

# **UPDATED ANALYSIS OF THE EFFECTS OF PASSENGER VEHICLE SIZE AND WEIGHT ON SAFETY**

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## TOPICS

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### 1. Overview of Past DRI studies

#### A. Cross-sectional analyses primarily based on Kahane (1997) methods

- 2002, 2003, 2004, 2005

#### B. Fleet multi-body computer simulations

- 2004, 2007

### 2. New DRI "Phase 1" Study

- Update the DRI (2004, 2005) analysis based on Kahane (2003) methods and data
- Investigate why DRI (200x) and Kahane (2003) results are different

## TOPICS

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### 3. Planned DRI “Phase 2” Study

- Update the DRI analysis based on NHTSA’s shared databases (i.e., updated to the 2008 model year and calendar year)

### 4. Potential DRI “Phase 3” Study

- Will review and investigate forthcoming Kahane (2011) methods and results
  - Are there differences between Kahane (2011) and DRI (2011)?
- Investigate other analytical approaches that may be appropriate
- Are there clear drivers of safety? (weight, size, etc.)

## TERMINOLOGY

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A – Number of accidents

F – Number of fatalities

VRV – Number of vehicle registration years

VMT – Number of vehicle miles traveled

IE – Number of induced-exposure cases

- Non size and weight related crashes, for purpose of determining vehicle exposure, including driver and environmental factors
- Two types:
  - “Stopped vehicle” – as determined by Kahane (1997)
  - “Non-culpable vehicle” – as determined by Kahane (2003)

# 1) OVERVIEW OF PAST DRI STUDIES

## A. DRI Cross-Sectional Studies of US Accident Data

Year	Methods	Body Types <sup>1</sup>	Result	Size and Weight	Rate	Data	States	Method	Report/Docket
2002	Kahane (1997)	All PC All LTV <sup>2</sup>	F/VRVY	Curb weight (only)	F/VRVY	Aggregated	50	Linear Regression	DRI-TR-02-02 NHTSA-2003-16318-2
2003	Based on Kahane (1997) Chapters 3 and 4	All PC All LTV <sup>2</sup>	F/A	Curb weight	F/A	Disaggregated	7	Logistic Regression	DRI-TR-03-01 NHTSA-2003-16318-3
			A/VRVY F/VRVY	Wheelbase Track	A/IE IE/VRVY	Aggregated	7	Linear	
2004	Weighted Logistic Regression adapted from Kahane (2003)	All PC	F/A A/VRVY F/VRVY	Curb weight Wheelbase Track	IE/VRVY	Disaggregated	7	Weighted Logistic Regression	DRI-TR-04-02 NHTSA-2003-16318-7
2005	Weighted Logistic Regression adapted from Kahane (2003)	All LTV <sup>2</sup>	F/A A/VMT F/VMT	Curb weight Wheelbase Track	IE/VMT	Disaggregated	7	Weighted Logistic Regression	DRI-TR-05-01 NHTSA-2003-16318-17

Note:

<sup>1</sup> Main results

<sup>2</sup> All LTV except large vans

### Note:

“Aggregated” data are data grouped by make-model-year, etc.

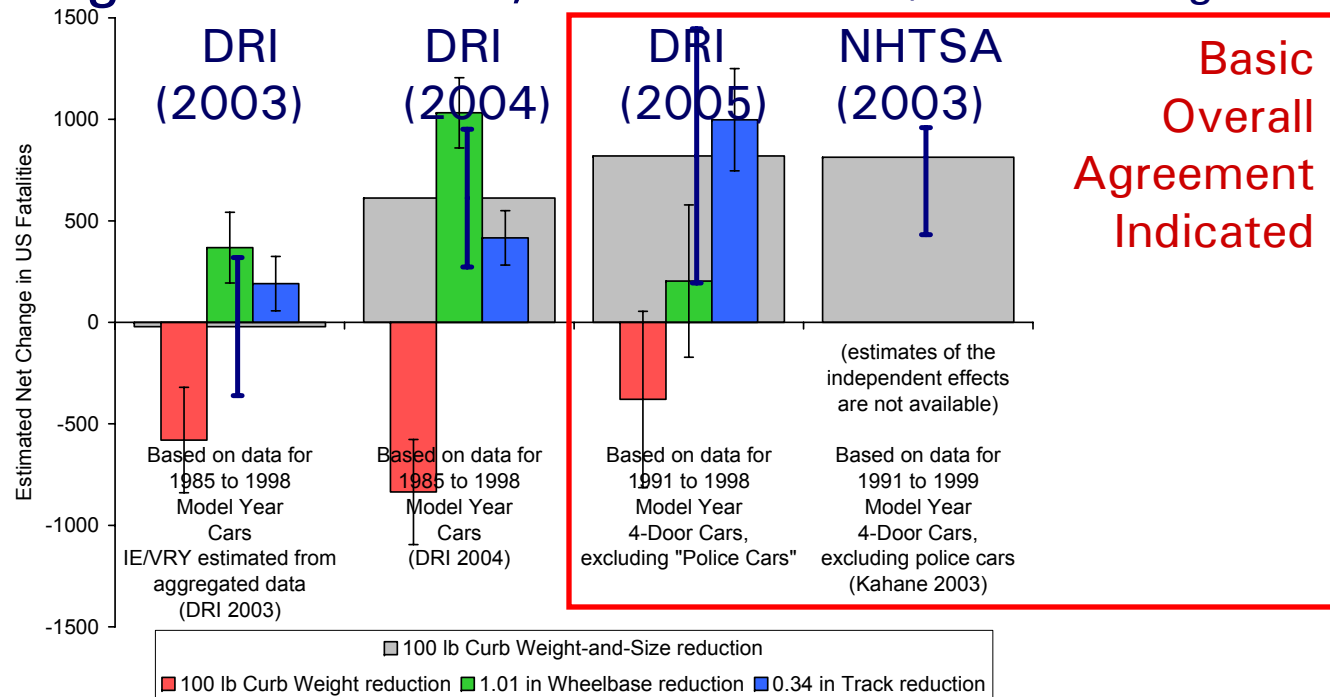
“Disaggregated” data are data for individual cases

DRI 200x studies were based on 1995 to 1999 CY data

# 1) OVERVIEW OF PAST DRI STUDIES

## A. DRI Cross-Sectional Studies of US Accident Data

- Passenger car results, as of 2005 (DRI 2005 Figure 10)



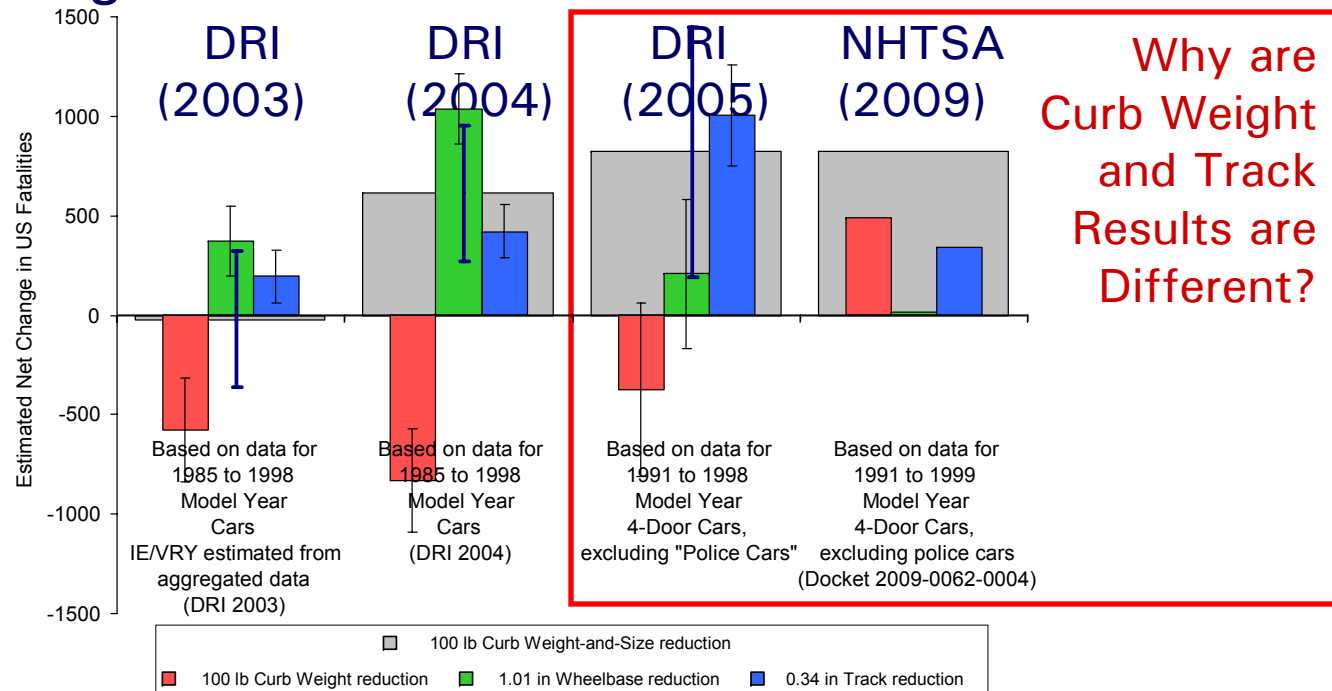
- Wheelbase and track reduction is harmful
- Weight reduction is not harmful
- Overall size and weight reduction result agrees with Kahane (2003)

Note: DRI error bars are  $\pm 2$ -sigma, based on various assumptions, and do not include all sources of uncertainty

# 1) OVERVIEW OF PAST DRI STUDIES

## A. DRI Cross-Sectional Studies of US Accident Data

- Passenger car results



- Updated figure based on information in MY 2011 CAFE FRIA (Docket NHTSA-2009-0062-0004)
- DRI curb weight and track results do not agree with NHTSA results (i.e., 3<sup>rd</sup> vs 4<sup>th</sup> set of red and blue bars)

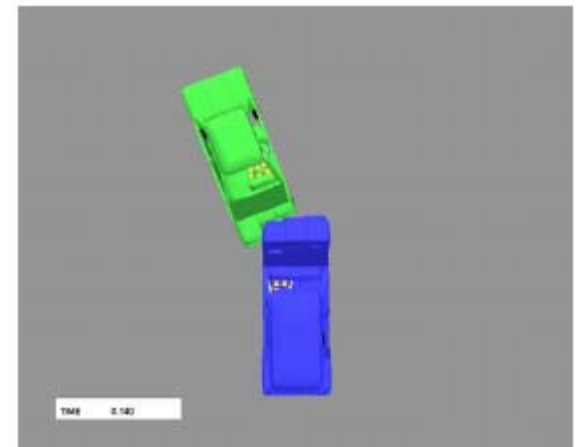
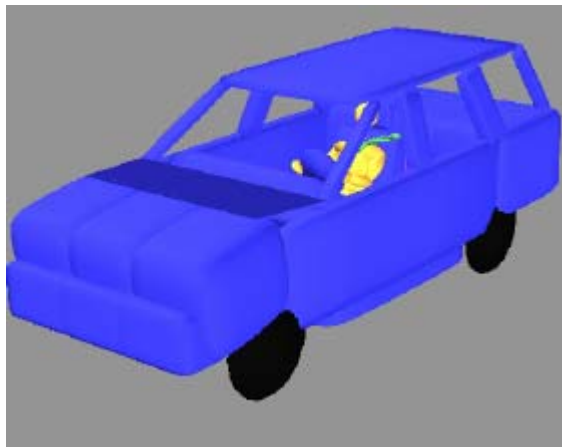
Note: DRI error bars are  $\pm 2$ -sigma, based on various assumptions, and do not include all sources of uncertainty

# 1) OVERVIEW OF PAST DRI STUDIES

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## B. Fleet Multi-Body Computer Simulations

- Investigate the effects of
  - Reduced weight SUV, holding size constant
  - Increase length SUV, holding weight constantUsing lightweight material substitution
- On crashworthiness and compatibility (F/A)
  - Not crash avoidance (A/VRY)
- Using crash simulations of 499 US crashes



t = 40 ms



# 1) OVERVIEW OF PAST DRI STUDIES

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## B. Fleet Multi-Body Computer Simulations (cont'd)

- Results



- Conclusions very similar to the DRI statistical results
  - SUV weight reduction of 20% has an overall benefit
  - SUV crush zone length increase of 20% has a larger overall benefit
- Methods and results are further described in DRI-TR-04-04-2 (Docket NHTSA-2003-16128-1452)

## **2) DRI PHASE 1 STUDY**

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A. Objectives

B. Methods

C. Preliminary Results

## **2.A) DRI PHASE 1 OBJECTIVES**

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### **Compare DRI's and Kahane's Results**

- a) Reproduce and confirm Kahane's past results:**
  - i. Databases**
  - ii. Methodologies**
- b) Comment on the key differences**

## 2.B) DRI PHASE 1 TECHNICAL APPROACH (DATABASES)

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### Update the DRI Databases to More Closely Match Kahane (2003)

- Added 2000 CY databases (FARS, state, registrations)
- Added PA accident data
  - Needed to better represent low fatality states and reduce Induced-exposure case weightings
  - Total number of “state-years” increased from 34 to 44
- Update vehicle curb weight data based on Kahane (2003)
- Newer vehicles (in progress)

## 2.B) DRI PHASE 1 TECHNICAL APPROACH (METHODS)

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### Update the DRI Methods to More Closely Match Kahane (2003)

- New analysis software was developed to attempt to more closely replicate the Kahane (2003) methods
  - Single stage weighted logistic regression
    - The “non-simultaneous” two-step regressions for F/IE and IE/VRY, with different (“mismatched”) control variables in each stage, used in DRI (2003), has been eliminated
    - US (or state) level IE registration weightings and fatalities
  - New control variable definitions (e.g., NITE)
  - New induced-exposure definition
    - “stopped” vehicle → “non-culpable” vehicle
  - New fatal crash type definitions
    - Added 3- , 4- vehicle fatal crashes
- Variance Inflation Factor (VIF) is also calculated, as <sup>13</sup> suggested by Kahane and other researchers

## 2.B) DRI PHASE 1 TECHNICAL APPROACH (ASSESS DIFFERENCES)

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### Possible Sources for Differences Between DRI and Kahane (2003, 2010) Results

- Differences in databases
  - Addressed by updating databases, to the extent possible
- Differences in data reduction details
- Differences in analysis methods
  - *“NHTSA believes that the analysis method is the issue, not the database”* (Kahane, 2010, p 502)<sup>1</sup>
    - Kahane (2003, 2010) used a one-step, single-stage method for F/VRY (and F/VMT)
    - DRI used “non-simultaneous” regressions for F/IE and IE/VRY, with different control variables in each stage

<sup>1</sup>Kahane, CAFE\_2012\_2016\_FRIA\_04012010.PDF, 2010

## 2.B) DRI PHASE 1 TECHNICAL APPROACH (ASSESS DIFFERENCES CONT'D)

### Possible Sources for Differences (cont'd)

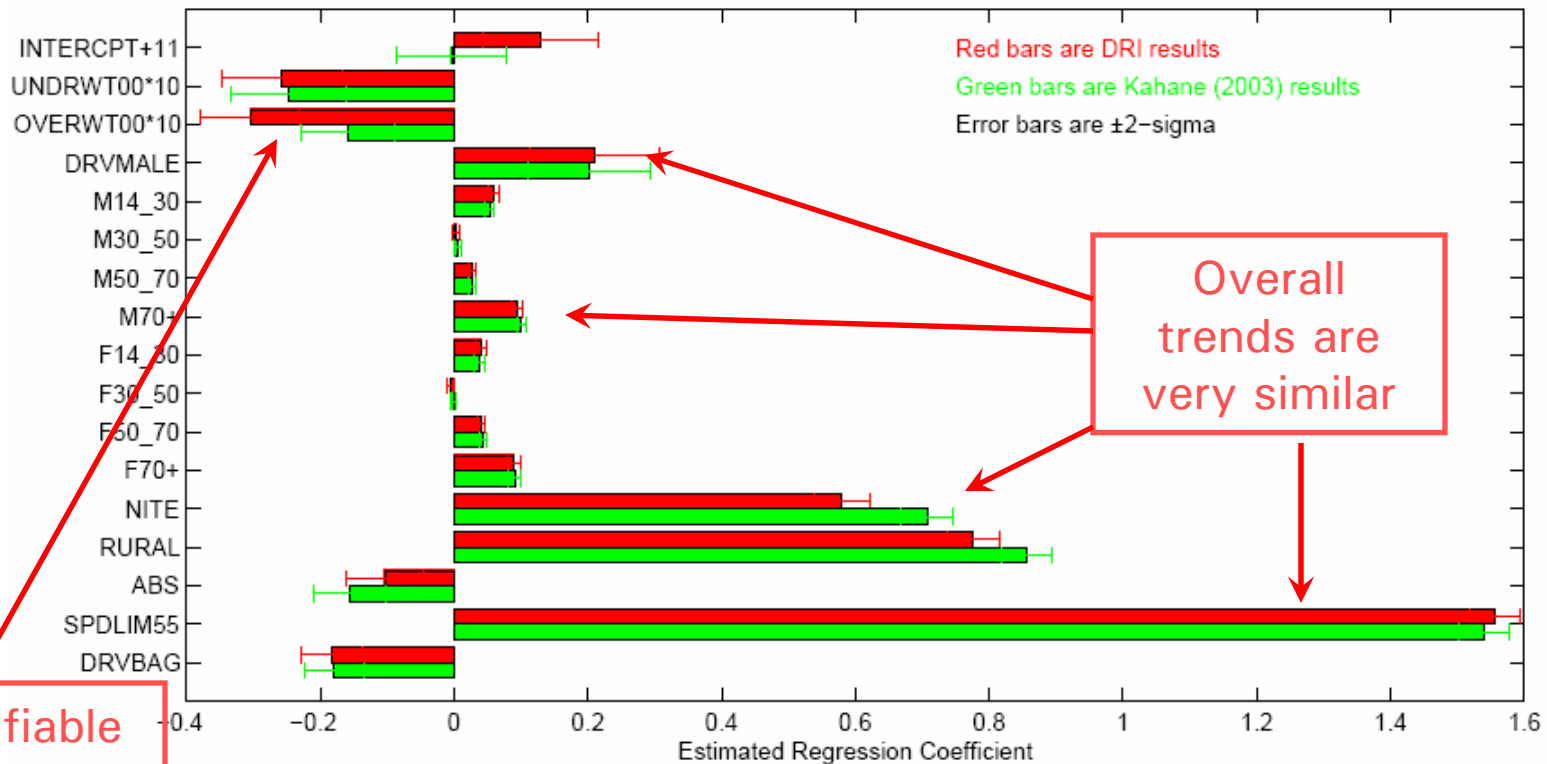
- The “non-simultaneous” multiple-stage method used by DRI (200x) for F/IE x IE/VR<sub>Y</sub>, which was adapted from Kahane (1997) Chapters 3 and 4, has mismatched control variables

Red shading indicates mismatched control variables →

Regression Coefficient	Stage		Combined Ln(F/VR <sub>Y</sub> )
	Ln(F/IE)	Ln(IE/VR <sub>Y</sub> )	
INTERCPT	A	B	A+B
CURBWT	A	B	A+B
WHEELBAS	A	B	A+B
TRAKWDTH	A	B	A+B
YOUNGDRV	A	B	A+B
OLDMAN	A	B	A+B
OLDWOMAN	A	B	A+B
FEMALE	A	B	A+B
NITE	A	B	A+B
SPDLIM55	A	B	A+B
CONVRTBL	A	B	A+B
TWODOOR	A	B	A+B
STAWAGON	A	B	A+B
VEHAGE	A	B	A+B
BRANDNEW	A	B	A+B
IL	A	B	A+B
MD	A	B	A+B
MO	A	B	A+B
NM	A	B	A+B
NC	A	B	A+B
OH	A	B	A+B
CY1996	A	B	A+B
CY1997	A	B	A+B
CY1998	A	B	A+B
CY1999	A	B	A+B
ABS4	A	0	A
AWD	A	0	A
FWD	A	0	A
WET	A	B	A+B
SNOW_ICE	A	B	A+B
DRAIRBAG	A	0	A
RFAIRBAG	A	0	A
RURAL	0	B	B
IL-CY96	0	B	B
OH-CY98	0	B	B

## 2.B) DRI PHASE 1 TECHNICAL APPROACH (ASSESS DIFFERENCES CONT'D)

In order to better understand the differences between the DRI and Kahane results we need to compare all of estimated regression coefficients



PRELIMINARY RESULTS



## 2.B) DRI PHASE 1 TECHNICAL APPROACH (ASSESS DIFFERENCES CONT'D)

DRI is using the following figures-of-merit to compare all estimated regression coefficients

$$\text{Root Mean Square} = \sqrt{\frac{1}{n} \sum_i \Delta_i^2} \quad \Delta_i^2 = \frac{(b_{i,B} - b_{i,A})^2}{s_i^2}$$

- Where  $\Delta > 2$  indicates a statistically significant difference, based on various assumptions and does not include all sources of uncertainty
- Example Results: Passenger Cars PRELIMINARY RESULTS

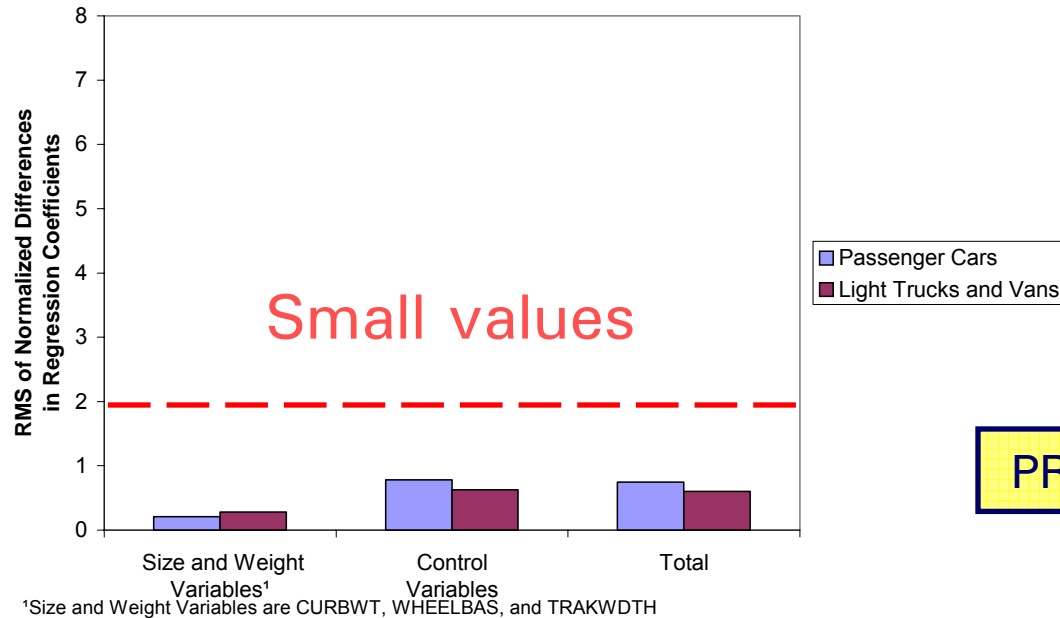
Crash Type	Delta <sup>2</sup> Sum			Number of Variables
	Size and Weight Variables	Control Variables	Total	
Principal Rollover	2.4	31.5	33.9	16
Hit Object	12.9	147.1	160.0	17
Ped-bike-motorcycle	22.1	60.5	82.6	16
Hit big truck	16.6	140.8	157.4	17
Hit passenger car	17.6	88.1	105.7	17
Hit light truck	14.7	85.3	99.9	17
Root Mean Square	2.68	2.49	2.52	100

Note: The size and weight variables are UNDRWT00 and OVERWT00

2.C)

# PRELIMINARY DRI PHASE 1 COMPARISON RESULTS

1) Differences between the DRI (2003) “simultaneous 3-way 2-stage” and 1-stage logistic regression results for  $F/IE = F/A \times A/IE$ \*



$$R.M.S. = \sqrt{\frac{1}{n} \sum_i \Delta_i^2}$$

$$\Delta_i^2 = \frac{(b_{i,B} - b_{i,A})^2}{s_i^2}$$

**PRELIMINARY RESULTS**

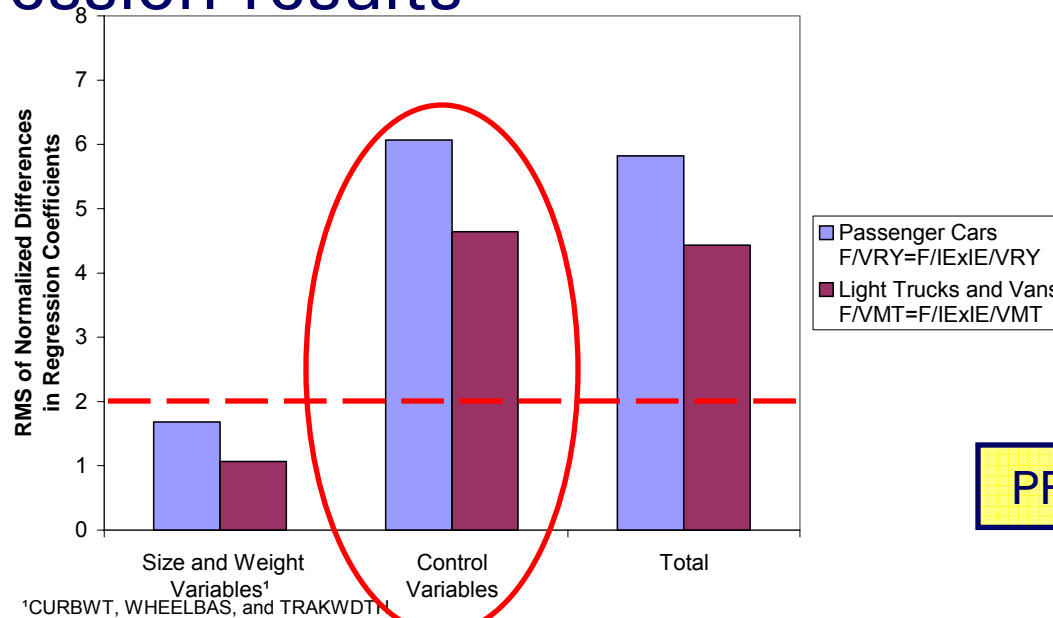
- These results indicate that the results for the “simultaneous 3-way 2-stage” method are not statistically significantly different from the more traditional 1-stage method

\* All 1985 to 1998 MY Passenger Cars, 1985 to 1997 MY LTVs excl. Large Vans

2.C)

# PRELIMINARY DRI PHASE 1 COMPARISON RESULTS (CONT'D)

2) Differences between the DRI (2004) "2-step" F/IE x IE/VR Y and "Kahane (2003) like" 1-step F/E regression results \*



$$R.M.S. = \sqrt{\frac{1}{n} \sum_i \Delta_i^2}$$

$$\Delta_i^2 = \frac{(b_{i,B} - b_{i,A})^2}{s_i^2}$$

**PRELIMINARY RESULTS**

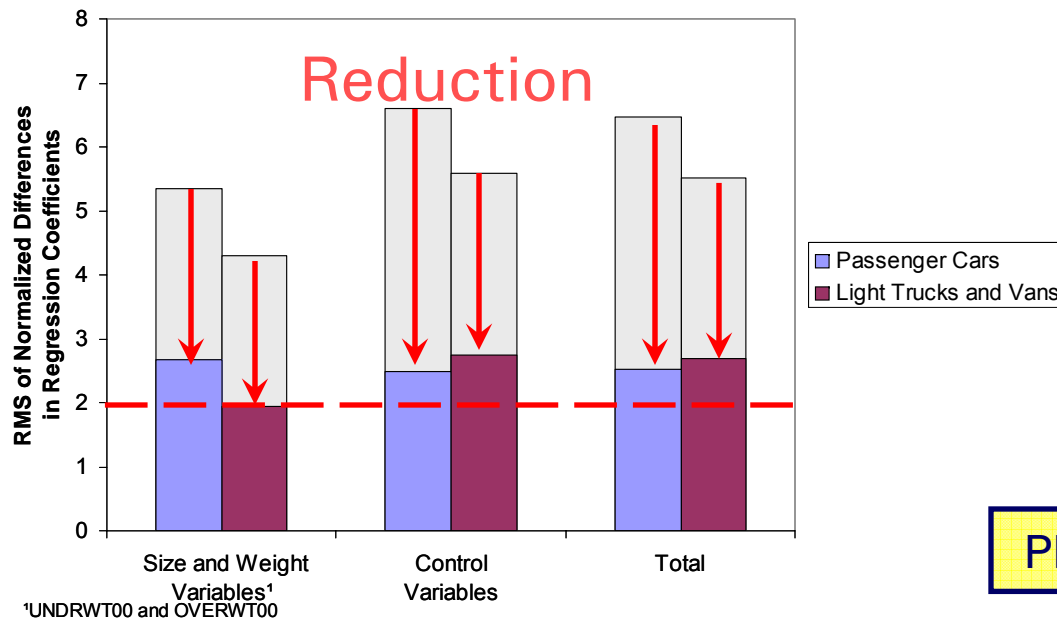
- These results indicate that the "non-simultaneous" 2-step method may be one source of difference between the DRI and NHTSA results. This is attributed in part to the different control variables used in the different regression steps.

\* All 1985 to 1998 MY Passenger Cars, 1985 to 1997 MY LTVs excl. Large Vans

2.C)

# PRELIMINARY DRI PHASE 1 COMPARISON RESULTS (CONT'D)

3) Differences between the DRI “Kahane (2003) Like” weighted 1-stage logistic regressions and the corresponding Kahane (2003) results\* were reduced



$$R.M.S. = \sqrt{\frac{1}{n} \sum_i \Delta_i^2}$$

$$\Delta_i^2 = \frac{(b_{i,B} - b_{i,A})^2}{s_i^2}$$

**PRELIMINARY RESULTS**

\* 1991 to 1998 MY 4-Door Passenger Cars, 1991 to 1997 MY LTVs

## 2.C)

# PRELIMINARY DRI PHASE 1 COMPARISON RESULTS (CONT'D)

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- 3) The differences between the DRI and Kahane (2003) results were reduced by:
- Changing the induced-exposure cases
    - From “stopped” vehicle to
    - To “non-culpable” vehicle
  - Changing fatal crash types
    - Adding 3 and 4 vehicle crashes
  - Adding 2000 FL induced-exposure data (a high fatality rate state)
  - Adding PA induced-exposure data (a low fatality rate state)
  - Changing curb weight data
    - From DRI (2002) values (TR-02-02 Appendices)
    - To Kahane (2003) values (Appendices)
  - Numerous other minor changes

## 2.C)

# PRELIMINARY DRI PHASE 1 COMPARISON RESULTS (CONT'D)

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3) Possible sources for the remaining differences between the DRI and Kahane (2003) results include:

- Differences in vehicle model years (e.g., 1999 MY) (in progress)

### Not resolvable without more information

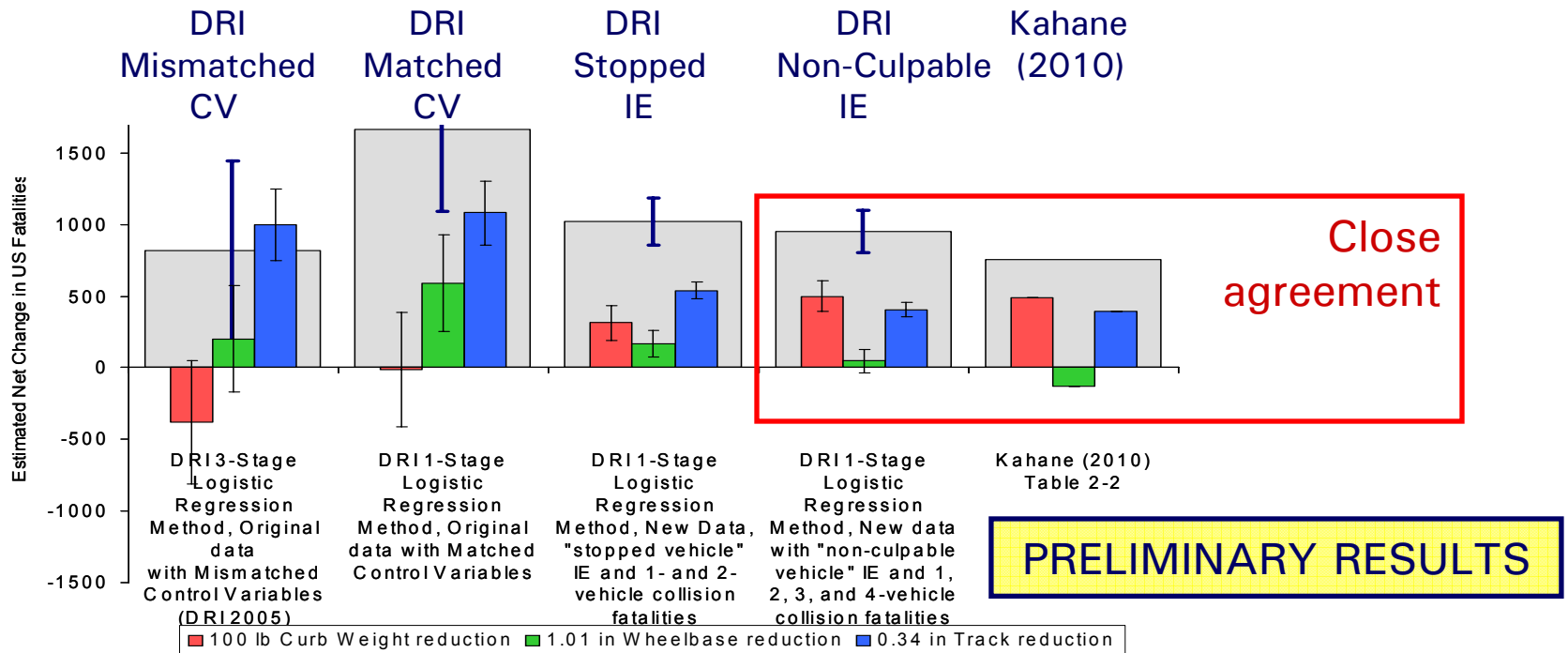
- Differences in other vehicle parameter data (e.g. ABS installation rates)
- Differences in the control variables derived from the FARS and state data (e.g., Florida RURAL)
- PA induced-exposure cases are heavily weighted, due to difficulty in determining the non-culpable vehicles
- Differences in large truck vs unknown vehicle type identification
- Non-Police Caprice and Crown Victoria registrations

2.C)

# PRELIMINARY DRI PHASE 1 US FATALITY RESULTS

## 4-Door Passenger Cars (excluding police cars)

- Effects of curb weight, wheelbase, and track reduction



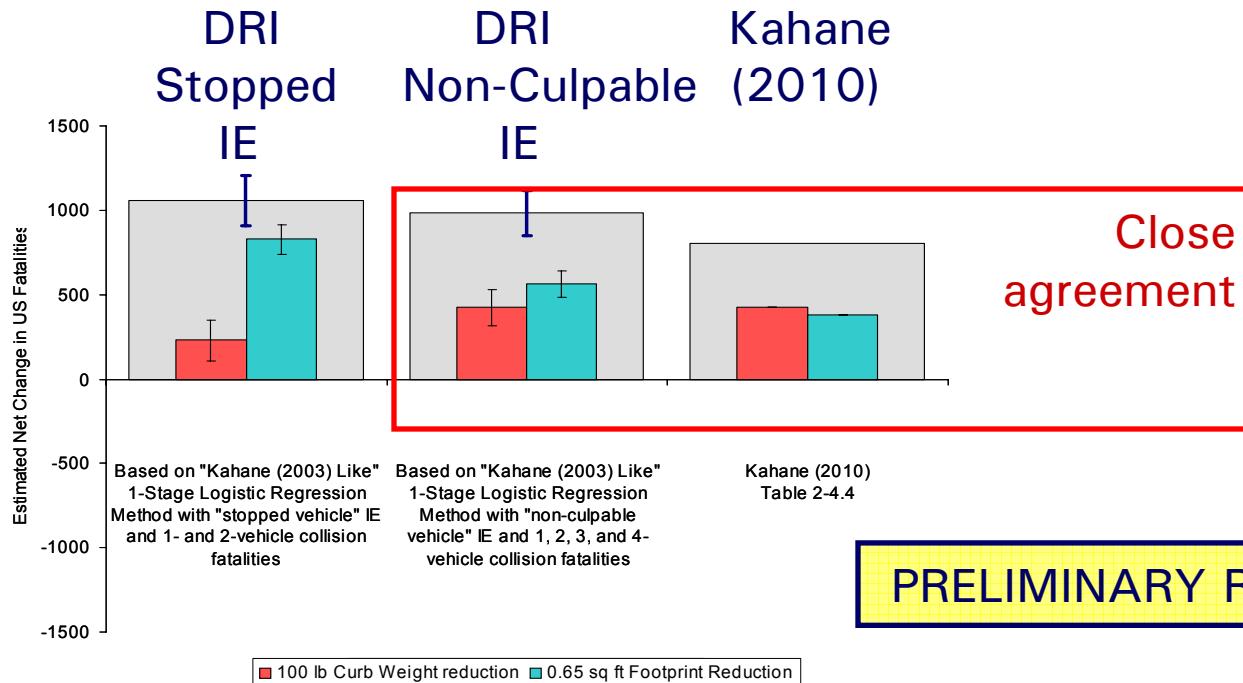
- Results tend to converge on the Kahane (2010) results if we use “non-culpable” vehicle and “3,4” vehicle crashes
- The results are very sensitive to the control variables used, and induced-exposure and fatal crash type definitions

## 2.C)

# PRELIMINARY DRI PHASE 1 US FATALITY RESULTS

## 4-Door Passenger Cars (excluding police cars)

- Effects of curb weight and footprint reduction



- Results tend to converge on the Kahane (2010) results if we use “non-culpable” vehicle and “3,4” vehicle crashes
- The curb weight and footprint results are very sensitive to the induced-exposure and fatal crash type definitions

Note: DRI error bars are  $\pm 2$ -sigma, based on various assumptions, and do not include all sources of uncertainty

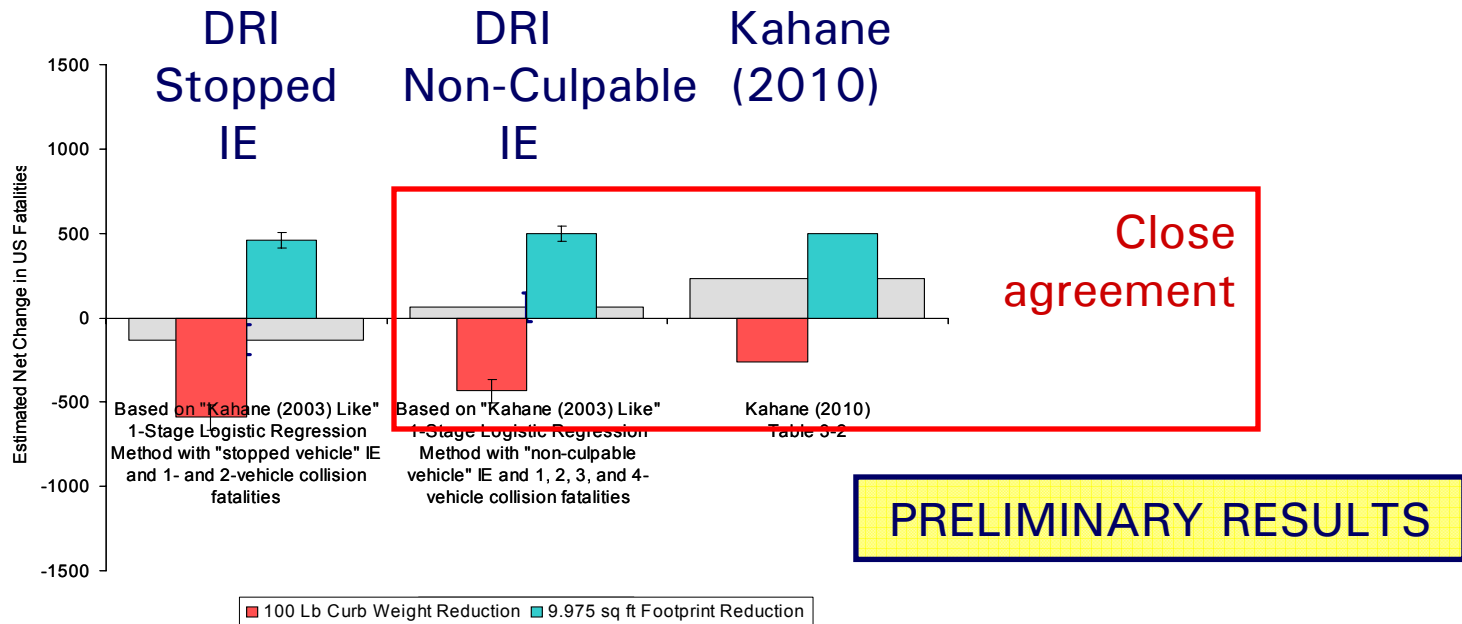


# 2.C)

# PRELIMINARY DRI PHASE 1 US FATALITY RESULTS

## Light Trucks and Vans

- Effects of curb weight and footprint reduction



- Results tend to converge on the Kahane (2010) results if we use “non-culpable” vehicle and “3,4” vehicle crashes
- The curb weight results are very sensitive to the induced-exposure and fatal crash type definitions

## 2.C)

# PRELIMINARY DRI PHASE 1 VARIANCE INFLATION FACTOR RESULTS

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Variance Inflation Factor (VIF) is a measure of multicollinearity

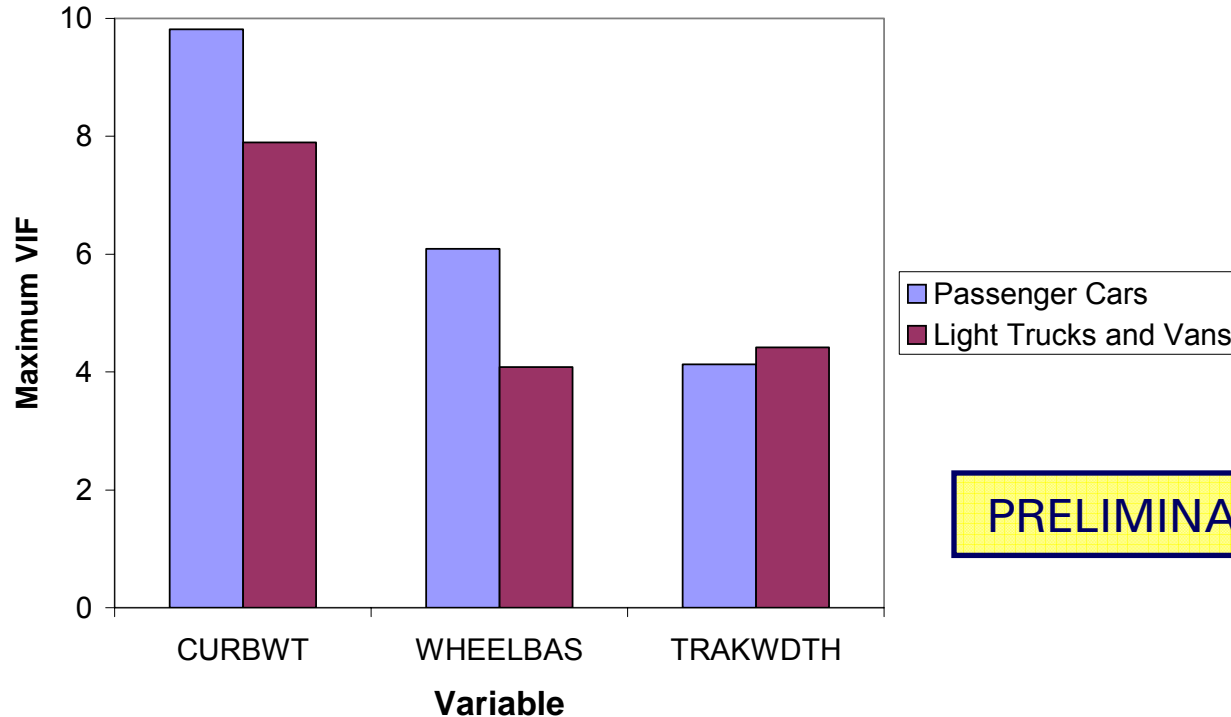
- Large values indicate more multicollinearity
- Allison (1999), p 50
  - Begins to *"get concerned"* if VIF is greater than 2.5
- Menard (2002), p 76
  - VIF greater than 5 is *"cause for concern"*
  - VIF greater than 10 *"almost certainly indicates a serious multicollinearity problem"*
- O'Brien (2007)
  - *"Values of the VIF of 10, 20, 40, or even higher do not, by themselves, discount the results of regression analyses"*
  - *"it may be reasonable to eliminate or combine highly correlated independent variables, but doing this should be theoretically motivated."*

## 2.C)

# PRELIMINARY DRI PHASE 1 VARIANCE INFLATION FACTOR RESULTS

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Maximum VIF values for the main DRI (200x)  
regression results



- Curb weight has the largest VIF
- This suggests that the curb weight variable is redundant with other variables in the regression and should be eliminated

**2.D)**

**PRELIMINARY DRI PHASE 1  
CONCLUSIONS**

Issue	Impact on Result
“Non-Simultaneous” 2-Stage vs 1-Stage with mismatched control variables (e.g., F/IE x IE/VRV vs F/VRV with ABS4 vs RURAL)	Large
Induced-exposure definition (i.e., stopped vs non-culpable vehicle)	Large
High state induced-exposure case weighting (due to too few induced-exposure states per Hi/Lo fatality state group)	Medium
Fatal crash type definition (i.e., crashes involving 3 or 4 vehicles)	Medium
US vs State level induced-exposure weighting and fatalities	Small
Identification of other vehicle types (MC, Large Truck, Unknown)	Small
2000 Calendar Year Data	Small
DRI 2002 vs Kahane 2003 curb weight data	Small
NM vs UT induced-exposure data	Assume small
2000 Model Year Data	Assume small
“Simultaneous 3-Way 2-Stage” vs 1-Stage with matched control variables (e.g., F/A x A/IE vs F/IE)	Very small
Other vehicle parameter data (e.g., track, %ABS)	Unknown
State control variable data reduction (e.g. FL RURAL)	Unknown

## DRI PHASE 1 RECOMMENDATIONS

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- Need Better Access and Disclosure to Compare Studies
  - Common, accessible and downloadable databases
  - Common definitions for key factors
  - Better disclosure of data reduction methods (e.g., state data reduction, vehicle parameter data)
  - Better disclosure of results (e.g., all regression coefficients, estimated confidence intervals, VIF)
- If small changes in methodologies change results...
  - Perhaps the effect of weight is too small in comparison to other factors (e.g., safety technologies)

## 3) **DRI PHASE 2**

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### Objectives

- To further update the analysis based on most recent calendar year data and model year vehicles (e.g., to 2008 model year and calendar year)
- Status
  - Have discussed with NHTSA and others the need to define and make the NHTSA data publically available
  - Access to detailed NHTSA methods and algorithms has yet to be discussed

## 3) DRI POSSIBLE PHASE 3

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### Objectives

- To review and investigate forthcoming Kahane (2011) methods and results
  - Investigate other analytical approaches that may be appropriate, e.g.,
    - Predictive fits and “parsimonious” models (i.e., PRESS type statistic)
    - Sensitivity analyses, e.g., model should be relatively insensitive to changes in:
      - “Non-culpable vehicle” vs “stopped car” induced-exposure definitions
      - Vehicle model years
      - Vehicle types (i.e., 2-door cars)
      - Vehicles with high portions of high-strength steel and lighter weight versus conventional designs
      - Other world regions
      - Etc.

### 3) **OVERALL OBSERVATIONS**

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1. A robust factor (e.g., curbweight) should be relatively insensitive to the exact data and methods used, however;
2. Following more exactly the changes made between the Kahane (1997) and Kahane (2003) methods has a large effect on the relative outcomes, and also explains much of the difference between the Kahane (2003) and DRI (200x) results
3. To facilitate identifying robust factors requires:
  - Use of a common database including data for:
    - Induced-exposure (expected)
    - Police-reported accidents (unknown)
    - Vehicle parameters (unknown)
  - Awareness of exact data reduction algorithms used <sub>32</sub> (unknown)