Safety Statistical Analysis

Tom Wenzel
Lawrence Berkeley National Laboratory

June 8, 2017

Project ID:
LM123

Overview

Timeline

- Start date: Mar 2010
- End date: Sep 2017
- 90% complete

Budget

- Total funding: $2,126,500
- FY16: $335,000
- FY17: $250,000

Barriers

- Barriers addressed
  - Fuel economy not top criterion when purchasing vehicle
  - Mass reduction is a cost-effective approach to improve fuel economy
  - Concern that mass reduction may reduce societal safety

Partners

- DOT National Highway Traffic Safety Administration
- EPA Office of Transportation and Air Quality
- California Air Resources Board

Relevance

- Objective: Estimate how changes in weight and size of contemporary vehicles would have affected historical societal risk, holding footprint and other variables constant
- Results enable NHTSA and EPA to set appropriate new vehicle standards that will encourage down-weighting of vehicles without affecting safety
- These standards will in turn encourage manufacturers to use advanced lightweight materials to reduce new vehicle weight without necessarily reducing size, and meet the VTO MYPP goals
- Standards will overcome some of the reluctance of consumers to purchase vehicles with high fuel economy

Strategy

- Facilitate collaboration among DOE, NHTSA, EPA, and CARB
- Improve upon, and increase transparency of, previous NHTSA analyses
- Phase 1: Replicate NHTSA 2016 regression analysis of US societal fatality risk per vehicle mile traveled (VMT)
  - Advise NHTSA on data, variables, and methods
- Phase 2: Conduct separate regression analysis of casualty (fatality + serious injury) risk using data from 13 states
  - Provide another perspective from NHTSA analysis
- Results used in DOT Volpe model to forecast effect of MY2017 to 2025 fuel economy/CO_2 emission standards on fatalities and casualties
  - 2016 Technical Assessment Report
  - EPA Proposed/Final Determination
  - NHTSA Proposed/Final Rule

  aka Mid-term Review
- Databases and programs made public, to allow replication of results

Milestones

- FY2016
  - Update Phase 1 and Phase 2 analyses using more recent data (model year 2003 to 2010 light-duty vehicles in 2005 to 2011)
  - Submit preliminary Phase 1 report to docket for mid-term review technical assessment report
  - Analyze effect on fatalities of changing mass disparity in two-vehicle crashes over time
  - Analyze trends in vehicle miles of travel using annual Texas odometer readings
- FY2017
  - Finalize updated Phase 2 analysis
  - Finalize analysis of changing mass disparity
  - Update the DRI simultaneous two-stage regression model of effect of mass reduction on U.S. crash frequency and risk per crash
  - Update the 2016 preliminary Phase 1 and Phase 2 analyses using one more year of data (through model year 2011 and calendar year 2012)
  - Submit reports to docket for final mid-term review

Two Analytical Approaches

- NHTSA/LBNL Phase 1 analyses (1997, 2003, 2010, 2012, 2016)
  - Numerator: US fatalities, from FARS
  - Denominator: vehicle miles of travel (VMT)
    - Uses detailed information on drivers and crashes from police-reported crashes in 13 states
    - Applies a weight to each vehicle in state crash data to scale up to national vehicle registrations (IHS, previously RL Polk)
    - Applies average annual miles driven by make/model (CarFax)
  - Result: US fatalities per vehicle miles of travel (VMT)
- LBNL Phase 2 analysis (2012, 2016)
  - All data from police-reported crashes in 13 states
  - Numerator: fatalities or casualties (fatalities + serious injuries)
  - Denominator: all crash-involved vehicles
  - Result: 13-state fatalities or casualties per crash
  - Also two components of casualties per VMT:
    - Crash frequency: crashes per mile of travel, using NHTSA weights
    - Crashworthiness/compatibility: casualties per crash

$$\frac{\text{casualties}}{\text{VMT}} = \frac{\text{crashes}}{\text{VMT}} + \frac{\text{casualties}}{\text{crash}}$$

Similarities in Two Approaches

- Both use MY2003-2010 light-duty vehicles in 2005 to 2011
- Both use multiple logistic regression to estimate effect of reducing vehicle mass on societal risk, while holding footprint constant
  - Likelihood that a crash resulted in fatality/casualty, to occupants in case vehicle and any crash partner (societal risk)
  - 3 vehicle types (cars, light trucks, CUVs/minivans); car and truck types each split into lighter- and heavier-than-average
  - 9 crash types
  - 3 x 9 = 27 regression models; results are weighted by effectiveness of ESC in 2017 (assumed large reductions in rollovers and 1-vehicle crashes with objects)
  - ~ 28 variables control for other vehicle (footprint, side airbags, ESC, etc.), driver (age and gender), and crash (urban/rural, night, high-speed roads, etc.) characteristics
- Both use same database of vehicle characteristics
  - Make/model, body type, curb weight, footprint, airbags, ABS, ESC, etc.
- Both estimate the recent <u>historical</u> relationship between vehicle mass or size and societal risk…
  - … but cannot predict this relationship in the <u>future</u>, with new lightweight materials and vehicle redesign

Differences in Two Approaches

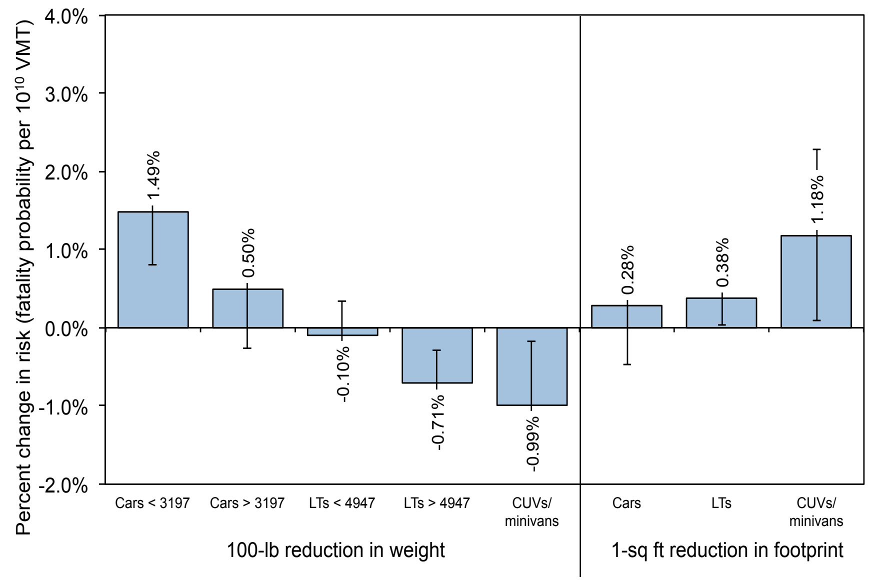
- Benefits of LBNL Phase 2
  - All data from same source (13 states crash data)
  - Estimates relationship of mass/size reduction on serious injuries <u>and</u> fatalities
  - Allows analysis of two components of casualty fatalities per VMT
    - Crash frequency (crashes per VMT)
    - Crashworthiness/compatibility (risk once a crash has occurred)
- Drawbacks of LBNL Phase 2
  - Limited to 13 states that provide Vehicle Identification Number (VIN)
    - Does relationship between weight/size and risk vary by state?
    - Are 13 states representative of national relationship?
  - Not enough fatalities in 13 states to also get robust results for fatality risk

Technical Accomplishments and Progress

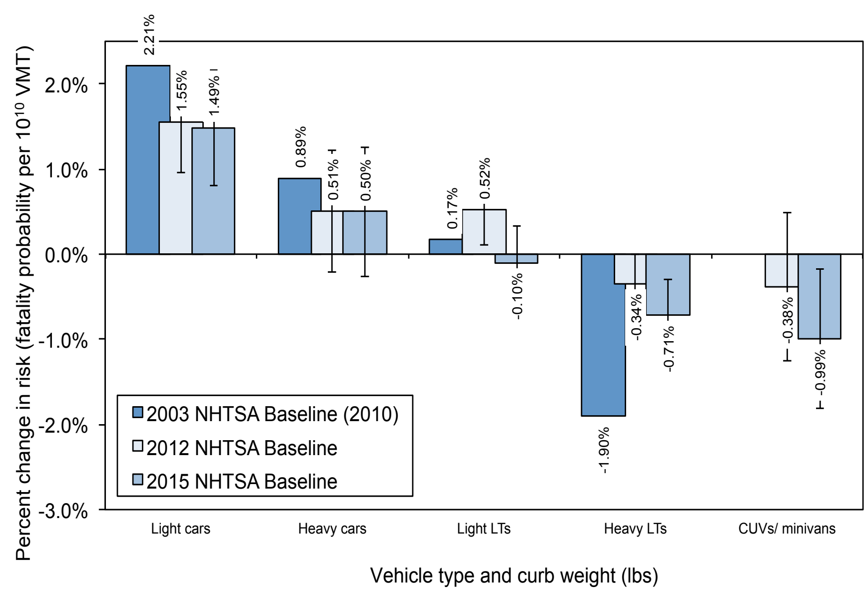
- Reviewed and commented on safety section of NAS subcommittee report on light-duty vehicle fuel economy (Jan 2015)
- Commented on NHTSA Preliminary report (Jun 2016)
- Phase 1: replicated NHTSA analysis of US fatality risk per VMT (preliminary Jun 2016)
- Phase 2: estimated 13-state casualty risk per crash (Nov 2016 draft)
- Contributed to safety section of EPA/NHTSA TAR (Jul 2016)
- Commented on TAR (Sep 2016)
- Compared VMT schedules with Texas odometer data (Feb 2017 draft)
- Simulated fatalities in 2-vehicle crashes from changes in mass disparity over time (Apr 2017 draft)

Results from 2016 LBNL Phase 1

- Baseline NHTSA results: Estimated effect of reduction in mass or footprint on societal risk is small
  - 100-lb reduction in mass associated with increases in risk only for cars
  - Based on NHTSA jack-knife method, no estimates significant at 95% level, only lighter cars and heavier light trucks significant at 90% level
  - 1-sq ft reduction in footprint associated with increases in risk in all vehicle types

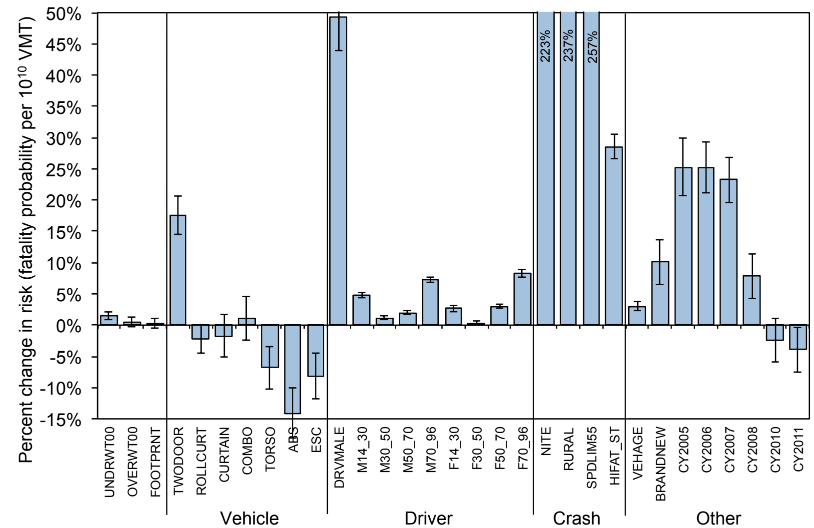


- 2016 results similar to 2012 results for cars
  - Compared to 2012, societal risk from mass reduction held constant for cars, but declined for LTs and CUVs/minivans…
  - … despite increase in mass disparity in two-vehicle crashes (increased 278 lbs for car v. LT crashes, and 200 lbs for LT v. LT crashes)

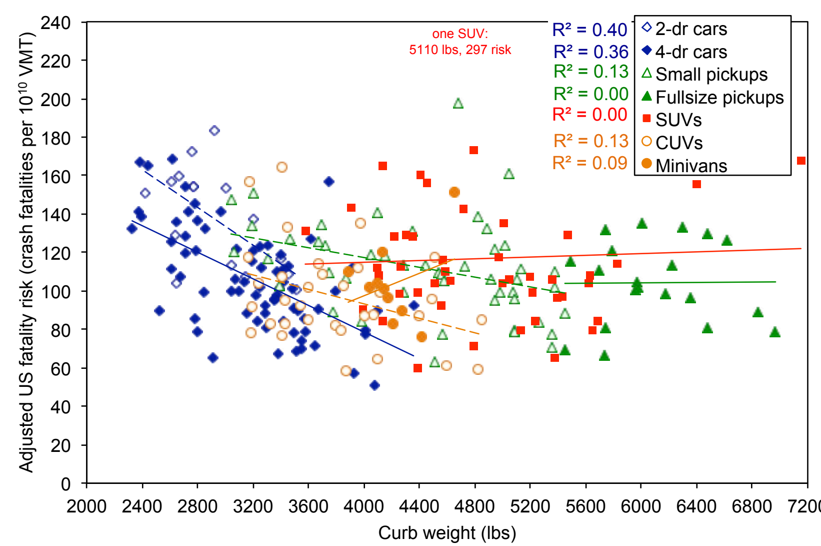


Results from 2016 LBNL Phase 1 (cont.)

- Effect of mass or footprint reduction is overwhelmed by other factors (shown for cars)
  - Other vehicle characteristics nearly 10x larger
  - Driver gender up to 30x larger
  - Certain crash characteristics over 150x larger

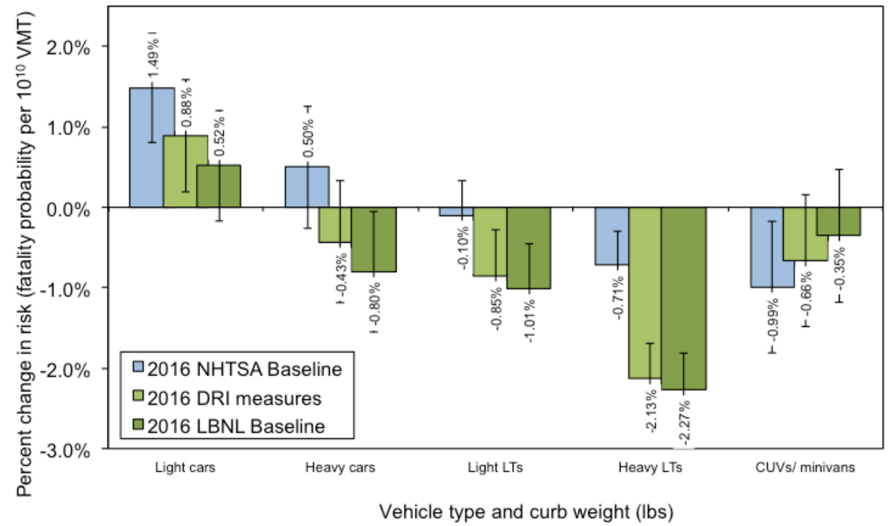


- Adjusted risk by make and model is standardized for same driver and crash circumstances
  - On average, societal fatality risk tends to decrease as mass increases (except for SUVs and full size pickups) …
  - … but very low correlation between societal fatality risk and mass by vehicle model
  - Correlation is highest in cars (R^2=0.40 and 0.36), but still large range in risk for car models with similar curb weight



Results from 2016 LBNL Phase 1 (cont.)

- 19 alternative regressions from 2012, plus 14 additional in 2016
  - Test sensitivity to data and variables used
- DRI measures reduce risk from mass reduction under NHTSA baseline
  - Use stopped instead of non-culpable vehicles as measure of exposure
  - Replace footprint with track width and wheelbase
- LBNL baseline reduces risk from mass reduction even further
  - DRI measures plus:
  - Reweight CUV/minivans by 2010 sales, weighted more towards CUVs
  - Adjust VMT weights using Texas odometer data
- NHTSA/EPA should conduct at least one additional run using alternative mass/safety coefficients
- Different mass reduction scenarios
  - 100-lb reduction, 2.55% reduction, reduction recommended by 2015 NAS committee
  - NAS reductions reduce net annual societal fatalities (i.e. save lives), using NHTSA, DRI, or LBNL regression coefficients

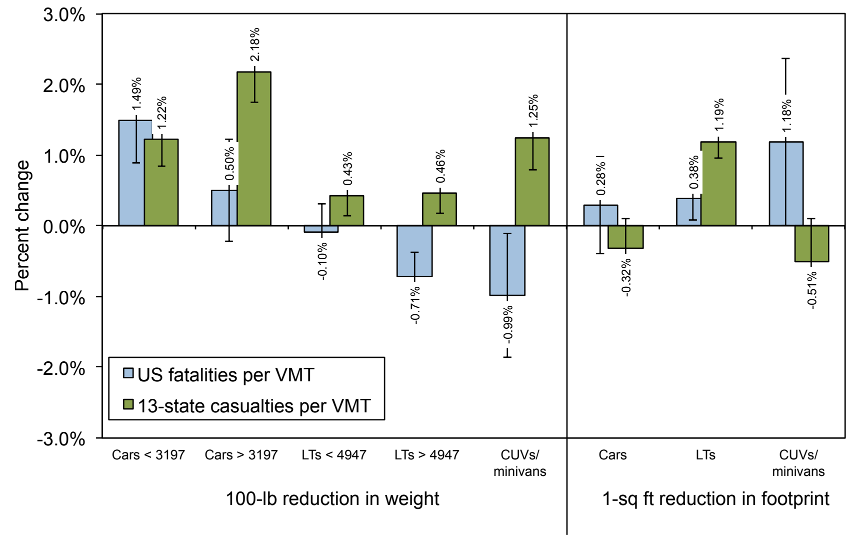


Vehicle type	Percent mass reduction: 1. 100-lb reduction	2. Percent reduction	3. 2015 NAS committee recommendations
Lgt car	3.59%	2.55%	5.0%
Hvy car	2.86%	2.55%	12.5%
Lgt LT	2.35%	2.55%	20.0%
Hvy LT	1.79%	2.55%	20.0%
CUV/Minivan	2.57%	2.55%	20.0%

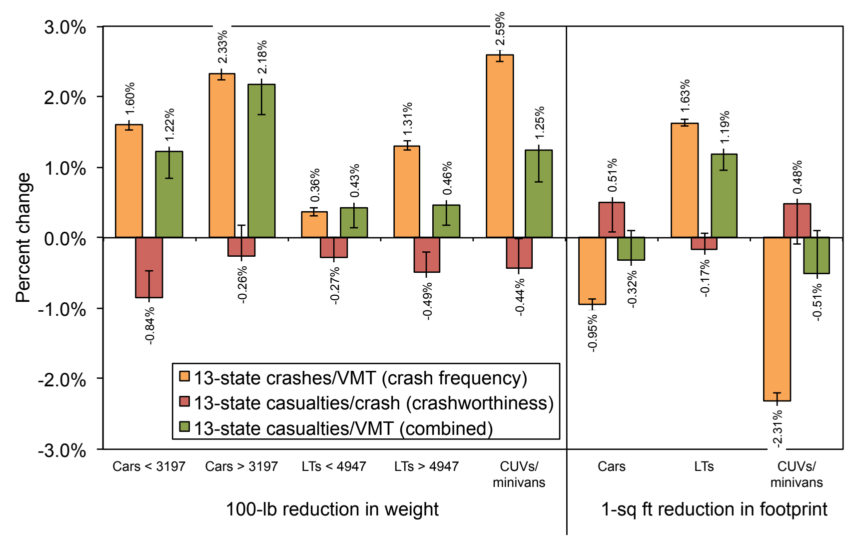
Coefficients used	Estimated change in societal fatalities: 1. 100-lb reduction	2. Percent reduction	3. 2015 NAS committee recommendations
NHTSA	91	36	-344
DRI	-159	-227	-1958
LBNL	-208	-268	-2079

Initial results from 2016 LBNL Phase 2

- 13-state societal casualty risk per VMT vs. US fatality risk per VMT
  - Comparable for cars …
  - … but not for light trucks or CUVs/minivans, with mass reduction associated with increases in casualty risk per VMT, especially for CUVs/minivans

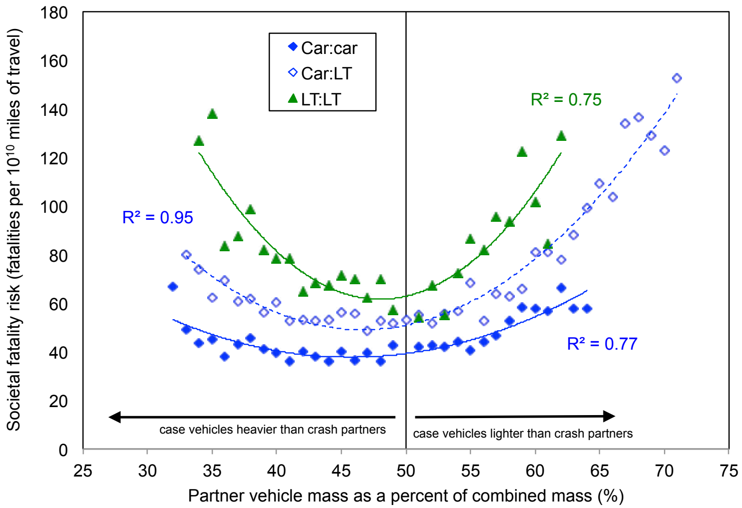


- Mass reduction increases crashes per VMT (crash frequency) but slightly reduces casualties per crash (crashworthiness/compatibility)
  - Contradicts belief that better handling and braking in lighter vehicles results in lower crash frequency
  - Results largely unchanged after accounting for:
    - Vehicle price, household income, driving record, alcohol/drug use, restraint use
    - Crash severity (by excluding crashes involving towed vehicles)



Effect of mass disparity over time on total fatalities

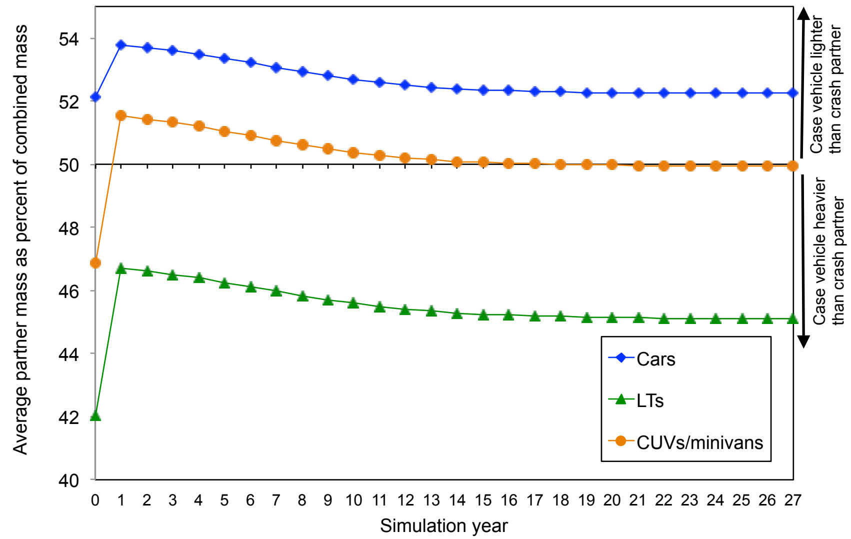
- NAS recommended analysis of mass disparity on fatalities in two-vehicle crashes
- 1. Estimate relationship between relative masses of two vehicles and societal risk
  - NHTSA baseline only considers if case vehicle and crash partner are lighter or heavier than average
  - Relationship between risk and crash partner mass as percent of combined mass
  - Risk increases as mass disparity increases, especially for LT:LT crashes



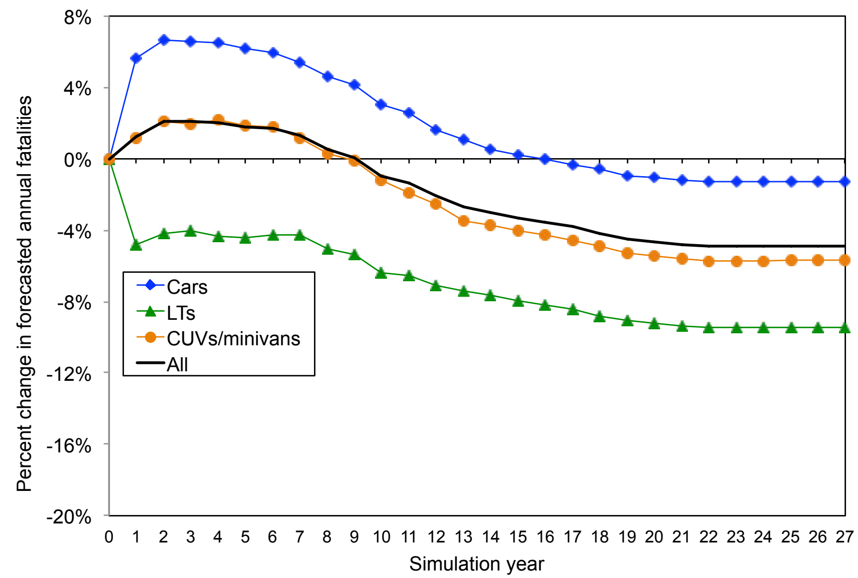
- 2. Simulate mass of case vehicle and crash partner 27 years into the future
  - Use current distribution of mass of case vehicles and crash partners, by age of each vehicle
  - Case vehicle mass is reduced in simulation year 1, to reflect effect of standards
    - NAS recommendations: light car 5%, heavy car 12.5%, light truck/CUV/minivan 20%
  - Crash partner mass is changed every year based on recent historical trends
    - 2.2% annual decrease between MY81 and MY87 for all vehicle types
    - 0.5% (cars, CUVs, minivans) or 2.2% (LTs) annual increase between MY88 and MY06
    - When a vehicle reaches MY07 assumed mass reduction from standards is applied
- 3. Estimate change in fatalities by multiplying coefficients from regression models by simulated vehicle weights in each simulation year

Results from simulation of mass disparity over time

- Simulated change in mass disparity (based on partner mass as a percent of combined mass)
- In Year 1 NAS-recommended mass reductions:
  - Increase mass disparity in crashes involving cars
  - Decrease mass disparity in crashes involving light trucks and CUVs/minivans
- By end of simulation period:
  - Crashes involving cars have slightly higher mass disparity
  - Crashes involving light trucks and CUVs/minivans have much lower mass disparity

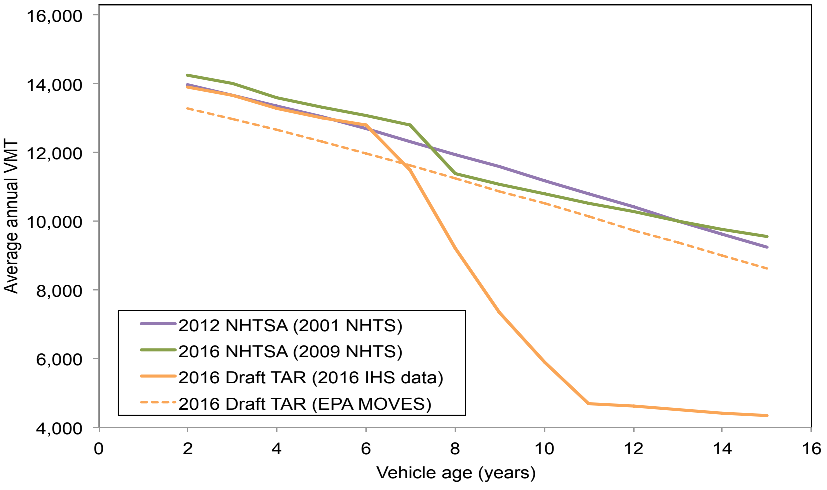


- Estimated change in fatalities
  - Car fatalities increase initially, but decrease after Year 16
  - CUV/minivan fatalities increase initially, but decrease after Year 9
  - Light truck fatalities decrease in Year 1
  - All fatalities are 1.2% higher in Year 1, 1.4% lower in Year 11, and 4.9% lower in Year 27
  - NHTSA baseline model estimates 1.4% decrease in fatalities in 2-vehicle crashes using NAS mass reductions

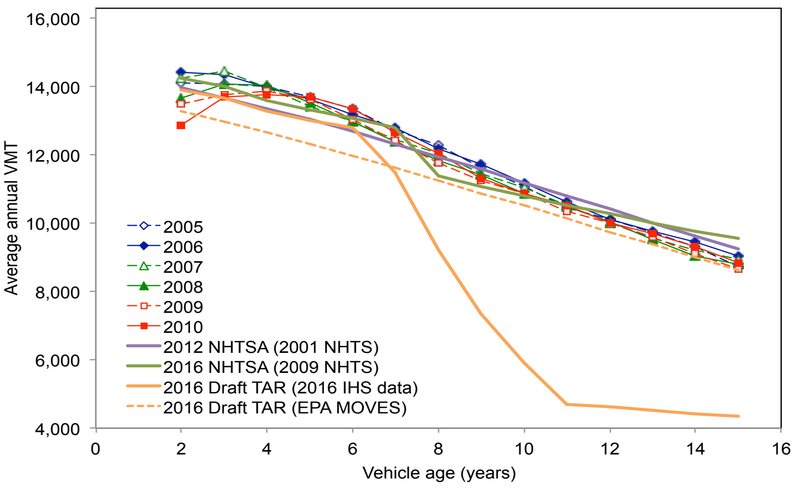


VMT schedule by vehicle age

- NHTSA VMT schedule (shown for cars)
  - Average VMT by age from 2001 National Household Transportation Survey (NHTS)
  - Analysis of 2009 NHTS introduced a one-year kink in curve for 8-year old cars
  - Analysis of 2016 IHS (Carfax) odometer data introduced a five-year kink in curve for 7-year old cars
  - Similar curves for light trucks
  - Substantially lower VMT for older vehicles lengthens the payback period of fuel economy technologies



- Annual odometer readings from TX
  - Emission program tests vehicles every year in four metro areas
  - Annual odometer readings from 7 million vehicles a year
  - Calculate annual VMT of individual vehicles by comparing odometer readings
  - TX data confirm previous VMT schedules, and refute recent schedules proposed by NHTSA



Response to Previous Year Reviewers' Comments

- Not reviewed last year

Collaboration and Coordination with Other Institutions

- Worked closely with NHTSA, EPA, and CARB on data, variables, and methodology used in regression analyses
- Reviewed and commented on 2016 NHTSA preliminary safety report and safety sections of 2016 Technical Assessment Report

Remaining Challenges and Barriers

- No challenges or barriers are identified for performing these analyses

Proposed Future Research

- Update Phase 1 and Phase 2 for Final Rule
  - One more year of data (MY2011 through calendar year 2012)
  - More recent odometer data from IHS/Carfax
  - Update analysis of fatalities in 2-vehicle crashes over time
  - Conduct analysis using DRI two-stage simultaneous method
- Update analyses for future review of federal standards

Any proposed future work is subject to change based on funding levels

Summary

- Regression analyses can inform regulators on what effect standards may have on safety…
- … but cannot predict that effect, especially given extensive use of new technologies and materials that breaks historical relationships
- Findings updated in 2016
  - Mass reduction in cars is associated with increases in risk similar to 2012
  - Mass reduction in light trucks and CUVs/minivans is more beneficial than in 2012
  - Effect of mass reduction on risk is overwhelmed by other vehicle, driver, and crash characteristics
  - Wide range in risk by vehicle models of similar mass, after accounting for vehicle, driver, and crash differences
  - Estimates are sensitive to data and variables used in regressions
  - NHTSA baseline estimates that NAS-recommended mass reduction would reduce fatalities
  - DRI measures and LBNL baseline estimate mass reduction could be even more beneficial
- Simulation of standards on mass disparity in two-vehicle crashes suggests fewer fatalities than NHTSA baseline regression
- TX odometer data confirm that VMT decreases linearly as vehicles age

Technical Back-Up Slides

Separate regression model for each of nine crash types

1. First-event rollover
2. Crash with stationary object
3. Crash with pedestrian/bicycle/motorcycle
4. Crash with heavy-duty vehicle
5. Crash with car/CUV/minivan < 3,157 lbs
6. Crash with car/CUV/minivan ≥ 3,157 lbs
7. Crash with light truck (pickup/SUV/van) < 4,303 lbs
8. Crash with light truck (pickup/SUV/van) ≥ 4,303 lbs
9. Other (mostly crashes involving 3+ vehicles)

- Market saturation of ESC assumed to reduce fatal crashes by:
  - Cars: rollovers by 60%, crashes with objects by 31%
  - Light trucks/CUVs/minivans: rollovers by 74%, crashes with objects by 45%
  - All: All other crashes by 7% in cars, 6% in light trucks/CUVs/minivans

- Coefficients by crash type reweighted by likely distribution after full adoption of ESC

Control variables

- Vehicle
  - UNDRWT00 (lbs less than average mass; 3,197 lbs for cars, 4,947 lbs for LTs)
  - OVERWT00 (lbs more than average mass; 3,197 lbs for cars, 4,947 lbs for LTs)
  - LBS100 (for CUVS/minivans only)
  - FOOTPRINT (wheelbase times track width)
  - Type: two-door car, SUV, heavy-duty (200/300 series) pickup, minivan
  - LT compatibility measure: bumper overlap, blocker beam
  - 5 side airbag variables: rollover curtain, curtain, torso, combo curtain/torso
  - ABS, ESC, AWD, vehicle age, if a brand new vehicle
- Driver
  - Male driver, 8 age variables: years younger/older than 50 (for age groups 14-30, 30-50, 50-70, 70-90, for male and female)
- Crash
  - At night, in rural county (<250 pop/sq mile), on road with 55+ mph speed limit, in high-fatality rate state (25 southern/mountain states, plus KS and MO)
  - Crash occurred in 2002, 2003, 2004, 2005, 2007, or 2008
- Not all variables used for each vehicle or crash type

Method to estimate registration and VMT weights

- 2.1 million non-culpable vehicles involved in two-vehicle crashes in 13 states
  - 6 crash states (AL, FL, KS, KY, MO, WY) represent states with high fatality rates
  - 7 crash states (MD, MI, NE, NJ, PA, WA, WI) represent states with low fatality rates
  - DRI proposed using 612,000 stopped vehicles involved in two-vehicle crashes
- Assign weight to each crash vehicle so that sum of weights equals total US vehicle registrations (from IHS Automotive), by MY and model
- Develop schedule of average annual VMT by vehicle age for cars and trucks, using 2009 National Household Travel Survey
- Use average odometer by make and model (from IHS Automotive/Carfax) to adjust annual VMT by make and model
- Regression model estimates the effect of 100-lb reduction in mass on societal fatalities per VMT, holding footprint constant

Analysis by vehicle model

- Logistic regression does not include a statistic for "goodness of fit" akin to R^2 in linear regression (how much of the variability in the data is explained by the regression model)
  - SAS includes a "pseudo-R^2", although different techniques give wildly different estimates
  - SAS pseudo-R^2 is less than 0.10 in NHTSA baseline regression
- LBNL analyzed relationship between mass and risk by vehicle model, using linear regression
  - Run logistic regression including all variables except mass and footprint
  - Estimate predicted risk, by applying coefficients for vehicle, driver and crash characteristics of induced exposure vehicles (and VMT)
  - (Residual risk = actual risk – predicted risk)
  - Run logistic regression including all variables
  - Estimate standardized risk for a 50-year old male driving a 4-year old vehicle in the day in a non-rural county on a high-speed road in a low-risk state
  - Adjusted risk = standardized risk * (actual risk / predicted risk)

19 alternative regression models in 2012 LBNL report

- Alternative definitions of risk
  1. Weighted by current distribution of fatalities (rather than after 100% ESC)
  2. Single regression model across all crash types (rather by crash type)
  3. Fatal crashes (rather than fatalities) per VMT
  4. Fatalities per induced exposure crash (rather than VMT)
  5. Fatalities per registered vehicle-year (rather than VMT)
- Alternative control variables/data
  6. Allow footprint to vary with mass (and vice versa)
  7. Account for 14 vehicle manufacturers
  8. Account for 14 manufacturers + 5 additional luxury vehicle brands
  9. Account for initial vehicle purchase price (based on Polk VIN decoder)
  10. Exclude CY variables
  11. Exclude crashes with alcohol/drugs
  12. Exclude crashes with alcohol/drugs, and drivers with poor driving record
  13. Account for median household income (based on vehicle zip code, from CA DMV data)
  14. Include sports, police, and all-wheel drive cars, and full size vans
- Suggested by DRI and peer reviewers
  15. Use stopped instead of non-culpable vehicles from 13-state crash data for induced exposure
  16. Replace footprint with track width and wheelbase
  17. Above two models combined
  18. Reweight CUV/minivans by 2010 sales
  19. Exclude non-significant control variables

14 additional regression models in 2016 update

- Different categories for light trucks

20. Exclude LTs over 10,000 GVWR (subject to HD truck rule)
21. Small pickups and SUVs analyzed separately from large pickups
22. Large pickups analyzed separately from small pickups and SUVs
23. Models 20 and 22 combined for large pickups

- Exclude certain types of cars

24. Include AWD cars, but not muscle or police cars
25. Include muscle and police cars, but not AWD cars
26. Exclude three high-risk car models
27. Include AWD cars, exclude three high-risk car models (Models 24 and 26)

- Two-piece variables

28. Use two-piece variable for CUV mass
29. Use two-piece variable for car and light truck footprint
30. Use two-piece variable for CUV mass, all footprint (Models 28 and 29)

- Changes to VMT weights

31. Remove kinks in NHTSA VMT schedules
32. Use Texas rather than IHS odometer ratios by vehicle model
33. Both adjustments to NHTSA VMT weights (Models 31 and 32)