

Lightweight Materials and Safety

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Factors Influencing Safety

Impacts on Safety

1. Drivers & driving environment

“crashworthiness factors are overwhelmed in importance by driver factors. Crashworthiness factors are relevant only when crashes occur.”

- Leonard Evans, “CAFE – why it is so difficult to estimate its effect on traffic fatalities and fuel use”, Presented at TRB, Jan 2003

2. Crashworthiness

Vehicle design and compatibility

3. All else being equal:

Vehicle size and weight

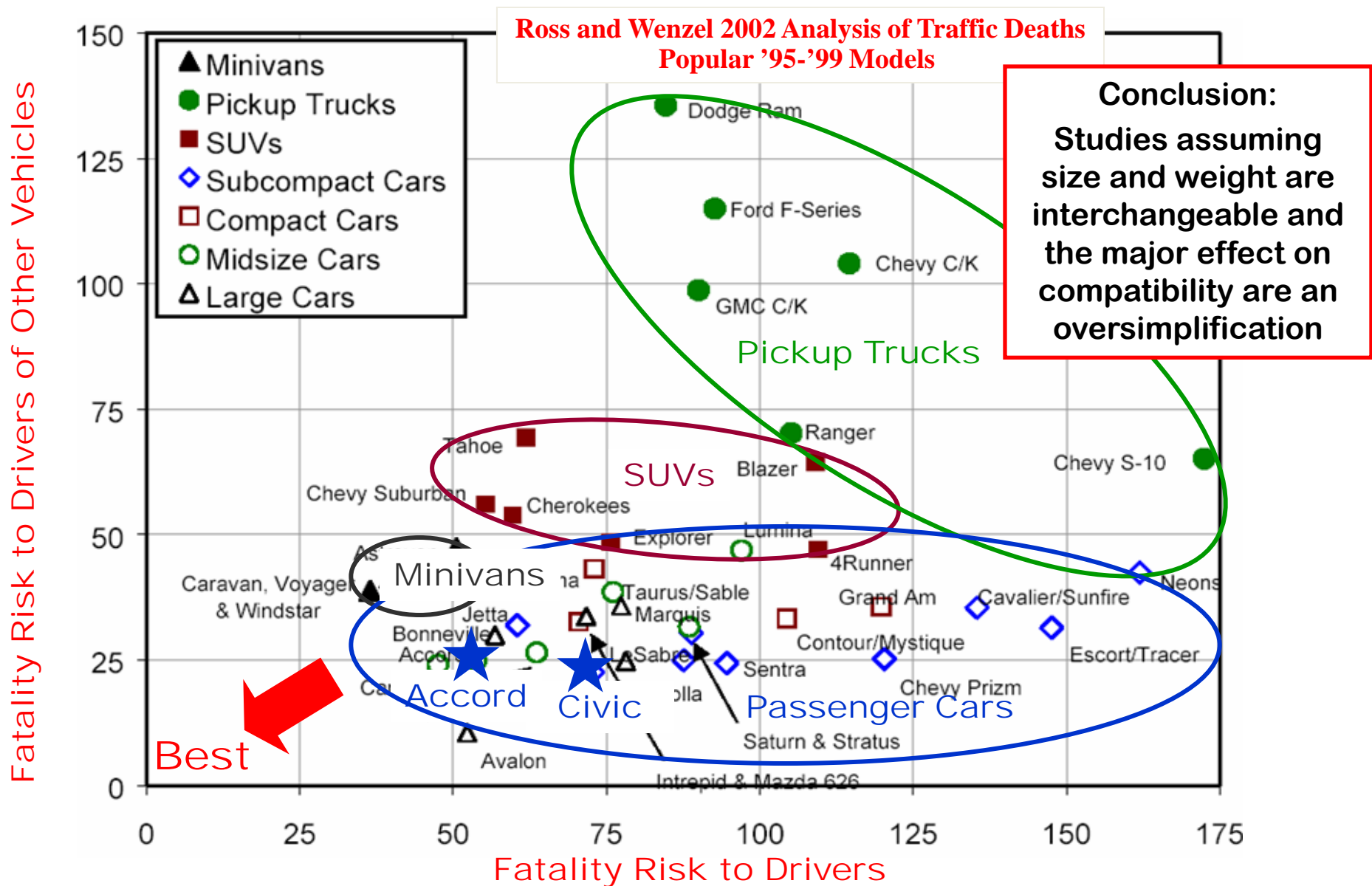
Crashworthiness:

1. Occupant deceleration:
 - Vehicle weight
 - Space for crush and to absorb energy
2. Occupant protection inside compartment:
 - Strength and rigidity to prevent intrusion
 - Restraint system's ability to restrain, cushion and protect occupants within the passenger compartment

Crash Compatibility Factors

- Vehicle protective structure **geometry**
 - Differences in vehicle structural geometry increases intrusion into occupant compartment of one vehicle
 - Unlike cars, light trucks have few “mating surface” requirements
- Relative vehicle and occupant compartment **stiffness**
 - The stiffer vehicle will crush less than the softer vehicle
 - Can increase intrusion into the occupant compartment of the softer vehicle
- Relative vehicle **weight**
 - Heavier vehicle experiences lower crash energy absorption
 - Lighter vehicle experiences higher energy absorption

Impact of Drivers, Roads, and Vehicles



Design Dominates

IIHS 50th Anniversary Crash Test



2009 Chevy Malibu
3452 pounds
192" long



1959 Chevy Bel Air
3629 pounds
209" long

Impact of Vehicle Design

- Energy management and rollover prevention are the most important factors for effective safety protection
- **1996-99 mid-size SUVs had a 50% higher fatality rate for their occupants than small SUVs, despite being larger and 850 pounds heavier (Kahane 2003)**

	Avg curb weight (p 197)	Fat. In My Vehicle (p 198)	Other Veh + Peds Fat (p 198)	Rollover Occ Fat (p 202)	Fixed-Object Occ Fat (p 202)	Ped-Bike-MC Fat (p 202)	heavy truck Fat in LTV (p 202)
Small SUVs	3,174	6.09	4.38	1.53	1.98	2.11	1.14
mid-size SUVs	4,022	9.16	4.52	4.42	2.64	1.72	0.84

- Difference cannot be explained by driving behavior:
 - Kahane 2003 found more “imprudent driving behavior per fatal-crash involved driver” for small SUVs than mid-size SUVs
- Rollover fatality rates in small SUVs 65% lower than in mid-size SUVs
- Fatality rates in collisions with fixed objects also significantly lower for small SUVs

2011 Ford Fiesta



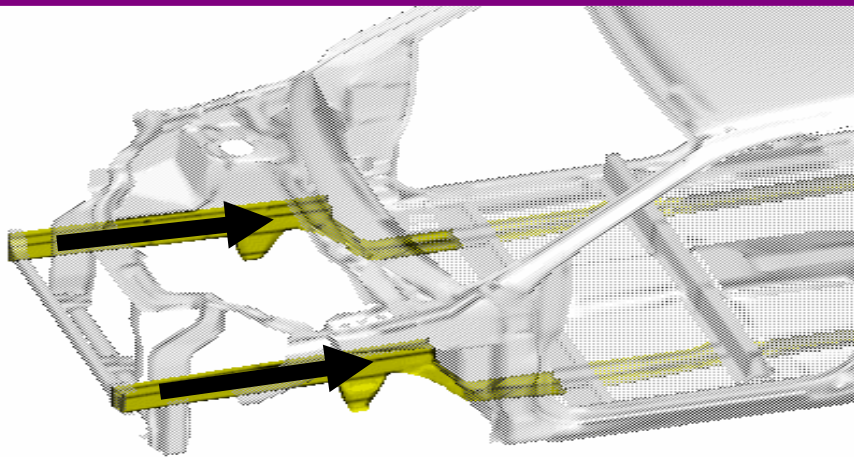
- First car in subcompact segment to earn top crash-test ratings in each of the U.S., China and Europe.
- “Top safety pick” from the Insurance Institute for Highway Safety under its new test standards.

- More than 55% of the body structure is made from ultra-high-strength steel
- Extensive use of high-strength, lightweight boron steel to help protect critical occupant safety zones

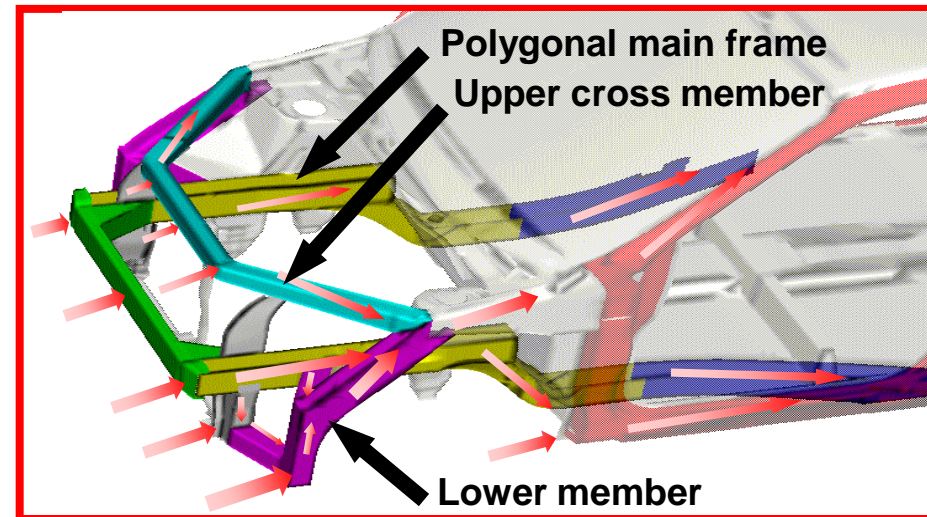
Compatibility efforts

- Safety is primarily a design issue. 2006 Civic is a case study of how to engineer a small car for highest safety performance

Previous Body



New ACE™ Body



- The ACE structure achieves its advantages by moving from *concentration to dispersion* of crash force, and optimizing crush stroke and energy management

ACETM Body Structure

- Despite shorter front end & increased weight from previous models, intrusion values are reduced – especially in the driver's footwell
 - Source: IIHS

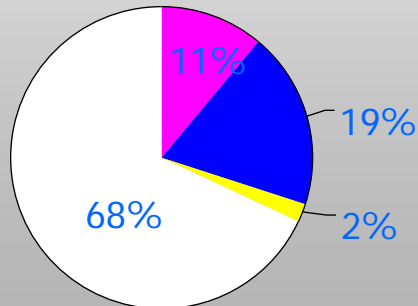
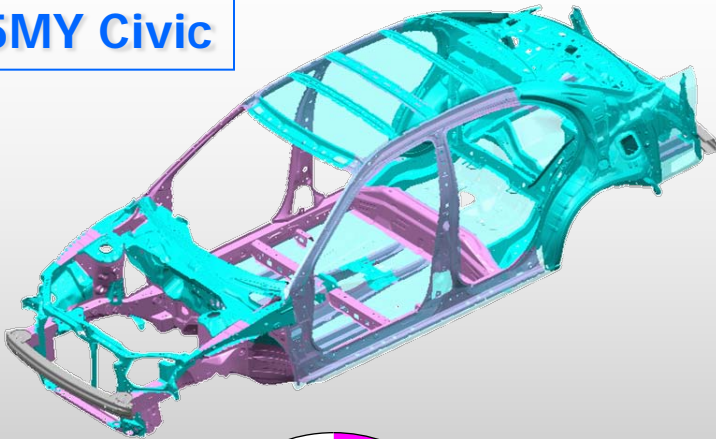
Passenger Compartment Intrusion Comparison

Model Year	Footwell Intrusion			Brake Pedal Intrusion
	Left	Center	Right	
2006	8	9	6	7
2001	11	11	10	8
1997	24	22	18	17

High Strength Steel Utilization

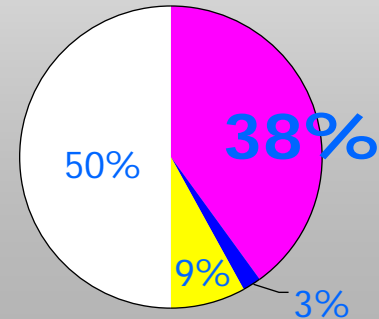
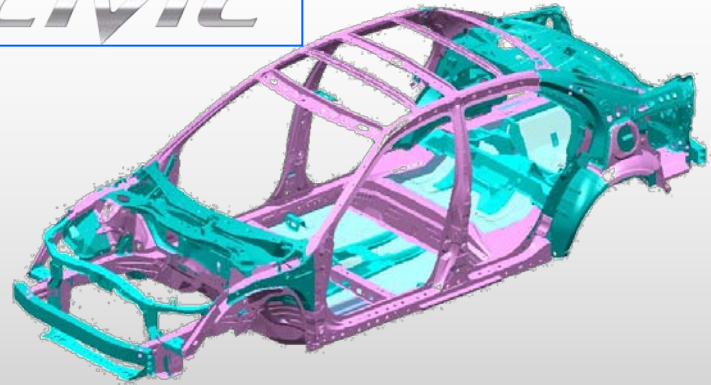
- High strength steel allows weight reduction and/or improved performance
- Usage of 590 MPa steel has more than tripled (11% → 38%)

05MY Civic



Usage Rate: 32%

CIVIC

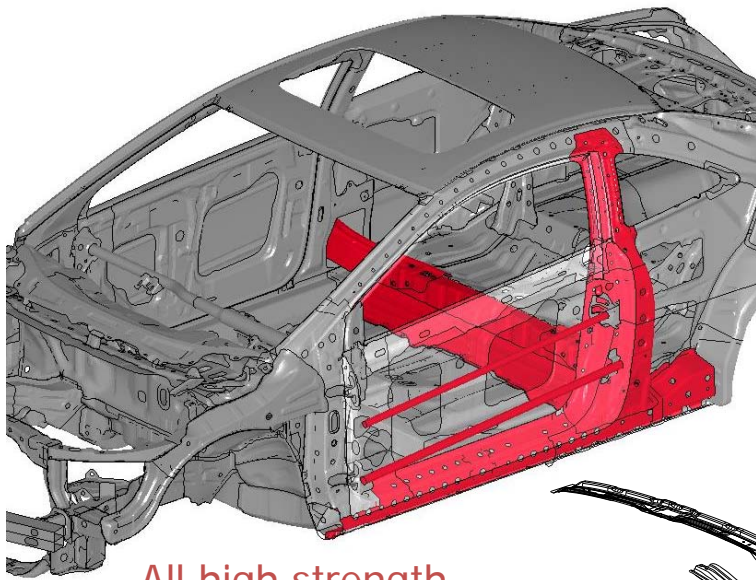


Usage Rate: 50%

50% of body now high strength steel

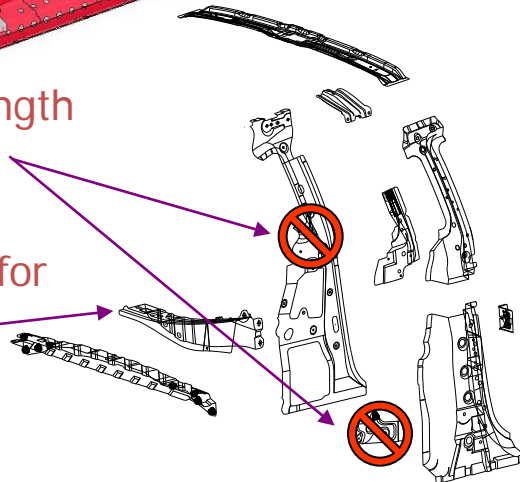
Side Impact Construction (Coupe)

- Most of side impact construction is high strength steel
- Concept is similar to previous model – but had to be optimized to account for NHTSA & IIHS modes



All high strength steel except

Floor gusset is key for reducing intrusion



IIHS Side Impact score improved one rating category with addition of high strength steel*

* Internal test data

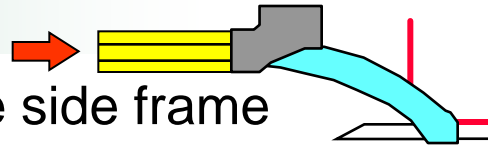
Linear Compression of Aluminum

2000 Honda Insight

Side frame structure to control frontal crash energy

First stage

Front end area of the side frame



The hexagonal cross section member is compressed for efficient absorption of impact energy.



Implications for Size and Weight

- (1) Compared to driver, driving influences, and vehicle design influences, safety impacts of size and weight are small and difficult to quantify
- (2) Safety of future vehicles will be dominated by vehicle design, not size or weight
- (3) Use of high-strength steel reduces weight and improves safety

Impacts of Weight and Size on Safety

Vehicle Interactions with Fuel Economy

Crash Effects

**Increase
Efficiency**



Does Not Affect Safety

**Decrease
Weight**



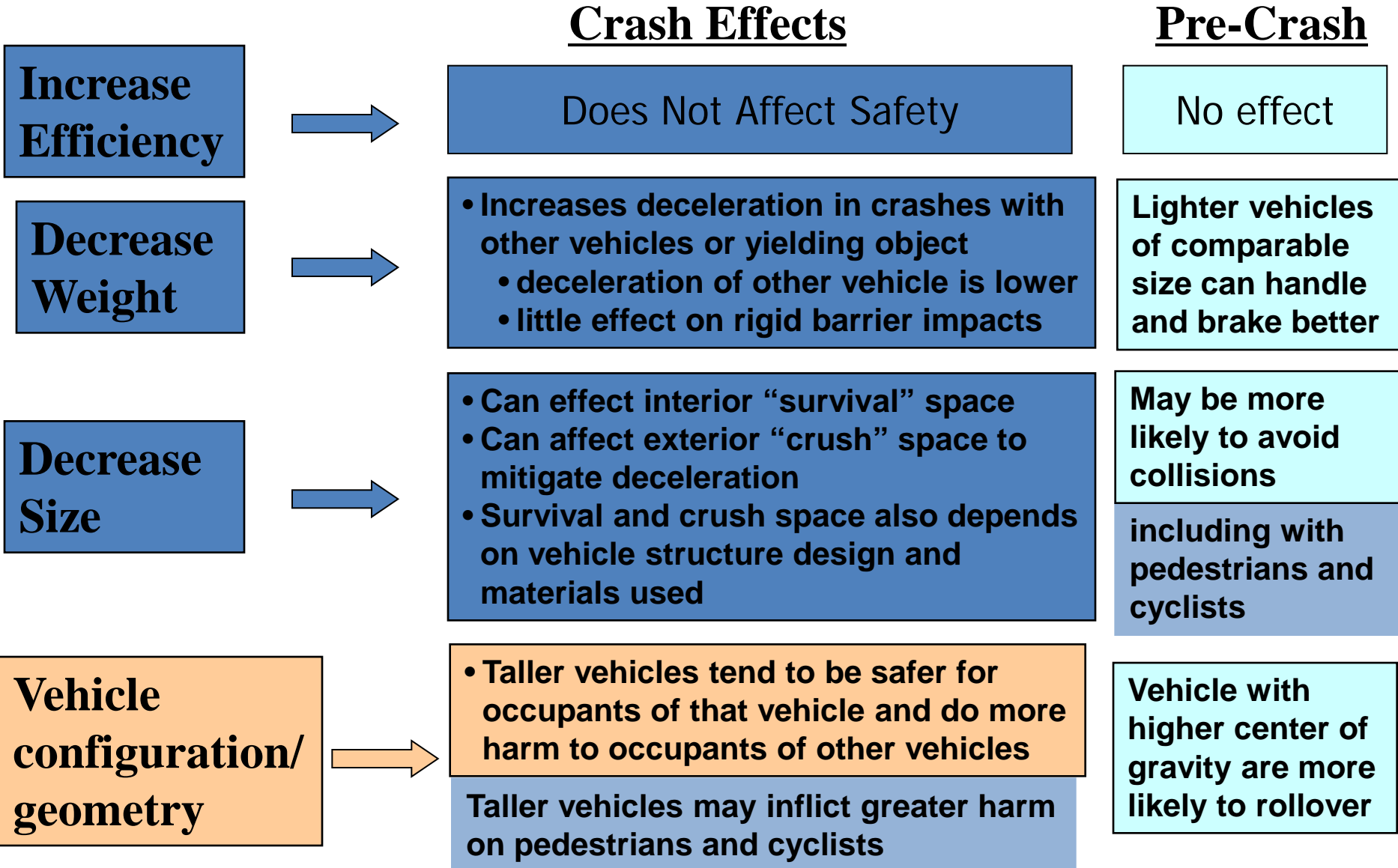
- **Increases deceleration in crashes with other vehicles or yielding object**

**Decrease
Size**



- **Can effect interior “survival” space**
- **Can affect exterior “crush” space to mitigate deceleration**

Vehicle Interactions with Fuel Economy



Theoretical Impact of Light Materials

- Reducing vehicle weight reduces the crash forces that must be managed in a crash – for both vehicles
 - If interior space and the space for managing the crash forces are maintained the reduced weight makes it easier to manage the crash forces and protect the occupants of both vehicles.
- High-strength steel and aluminum have better crash characteristics than conventional steel
 - The safety benefit of high-strength steel is the primary reason for its rapidly increased market penetration.
 - Aluminum provides more uniform management of crash forces.
- Reducing vehicle weight improves vehicle handling and braking.

Supporting Work

Other researchers have also concluded that modern safety is primarily a design issue, not a weight issue

– Dr. Leonard Evans

- 1982 - Car mass and likelihood of occupant fatality, SAE 820807
 - “the likelihood that a car has an occupant or driver fatality is related to the mass of the car.”
- 2004 - How to Make a Car Lighter and Safer, SAE 2004-01-1172

– Robert B. Noland, Motor Vehicle Fuel Efficiency and Traffic Fatalities, The Energy Journal, Vol. 25, No. 4, 2004

- “Overall results suggest that while there may have been an association between fleet fuel efficiency improvements and traffic fatalities in the 1970s, this has largely disappeared.”

– Delannoy, P. and Faure, J., "Compatibility Assessment Proposal from Real Life Accident (94)", Proceedings of the 18th International Technical Conference on the Enhanced Safety of Vehicles, Nagoya, Japan, 2003

2010 NHTSA Safety Study

Fatality Increase per 100-Pound Reduction (%)¹⁴⁵

	Actual Regression Result Scenario	NHTSA Expert Opinion Upper-Estimate Scenario ¹⁴⁶	NHTSA Expert Opinion Lower-Estimate Scenario
Cars < 2,950 pounds	2.21	2.21	1.02
Cars ≥ 2,950 pounds	0.90	0.90	0.44
LTVs < 3,870 pounds	0.17	0.55	0.41
LTVs ≥ 3,870 pounds	-1.90	-0.62	-0.73

Estimated lifetime change in fatalities compared to 2011MY baseline fleet

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
NPRM “Worst Case”	34	54	194	313	493
NHTSA Expert Opinion Final Rule Upper Estimate	9	14	26	24	22
NHTSA Expert Opinion Final Rule Lower Estimate	2	4	(17)	(53)	(80)
Actual Regression Result Scenario	0	2	(94)	(206)	(301)

NHTSA Ignored their own model and established “expert opinion” upper and lower estimates.

Primary factor: Eliminated rollover fatalities reductions with weight reduction

Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule
 [EPA-HQ-OAR-2009-0472; FRL_8959-4; NHTSA-2009-0059] RIN 2060-AP58; RIN 2127-AK50

Expert Opinion Changes – Light Trucks

LDTs < 3,870 pounds – Fatality increase per 100-pound mass reduction, no change in footprint

Crash Type	Annual Baseline ⁴³⁴ Crash Fatalities	Scenarios – Effects of 100-Pound Reductions While Maintaining Footprint					
		Actual Regression Result Scenario		Upper-Estimate Scenario		Lower-Estimate Scenario	
		Percent Change	Fatality Change	Percent Change	Fatality Change	Percent Change	Fatality Change
First-event rollover	1,319	-4.61	-60.8	0	0	0	0
Fixed object	1,687	.08	1.3	.35	5.9	0	0
Ped/bike/motorcycle	1,148	.51	5.9	0	0	0	0
Heavy truck	584	4.43	25.9	1.38	8.1	.53	3.1
Car	2,062	-.17	-3.5	0	0	0	0
LTV < 3,870 pounds ⁴³⁵	247	6.00	14.8	0	0	0	0
LTV ≥ 3,870 pounds	1,010	3.00	30.3	3.00	30.3	3.00	30.3
Overall	8,057	.17	13.9	.55	44.3	.41	

LDTs > 3,870 pounds – Fatality increase per 100-pound mass reduction, no change in footprint

Crash Type	Annual Baseline ⁴³⁶ Crash Fatalities	Scenarios – Effects of 100-Pound Reductions While Maintaining Footprint					
		Actual Regression Result Scenario		Upper-Estimate Scenario		Lower-Estimate Scenario	
		Percent Change	Fatality Change	Percent Change	Fatality Change	Percent Change	Fatality Change
First-event rollover	2,183	-4.94	-107.8	0	0	0	0
Fixed object	2,639	-.55	-14.5	.35	9.2	0	0
Ped/bike/motorcycle	2,043	-.48	-9.8	0	0	0	0
Heavy truck	860	-.67	-5.8	1.38	11.9	.53	4.6
Car	5,186	-1.78	-92.3	-1.78	-92.3	-1.78	-92.3
LTV < 3,870 pounds ⁴³⁷	1,010	-1.92	-19.4	-1.92	-19.4	-1.92	-19.4
LTV ≥ 3,870 pounds	784	-3.84	-30.1	0	0	0	0
Overall	14,705	-1.90	-279.7	-.62	-90.6	-.73	-107.1

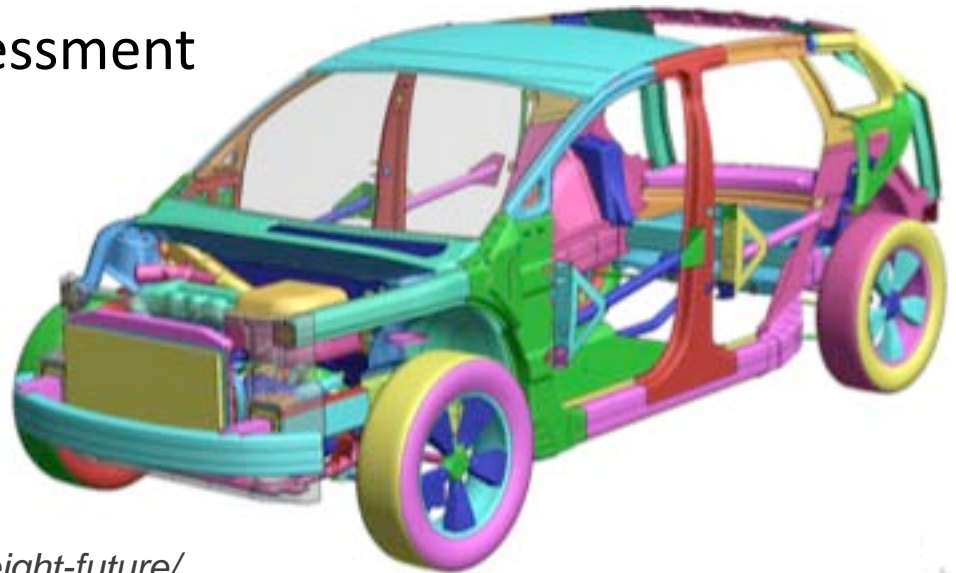
Assessing Safety of Lightweight Materials

DRI Analysis of Down-Weighted Vehicles

- Statistically analyzing conventional design does not address the engineering concepts used to intelligently down-weight vehicles
- ICCT will contract with DRI to analyze the relative safety of a subset of vehicles with high portions of high-strength steel and lighter weight versus conventional designs
 - Study suggested by Bill Walsh (NHTSA retired)
 - Study will start after updated analyses of conventional vehicles is completed
 - Completion: Fall 2011

Lotus Assessment of Mass-Reduced Designs

- Initial study: Design 20% (HSS) and 33% (advanced materials) mass-reduced Toyota Venza – Completed March 2010
- Ongoing Computer-Aided Engineering (CAE), simulation work on 30% + mass-reduced vehicle to validate safety crashworthiness
 - Involves CARB/EPA/NHTSA collaboration
 - Simulate body-in-white and closure behavior in front, side, offset crashes
 - Includes detailed cost assessment
 - Completion: June 2011



FEV Assessment of HSS Design

- EPA and ICCT have funded FEV to assess the crashworthiness of the 20% lightweight (high strength steel) Toyota Venza design
 - Very similar in scope to the NHTSA project and will include CAD and crash models
 - Vehicle design will meet all major safety test requirements
 - Detailed cost analysis will also be done
 - Completion: February 2012

Summary

- Future vehicle safety is primarily dependent on design and vehicle compatibility
 - Good lightweight materials and designs will reduce fatalities; bad designs will not
- Advanced materials can decouple size from mass (weight), creating important new possibilities for simultaneously improving both fuel economy and safety without compromising functionality
- Historical analyses of the impact of size and weight on safety are difficult and not very robust
 - Projecting these results onto new materials and safety designs is even less accurate and robust

Thank You

