An Assessment of the Effects of Passenger Vehicle Weight and Size on Accident and Fatality Risk Based on Data for 1991 through 2007 Model Year Vehicles

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Topics

- Acronyms
- Background
- Basic Methodology
- Results
- Discussion
- Summary and conclusions

Acronyms

CY – Calendar year

LTV – Light Truck or Van

- CUV – Crossover Utility
- SUV – Sport Utility Vehicle
- TBLTV – Truck based LTV
- Minivans

MY – Model Year

PC – Passenger Car

SV – Subject vehicle

Background

- Understanding the effects of vehicle weight and size on overall safety are necessary to assess the risks and benefits of weight reduction and other vehicle design goals such as improving fuel economy
- Early research
  - Assumed that weight and size were not independent and the effects of size were implicitly attributed to weight
  - Focused on self protection viewpoint (e.g., SV drivers)
  - Focused on specific crash types (e.g., front-front collisions)
  - Results indicated that weight and size reduction was harmful
- More recent research has focused on
  - Comprehensive models for all crash types and persons
  - Societal viewpoint (SV occupants and collision partners)
  - Independent effects of weight and size

Methodology: Fatality and Accident Risk Models

- Assumed two-stage model

$$\underbrace{\log\left(\frac{F}{E}\right)}_{\text{Measure of overall fatality risk}} = \underbrace{\log\left(\frac{F}{A}\right)}_{\text{Measure of crashworthiness \& crash compatibility}} + \underbrace{\log\left(\frac{A}{E}\right)}_{\text{Measure of crash involvement}}$$

  - *F* represents the number of fatalities (all persons)
  - *A* represents the number of accidents
  - *E* represents the amount of exposure
    - Number of registered vehicles (VRY), or
    - Number of vehicle miles traveled (VMT)

Methodology: Fatality and Accident Risk Models (cont'd)

- Assumed that each stage can be modeled by vehicle, driver, and environmental factors (x_i)

$$\log\left(\frac{F}{E}\right) = \beta_{F/E,0} + \sum_{i=1} \beta_{F/E,i}\ x_i + \varepsilon_{F/E}$$

$$\log\left(\frac{F}{A}\right) = \beta_{F/A,0} + \sum_{i=1} \beta_{F/A,i}\ x_i + \varepsilon_{F/A}$$

$$\log\left(\frac{A}{E}\right) = \beta_{A/E,0} + \sum_{i=1} \beta_{A/E,i}\ x_i + \varepsilon_{A/E}$$

where

- "β" are coefficients with unknown values to be estimated
- the effects of each stage are related

$$\beta_{F/E,i} = \beta_{F/A,i} + \beta_{A/E,i}$$

Methodology: Fatality and Accident Risk Models (cont'd)

- Vehicle weight and size variables - the main variables of interest
  - Subject vehicle curb weight
    - Linear
    - Piecewise linear
      - Introduced by NHTSA to address possible non-linear effects
  - Subject vehicle size
    - Wheelbase and track width
      - Related to pre-crash vehicle dynamics
      - Related to vehicle length and width, which are related to crashworthiness and crash compatibility
    - Footprint
      - Equal to wheelbase x track width
      - Related to proposed fuel economy rules

Methodology: Fatality and Accident Risk Models (cont'd)

- Other control variables – selected by NHTSA that may also affect safety and are available in the accident and exposure databases
  - Other vehicle-related factors
    - Subtype (e.g., 2-door car, SUV)
    - Equipment (e.g., ABS, ESC, airbags)
    - Vehicle age
  - Driver
    - Age group
    - Sex

    (these variables also represent mean values for various other driver factors correlated with these variables, e.g., risk taking)
  - Environment and other factors
    - Rural or urban road, High or low speed limit, Daytime or nighttime
    - State group (higher or lower than average fatality rate)
    - Calendar year (for other changes over time)

Methodology: Data

Attribute	Phase I	Phase II
Calendar years	1995-2000	2002-2008
Model years	1991-1999	2000-2007
Fatal accident data	US FARS	US FARS[2]
Non-fatal accident data	8 States	10 States
Induced-exposure data[1]	8 States	13 States[2]
Vehicle types	PC, LTV	PC, TBLTV, Minivan/CUV
Crash types (all crashes)	6 Crash types	9 Crash types

- Comprehensive, with some exceptions (e.g., Phase I excluded 2-door PC, Phase II excluded midsize vans)

[1]Induced-exposure is defined on the next slide

[2]Data was reduced by NHTSA

Methodology: Induced-Exposure Data

- Case-by-case data that provides exposure information about the vehicle drivers and environment (e.g., driver age, nighttime, rural road, and speed limits) in order to control for driver and environmental risk factors
  - Cases from state accident data using one of two methods:
    - Stopped-vehicle case selection criteria (Kahane (1997) method)
      - Subject vehicle was legally stopped
    - Non-culpable vehicle criteria (Kahane (2003+) method)
      - Other vehicle driver was at-fault based on coded data
      - Subject vehicle driver was not at-fault based on coded data
  - Assumes the cases are randomly sampled from exposure
    - SV drivers were blamelessly involved in the crash
- Cases are weighted such that aggregated data represents make-model-year VRY or VMT

Methodology: Induced-Exposure Data (Cont'd)

- Comparison of VMT weighted average values for non-culpable vehicle and stopped vehicle induced-exposure data indicate:
  - Vehicle, region, and CY variables are nearly the same
  - Driver and environmental exposure are different

Data Variable	Mean VMT Weighted Value		Percent Difference
	Non-Culpable Vehicle	Stopped-Vehicle	
CURBWT	3780.9	3780.5	n.s.
TRAKWDTH	61.62	61.62	n.s.
WB_MIN	113.52	113.52	n.s.
FOOTPRNT	48.81	48.80	n.s.
VEHAGE	2.857	2.857	n.s.
BRANDNEW	0.121	0.121	n.s.
DRVMALE	0.509	0.494	3.0%
M14_30	0.846	0.726	15.2%
M30_50	4.803	4.532	5.8%
M50_70	1.627	1.533	6.0%
M70PLUS	0.187	0.149	22.8%
F14_30	0.977	0.904	7.7%
F30_50	5.154	5.197	-0.8%
F50_70	1.166	1.102	5.6%
F70PLUS	0.112	0.086	25.8%
NITE	0.174	0.154	12.1%
RURAL	0.214	0.198	8.0%
SPDLIM55	0.168	0.123	31.4%
HIFAT_ST	0.407	0.407	n.s.
CY2002	0.075	0.075	n.s.
CY2003	0.100	0.100	n.s.
CY2004	0.125	0.125	n.s.
CY2005	0.149	0.149	n.s.
CY2006	0.171	0.171	n.s.
CY2007	0.191	0.191	n.s.
CY2008	0.188	0.188	n.s.
Number of cases	2,457,228	677,146	113.6%
VMT weighted cases	8,443,608,546,981	8,441,562,071,535	0.02%
Average weighting	3,436,233	12,466,384	-113.6%

Methodology: Model Coefficient Estimation Methods

- The model "β" coefficients were estimated by logistic regressions of case-by-case data
  - One-stage models for Fatalities/Exposure (F/E)
    - Based on data for individual
      - Fatal cases
      - VRY or VMT weighed induced-exposure cases
  - Two-stage models for F/A, A/E, and F/E
    - Based on data for individual fatal, non-fatal, and exposure cases
    - Model coefficients were constrained to be consistent using a "simultaneous three-way" method

$$\beta_{F/E,i} = \beta_{F/A,i} + \beta_{A/E,i}$$

Results: Candidate Models

- The one-stage and two-stage models were evaluated using the following candidate vehicle size variables and types of induced-exposure data

Model	Size Variables	Induced-Exposure
A	Wheelbase Track width	Stopped-vehicle
B	Wheelbase Track width	Non-culpable vehicle
C	Footprint	Stopped-vehicle
D*	Footprint	Non-culpable vehicle

*NHTSA's preferred baseline model for their 2011 and 2012 reports

Results: Phase I (1991-1999 MY)

- One-stage model results for Fatalities/VRY
  - Sensitive to data and methods, e.g.,
    - Induced-exposure method
      - Stopped-vehicle
      - Non-culpable vehicle
  - Similar to Kahane (2003, 2010) provided the data and methods were the same
    - Data were independently reduced by DRI and NHTSA

Results: Phase I (1991-1999 MY)

- Two-stage model results
  - Similar to DRI one-stage results but not exactly the same
    - Differences may be due to unmodeled factors that affect accident risk and reporting, e.g.
      - State data not available for some years
      - Different state accident severity reporting thresholds
    - One-stage and two-stage weight and size results are in close agreement
  - Therefore also sensitive to data and methods
    - Accidents/Exposure results are sensitive to the induced-exposure method

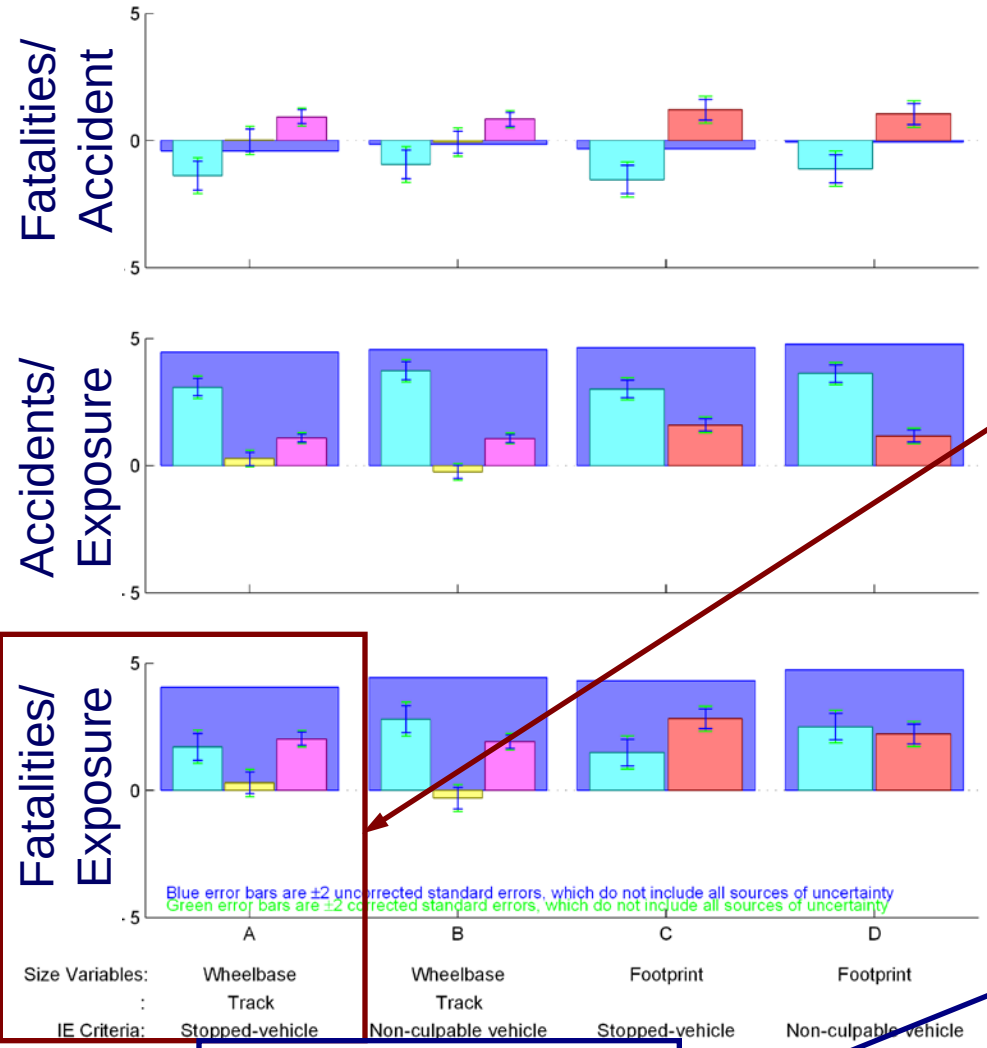
Results: Phase II (2000-2007 MY)

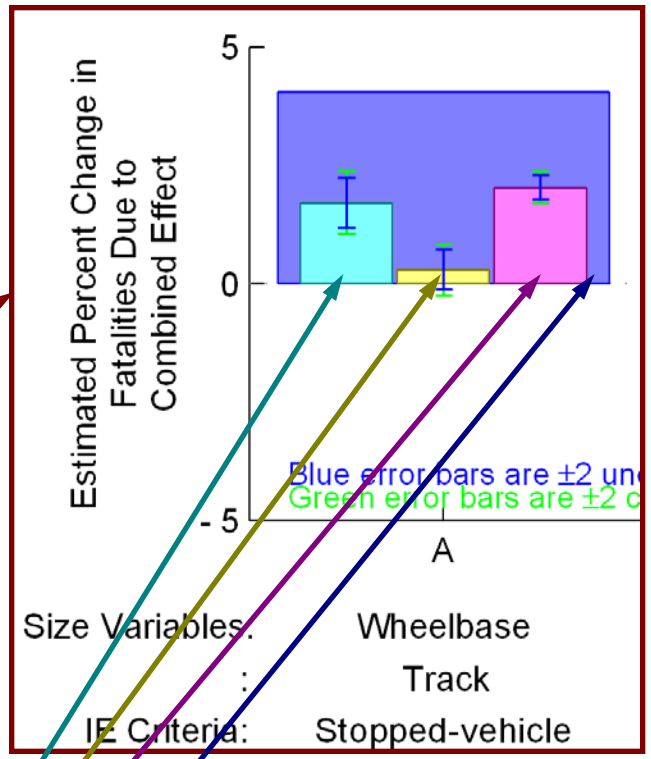
- One-stage model results for Fatalities/VMT
  - Sensitive to data and methods, e.g.,
    - Induced-exposure method
      - Stopped-vehicle
      - Non-culpable vehicle
    - Vehicle size terms in the model
      - Wheelbase and track width
      - Footprint
    - Exposure measure
      - Vehicle miles traveled
      - Vehicle registration years
  - All results very close to Kahane (2012) results
    - Using NHTSA reduced fatal and exposure data

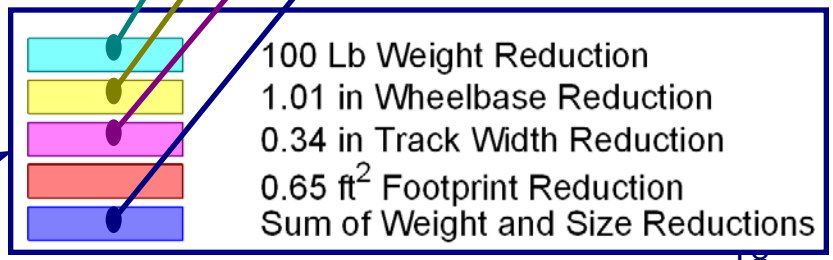
Results: Phase II (2000-2007 MY)

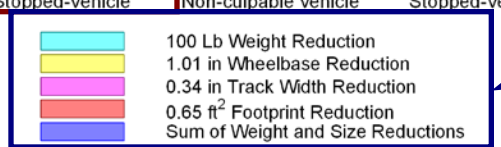
- Two-stage model results
  - Results are similar to NHTSA and DRI one-stage results but not exactly the same
    - Differences may be due to unmodeled factors that affect accident risk and reporting
    - One-stage and two-stage weight and size results are in close agreement
  - Therefore also sensitive to data and methods
    - Accidents/Exposure results are sensitive to the induced-exposure method

Results:
Bar Chart Key



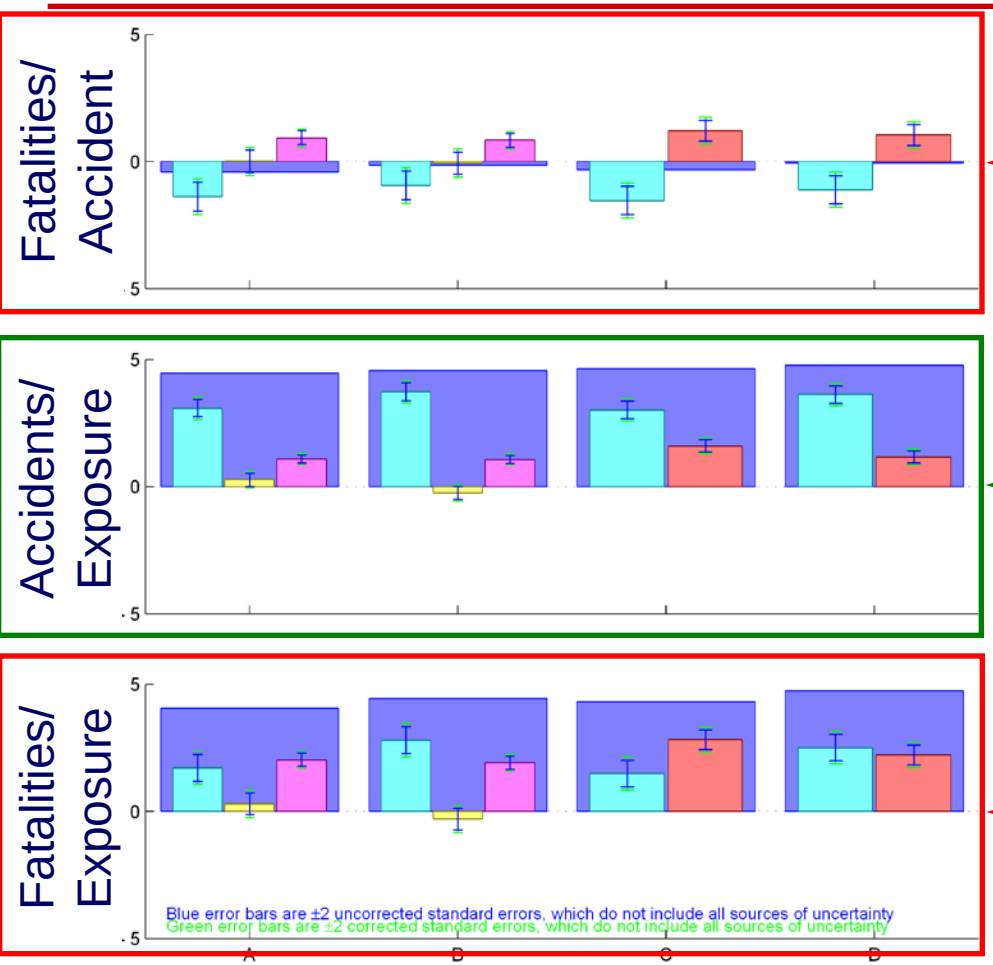






Results:

Stages are arranged in Rows



Fatalities/Accident is a measure of crashworthiness and crash compatibility

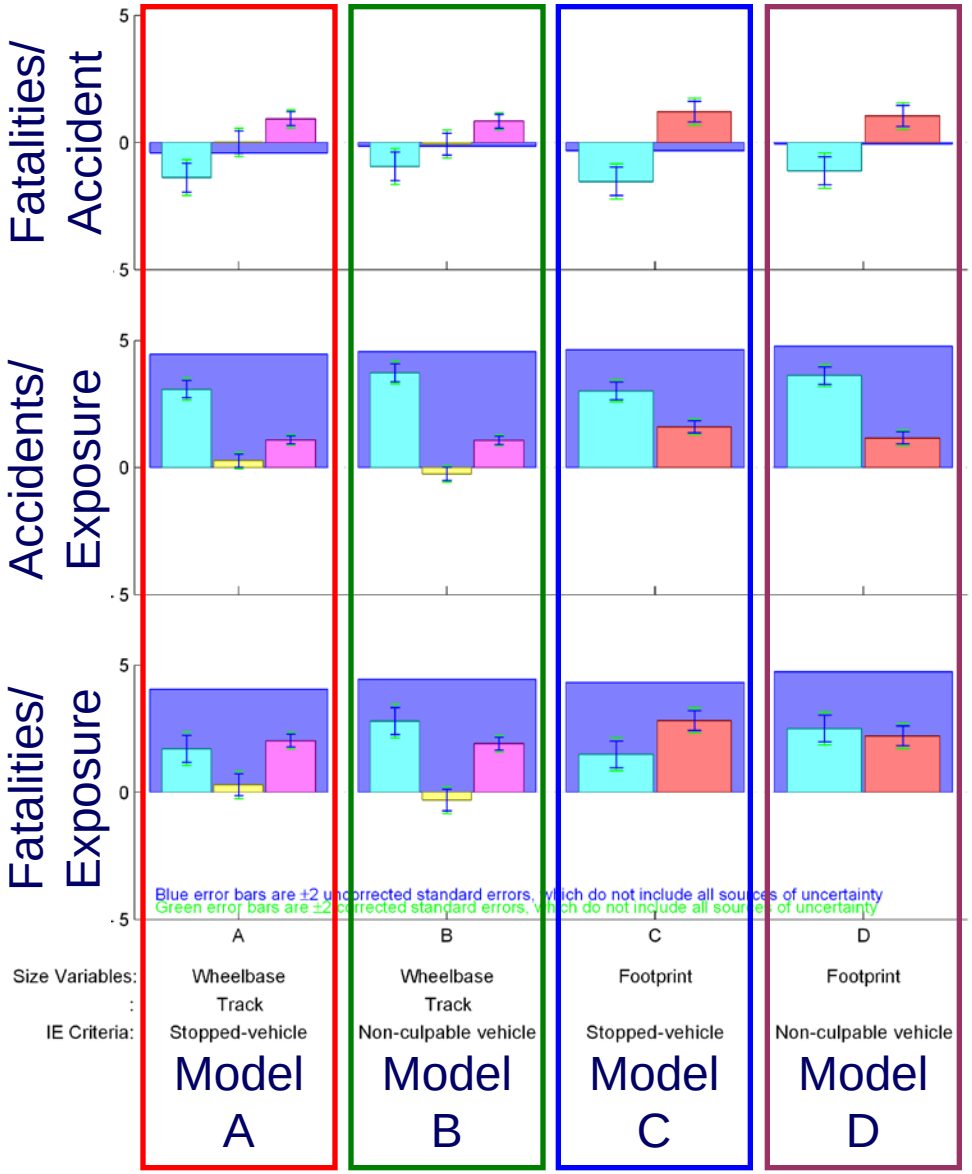
+

Accidents/Exposure (e.g., VRY or VMT) is a measure of crash involvement

=

Fatalities/Exposure is a combined measure of crash involvement, crashworthiness and crash compatibility

Results:
Models are arranged in Columns



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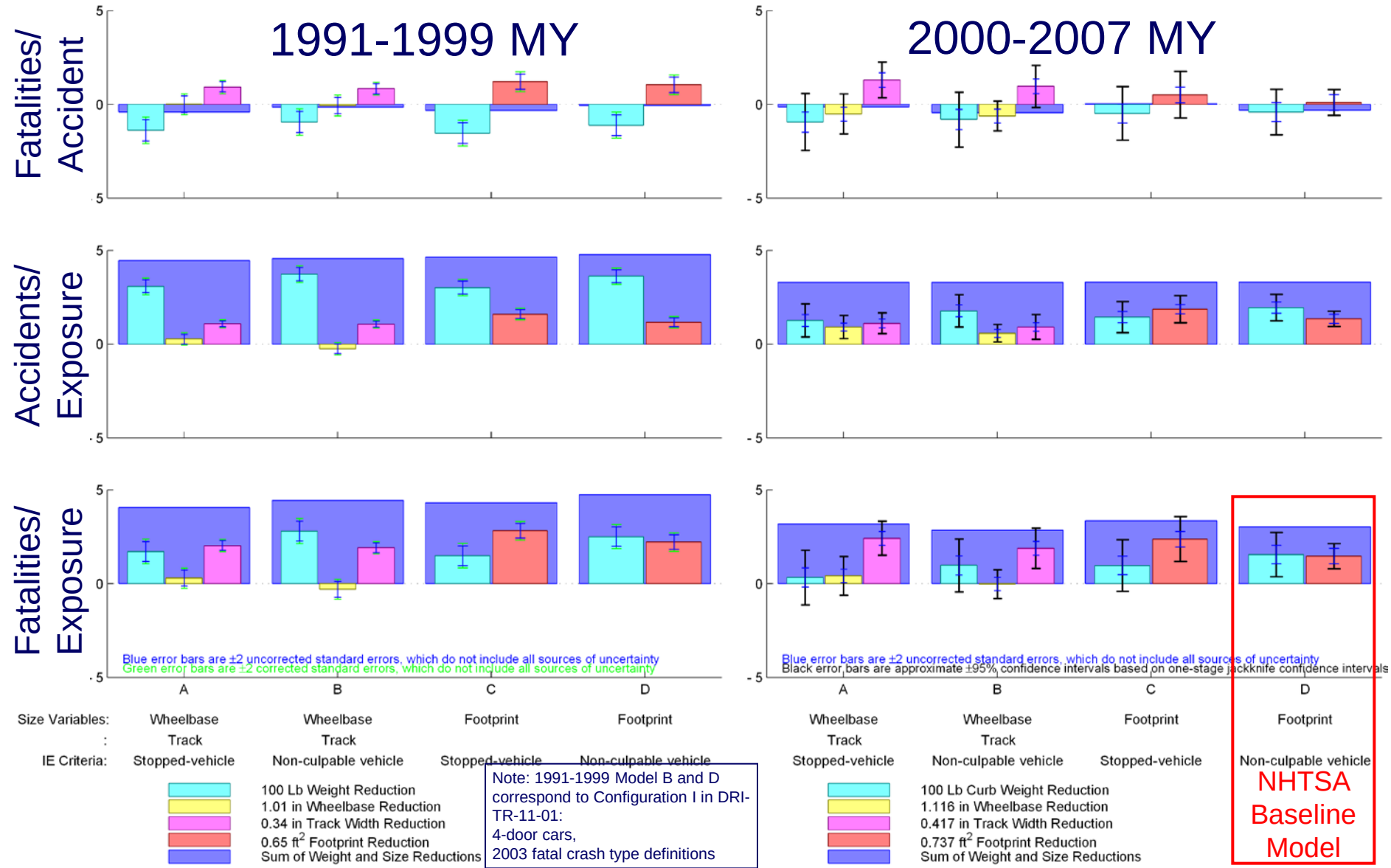
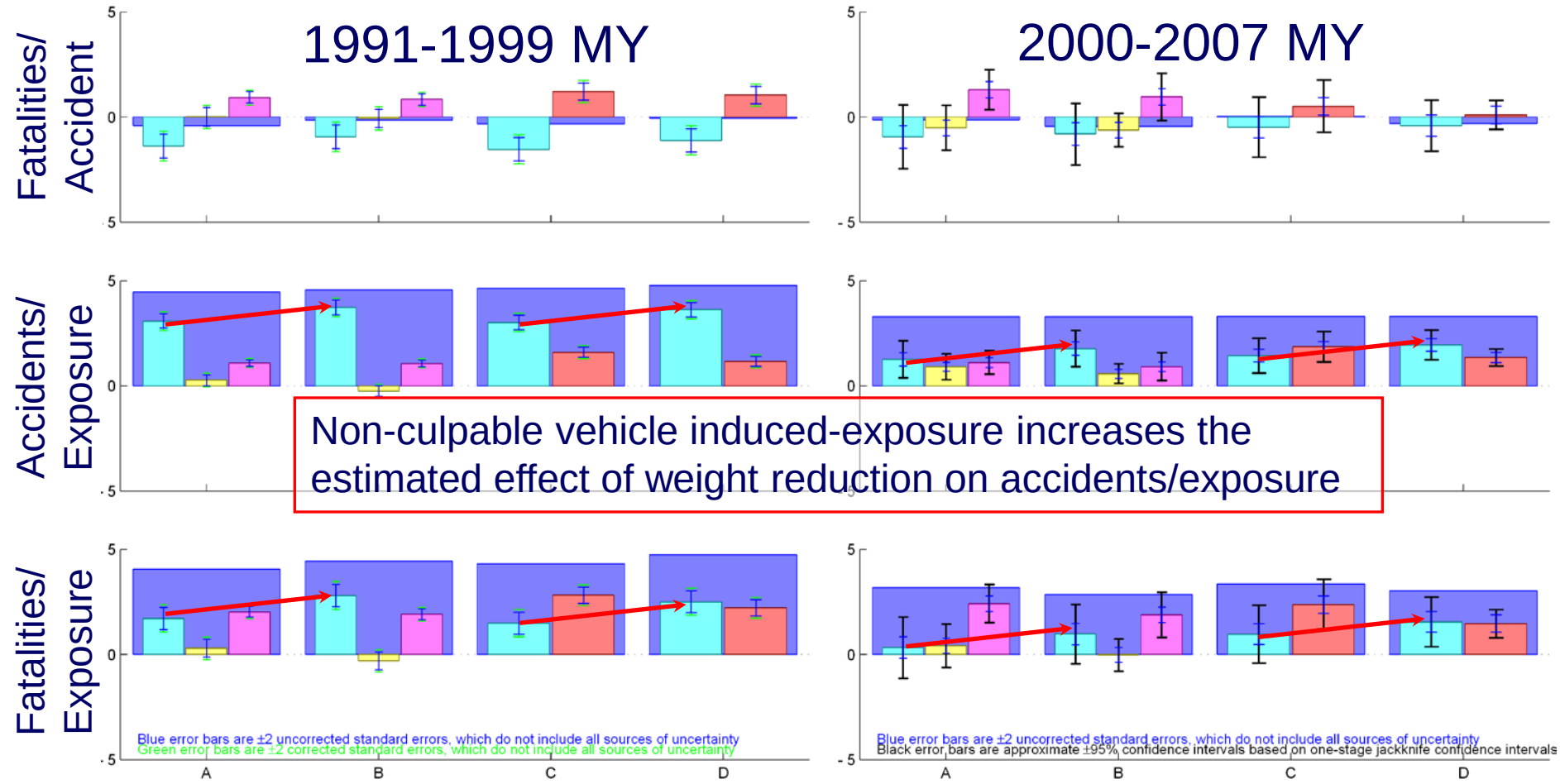
Results:
Lighter Passenger Cars



Note: 1991-1999 Model B and D correspond to Configuration I in DRI-TR-11-01:
4-door cars,
2003 fatal crash type definitions

Dynamic Research, Inc.

Results:
Lighter Passenger Cars



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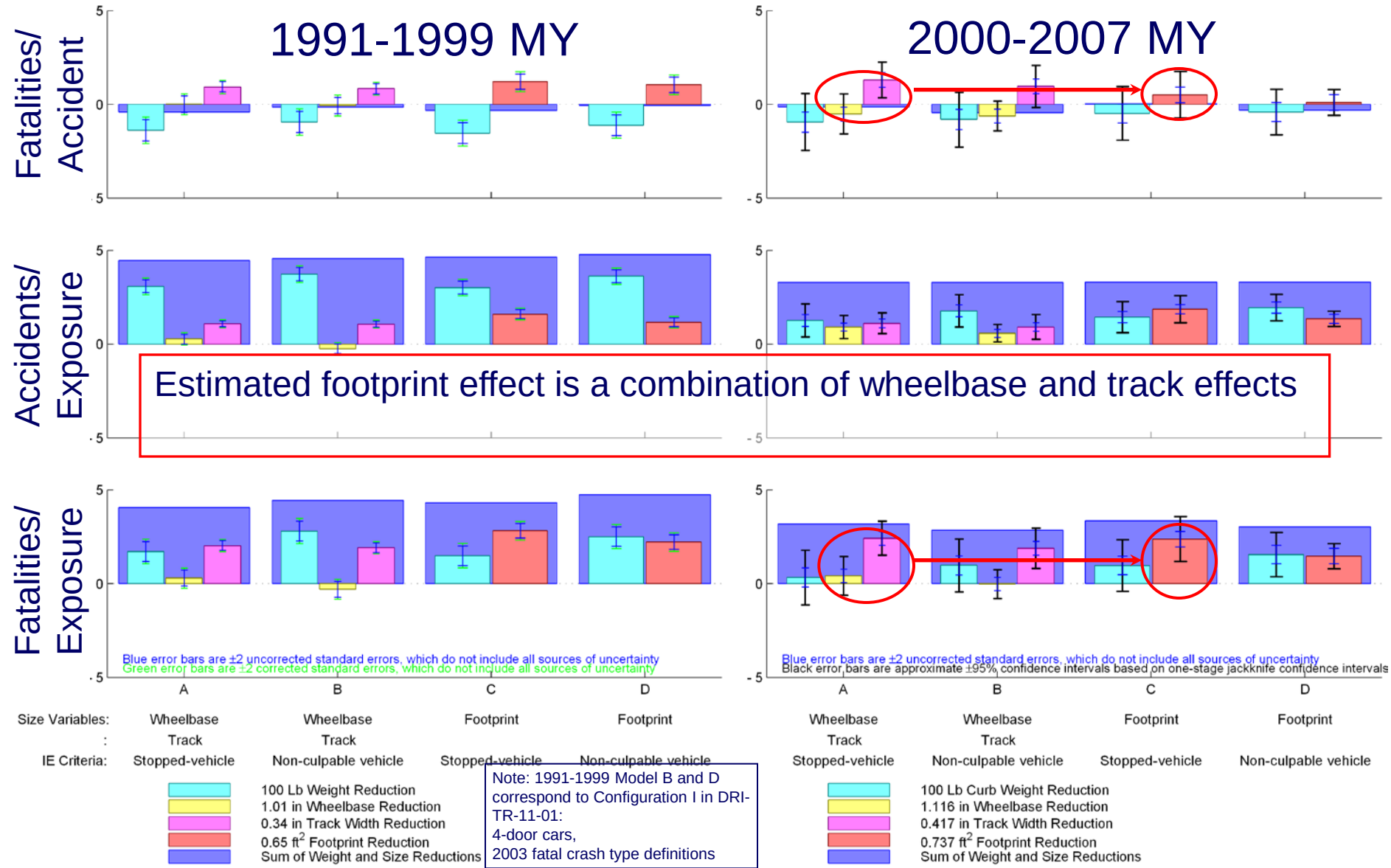
Lighter Passenger Cars



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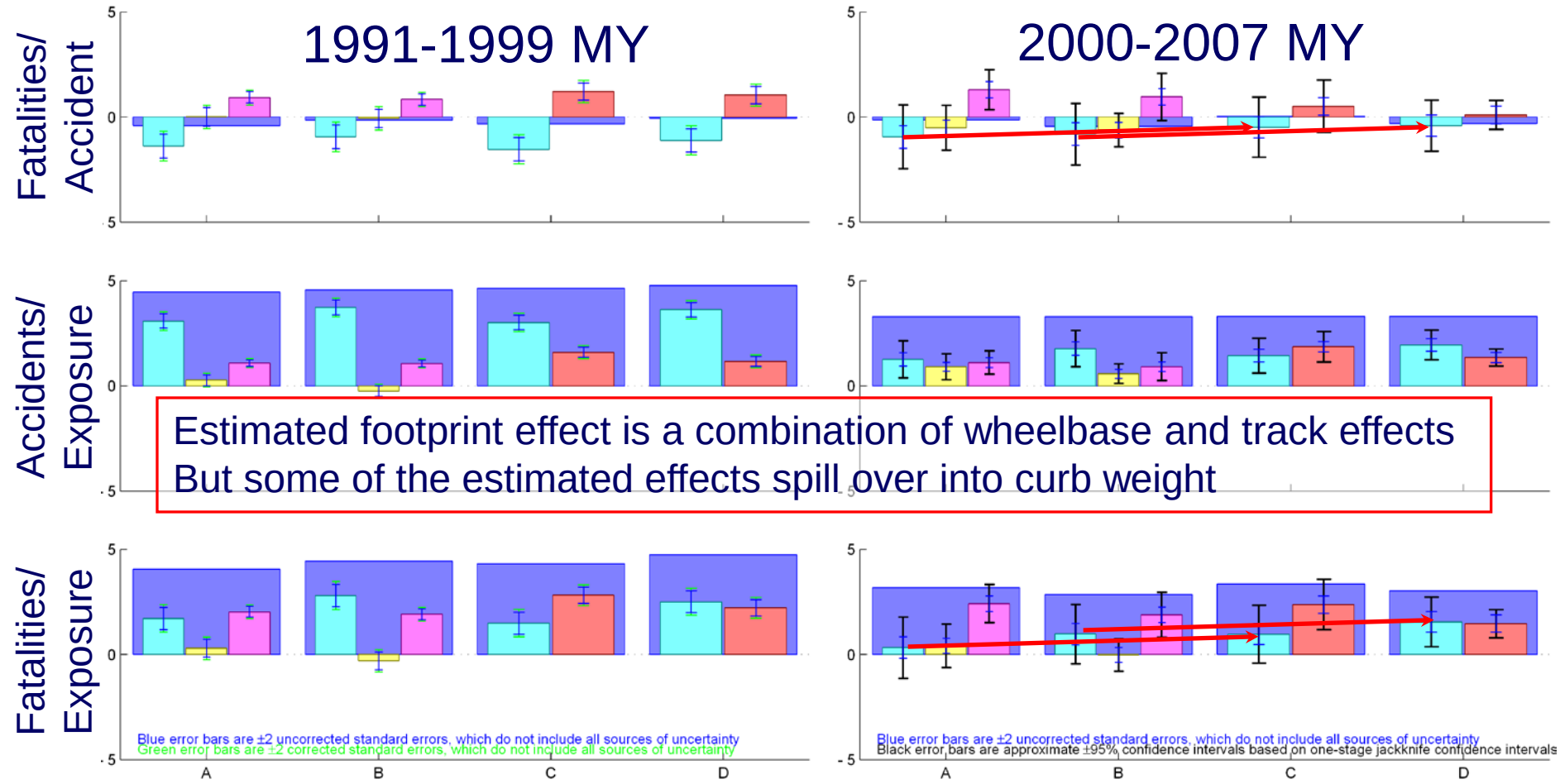

	A	B	C	D	A	B	C	D
Size Variables:	Wheelbase	Wheelbase	Footprint	Footprint	Wheelbase	Wheelbase	Footprint	Footprint
:	Track	Track			Track	Track		
IE Criteria:	Stopped-vehicle	Non-culpable vehicle	Stopped-vehicle	Non-culpable vehicle	Stopped-vehicle	Non-culpable vehicle	Stopped-vehicle	Non-culpable vehicle

100 Lb Weight Reduction
1.01 in Wheelbase Reduction
0.34 in Track Width Reduction
0.65 ft^2 Footprint Reduction
Sum of Weight and Size Reductions

Note: 1991-1999 Model B and D correspond to Configuration I in DRI-TR-11-01:
4-door cars,
2003 fatal crash type definitions

100 Lb Curb Weight Reduction
1.116 in Wheelbase Reduction
0.417 in Track Width Reduction
0.737 ft^2 Footprint Reduction
Sum of Weight and Size Reductions

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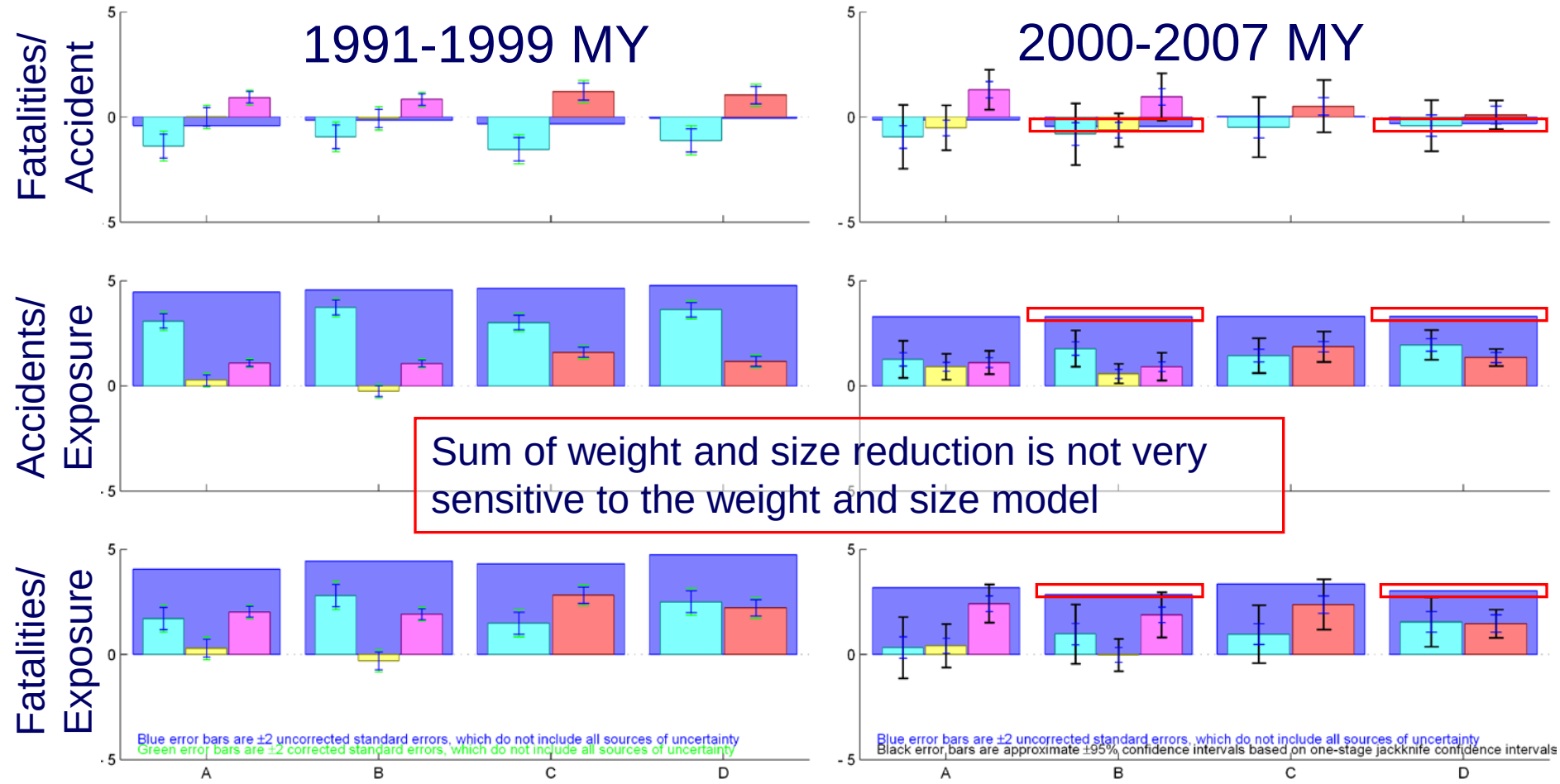
Results:
Lighter Passenger Cars



	A	B	C	D	A	B	C	D
Size Variables:	Wheelbase	Wheelbase	Footprint	Footprint	Wheelbase	Wheelbase	Footprint	Footprint
:	Track	Track			Track	Track		
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100 Lb Weight Reduction
1.01 in Wheelbase Reduction
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Sum of Weight and Size Reductions

Note: 1991-1999 Model B and D correspond to Configuration I in DRI-TR-11-01:
4-door cars,
2003 fatal crash type definitions

100 Lb Curb Weight Reduction
1.116 in Wheelbase Reduction
0.417 in Track Width Reduction
0.737 ft^2 Footprint Reduction
Sum of Weight and Size Reductions

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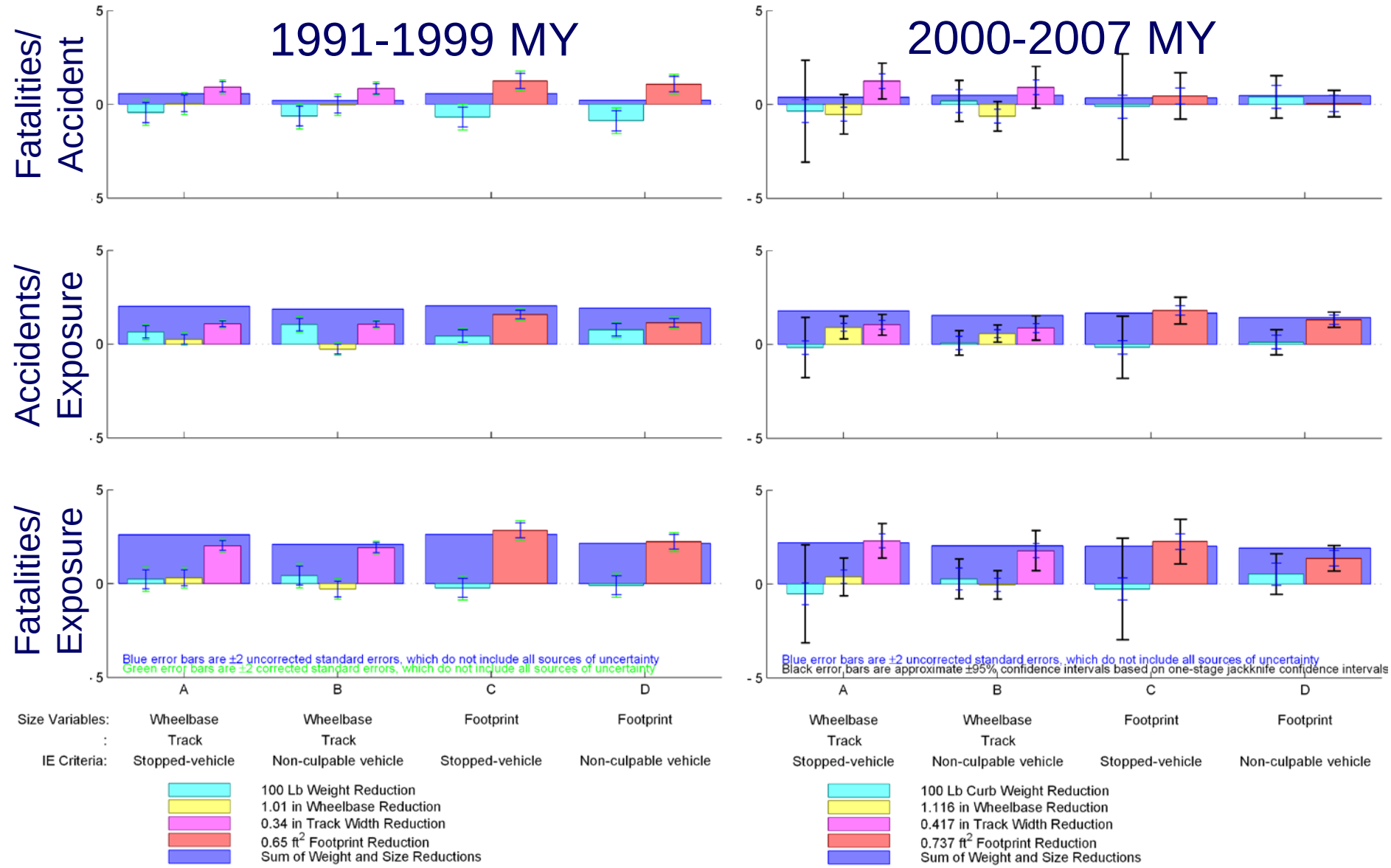
Results:
Heavier Passenger Cars



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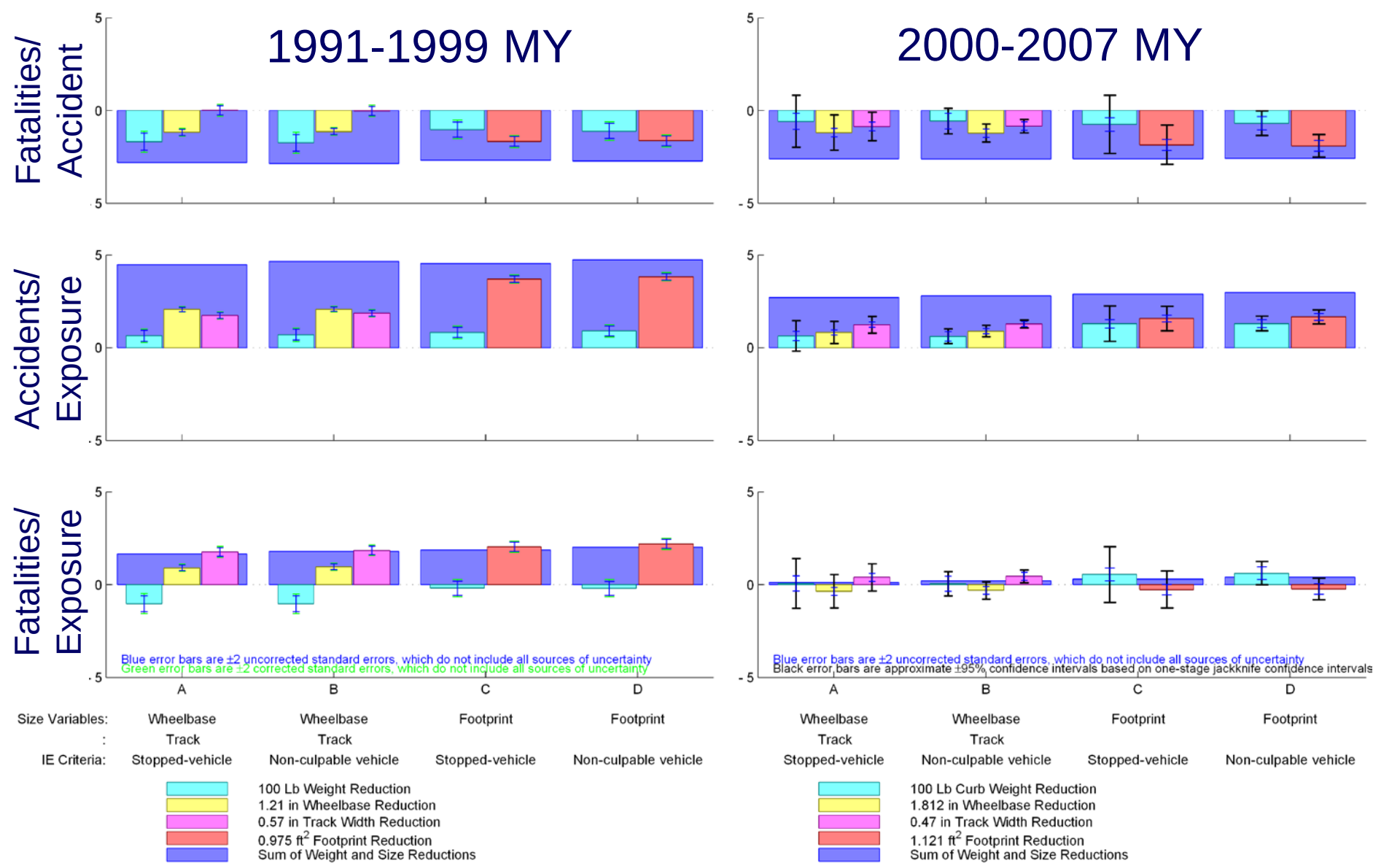
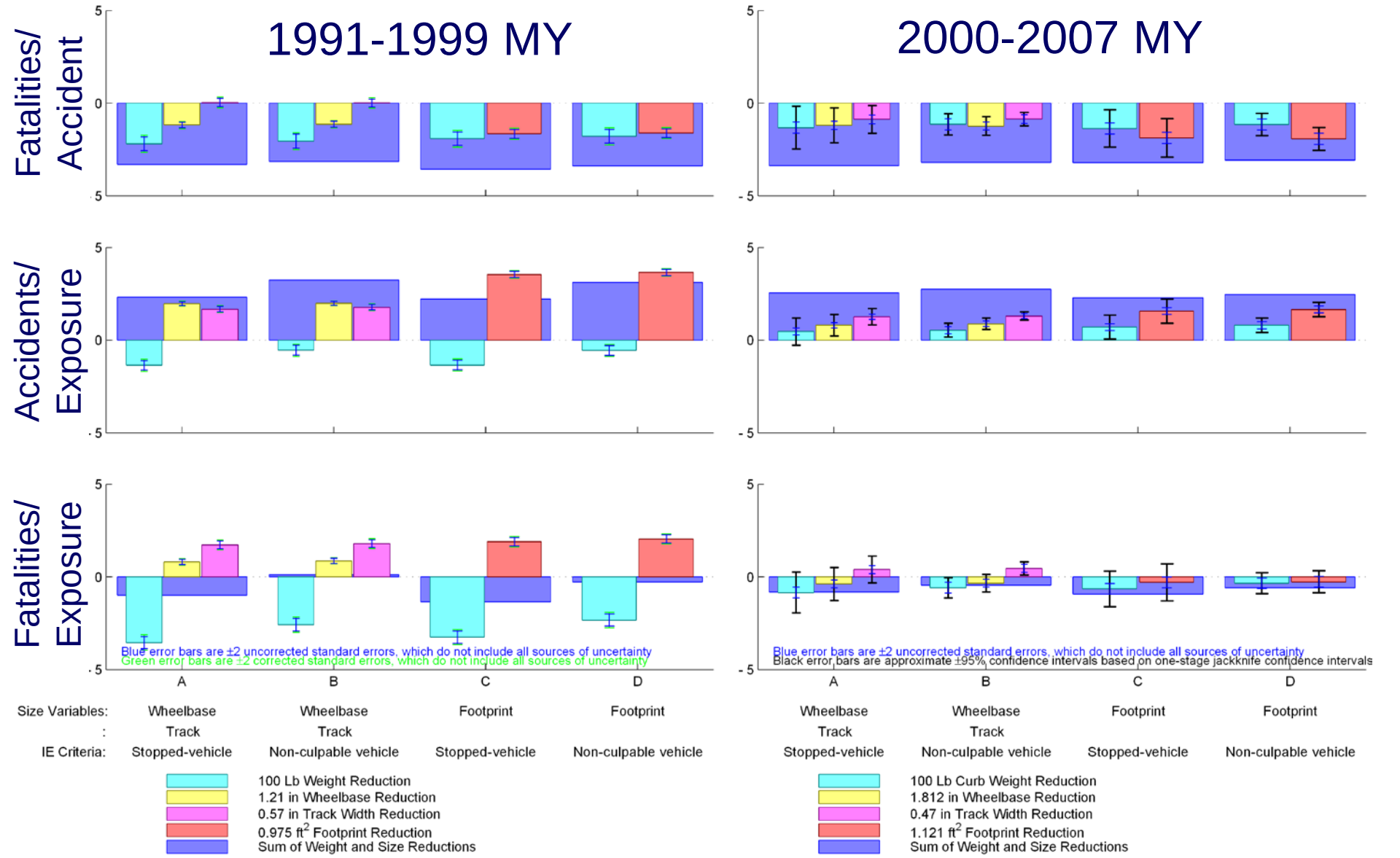
Results: Lighter LTVs



Dynamic Research, Inc.

Results: Heavier LTVs



Discussion: Common Observations

- Common observations based on Phase I and II results based on different data
  - The estimated combined effect of weight and size reduction is not very sensitive to the size model (wheelbase and track width vs. footprint)
    - The estimated effect of curb weight does depend on the size model
  - Combined effect of weight and size reduction
    - Has a small effect on or tends to reduce Fatalities/Accident (crashworthiness and compatibility) depending on the vehicle type
    - Tends to increase Accidents/Exposure (crash involvement)
      - Reasons are unknown at this time but might be due to factors that have not been controlled for, such as driver risk-taking

Discussion: Common Observations (Cont'd)

- Common Phase I and II results for passenger cars
  - Estimated effects of
    - PC weight reduction on Fatalities/Accident are small (not statistically significant) or to decrease fatalities
    - PC wheelbase reduction on Fatalities/Accident are small (not statistically significant)
    - PC track width (or footprint) reduction on Fatalities/Accident or Accidents/Exposure are either small or to increase fatalities
    - Combined effects of PC track width (or footprint) reduction on Fatalities/Exposure are to increase fatalities

Discussion: Common Observations (Cont'd)

- Common Phase I and II results for passenger cars (cont'd)
  - The relatively small estimated effect of curb weight and wheelbase (or footprint) reduction on passenger car crashworthiness and crash compatibility may be due to an equalizing effect of crash based Safety Standards, NCAP tests, IIHS tests, star ratings, and intelligent vehicle design
  - Use of non-culpable vehicle induced-exposure data tends to increase the estimated increase in Accidents/Exposure (and therefore fatalities) due to PC weight reduction, compared to the stopped-vehicle induced-exposure data

Discussion: Common Observations (Cont'd)

- Common Phase I and II results for truck based LTVs
  - The estimated effects of LTV wheelbase or footprint reduction are to
    - Decrease Fatalities/Accident
    - Increase Accidents/Exposure
  - The estimated effects of LTV track width reduction are to increase Accidents/Exposure

- Other results such as the estimated effect of LTV weight reduction were mixed or not statistically significant, depending on the model years and weight group

Discussion

- Differences between Phase I and Phase II
  - The estimated effects of lighter car and lighter LTV weight and size reduction on increased crash involvement was smaller for the 2000-2008 MY vehicles, and this decreased the overall numbers of fatalities, compared to the 1991-1999 MY vehicles
    - This is a desirable long term trend if it continues
- Phase II results also indicated that
  - The estimated effects of weight reduction on overall fatalities were not statistically significant in all passenger vehicle types, weight groups, and size models with some exceptions (which may be due to random chance)

Limitations

- There are a number of limitations to these results, including
  - Results are based on past data, which may not be predictive of future trends or future vehicles
  - The induced-exposure data may not be representative sample of US exposure
  - The results may depend on the choice of control variables used in the analysis

Summary and Conclusions

- The effects of vehicle weight and size were estimated in two phases using different data sets:
  - Phase I: 1991-1999 MY vehicles in the 1995-2000 CY
  - Phase II: 2000-2007 MY vehicles in the 2002-2008 CY
  - Similar results suggest results are robust

- Overall results tend to confirm the one-stage model results reported by NHTSA provided the same data and methods are used

Summary and Conclusions

- Results based on the latest available data indicate that the estimated effects of weight reduction on fatalities:

Volpe Model Coefficients (One-Stage Model Results)

Light Passenger Vehicle Type	Estimated Percentage Change In Fatalities due to a 100 Pound Curb Weight Reduction			
Induced-Exposure	Non-Culpable Vehicle		Stopped-Vehicle	
Weight and Size Parameters	Curb Weight and Footprint	Curb Weight, Wheelbase and Track Width	Curb Weight and Footprint	Curb Weight, Wheelbase and Track Width
	Pt. Est. ± CI	Pt. Est. ± CI	Pt. Est. ± CI	Pt. Est. ± CI
Cars Weighing Less Than 3106 lbs	**1.56% ± 1.17%**	0.96% ± 1.41%	0.97% ± 1.37%	0.26% ± 1.46%
Cars Weighing 3106 lbs or More	0.51% ± 1.09%	0.24% ± 1.06%	-0.62% ± 2.70%	-0.90% ± 2.61%
Truck Based LTVs Weighing Less Than 4594 lbs	0.52% ± 0.63%	-0.07% ± 0.66%	0.35% ± 1.50%	-0.10% ± 1.34%
Truck Based LTVs Weighing 4594 lbs or More	-0.34% ± 0.56%	**-0.58% ± 0.55%**	-0.80% ± 0.96%	-0.96% ± 1.10%
Minivans and CUVs	-0.38% ± 1.11%	-0.25% ± 1.17%	-0.32% ± 1.46%	-0.14% ± 1.67%

  - Are small and not statistically significant for most of the vehicle types/weight groups, size models, and induced-exposure data considered, with a few exceptions (therefore may be due to random chance)

Summary and Conclusions

- Results based on the latest available data indicate that the estimated effects of weight reduction on fatalities:

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- Are small considering the range of estimates and confidence intervals for the different models considered

Summary and Conclusions

- Results based on the latest available data indicate that the estimated effects of weight reduction on fatalities:

Volpe Model Coefficients (One-Stage Model Results)

Light Passenger Vehicle Type	Estimated Percentage Change In Fatalities due to a 100 Pound Curb Weight Reduction			
	Induced-Exposure	Non-Culpable Vehicle		Stopped-Vehicle	
	Weight and Size Parameters	Curb Weight and Footprint	Curb Weight, Wheelbase and Track Width	Curb Weight and Footprint	Curb Weight, Wheelbase and Track Width
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Minivans and CUVs		-0.38% ± 1.11%	-0.25% ± 1.17%	-0.32% ± 1.46%	-0.14% ± 1.67%

- Crash based Safety Standards, NCAP tests, IIHS tests, star ratings and intelligent vehicle design may tend to decrease the effects of weight and size reduction on crashworthiness and crash compatibility

Summary and Conclusions

- More detailed discussion of methods, data, and results in the following reports and SAE paper
  - Phase I report
    - Original, January 2012 (DRI-TR-11-01, NHTSA-2010-0152-0030)
    - Peer reviewed, forthcoming (DRI-TR-11-01-1)
  - Phase II report
    - Preliminary, Revised June 2012 (DRI-TR-12-01-1, NHTSA-2010-0152-0038)
    - Updated and peer reviewed, forthcoming (DRI-TR-13-02)
  - Summary report
    - Original, Revised June 2012 (DRI-TR-12-01-1, NHTSA-2010-0152-0039)
    - Updated and peer reviewed, forthcoming (DRI-TR-13-04)
  - SAE Paper 2013-01-0747

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- The Energy Foundation

Questions

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Thank You!