crash occurred Type: Numeric8

0	6:00 a.m. to 6:59 p.m.
.01-.99	In 2002-2006 Alabama data, estimated probability that the crash occurred from 7:00 p.m. to 5:59 a.m., depending on light condition and month (as inferred from case number)
1	7:00 p.m. to 5:59 a.m.

PASSIVE – Frontal air bags Type: Numeric8

0	Not equipped with frontal air bags
2	Dual frontal air bags
3	Dual frontal air bags with a manual on-off switch for the RF passenger
9	Unknown if equipped and/or what type

RDSUR – Road surface condition Type: Numeric8

0	Dry
1	Wet, muddy, or oily
2	Snow, ice, or slush
9	Unknown

REGWTFA – Registration-year weight factor Type: Numeric8

0 – 18292	Weight factor; share of the nation's vehicle registration years allocated to this induced-exposure case

ROLLCURT – Head curtain air bags designed to deploy in rollovers Type: Numeric8

0	Not equipped with rollover curtain bags
.01-.99	proportion of vehicles with rollover curtain bags (optional but cannot be identified from 1st 12 digits of VIN)
1	Rollover curtains for driver and RF passenger (Note: CURTAIN should also be coded 1)

RURAL – County population density Type: Numeric8

0	Crash occurred in a county with ≥ 250 inhabitants per square mile in the 2000 census
1	Crash occurred in a county with < 250 inhabitants per square mile

SPDLIM55 – Speed limit 55+ Type: Numeric8

0	Speed limit < 55 mph or not reported, for all roadways involved in the crash
1	Speed limit ≥ 55 mph for at least one roadway involved in the crash

SQUADCAR – Police model Type: Numeric8

0	Not a Ford Crown Victoria or Chevrolet Impala “police” model and not a 2004-2005 Chevrolet Impala SS
1	Ford Crown Victoria or Chevrolet Impala “police” model or 2004-2005 Chevrolet Impala SS

STATE – State where the crash occurred Type: Numeric8

1	Alabama
12	Florida
20	Kansas
21	Kentucky
24	Maryland
26	Michigan
29	Missouri
34	New Jersey
42	Pennsylvania
53	Washington State
55	Wisconsin
56	Wyoming

TORSO – Side air bag with torso protection Type: Numeric8

0	Not equipped with torso bags
.01-.99	proportion of vehicles with torso bags (optional but cannot be identified from 1st 12 digits of VIN)
.25	Torso bag for RF passenger only
1	Torso bags for driver and RF passenger

TRAKWDTH – Track width (inches, average of front and rear wheels) Type: Numeric8

45.2 – 72.65	Average of front and rear track width, in inches

V1 – 1st character of the VIN Type: Character1

V2 – 2nd character of the VIN Type: Character1

V3 – 3rd character of the VIN Type: Character1

V4 – 4th character of the VIN Type: Character1

V5 – 5th character of the VIN Type: Character1

V6 – 6th character of the VIN Type: Character1

V7 – 7th character of the VIN Type: Character1

V8 – 8th character of the VIN Type: Character1
V11 – 11th character of the VIN Type: Character1
V12 – 12th character of the VIN Type: Character1

VEHAGE – Vehicle age in years (CY – MY) Type: Numeric8

0 – 8	Age of the case vehicle (years)

VMTWTFA – VMT weight factor Type: Numeric8

103 – 265,082,805	Weight factor; share of the nation's VMT allocated to this induced-exposure case

VTYP – Case vehicle type Type: Numeric8

1	Passenger car, 2 doors
2	Passenger car, 4 doors
3	Pickup truck, light duty (compact or 150-series)
4	Pickup truck, heavy duty (250- or 350-series)
5	SUV, truck-based
6	CUV (crossover SUV)
7	Minivan, except Chevrolet Astro or GMC Safari
7.1	Chevrolet Astro or GMC Safari
8	Full-sized van

WHEELB – Wheelbase (inches) Type: Numeric8

73.0 – 170.3	Wheelbase (and if this is a pickup truck, wheelbase for the shortest bed available for this 12-character VIN)