A Design Science Approach to Understanding Changes in the Automotive Vehicle Industry

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University of Michigan

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Wednesday, June 17, 2009
MIT

ENERGY

We're In For Stormy Weather

Overshadowed by the economic headlines, serious climate trouble looms ahead.

By Ban Ki-Moon | NEWSWEEK
Published Dec 30, 2008

Green Science . Policy . Living
News About the Environment

U.S. Carbon Emissions Fall by Most Since '82

Recession, Oil Prices Cited in 2008 Decline

By Steven Mufson
Washington Post Staff Write
Thursday, May 21, 2009

Unseasonably Higher, Gas Prices Add to Strain on U.S. Consumers

By CLIFFORD KRAUSS
Published: November 8, 2007

US to spend $1 billion to restart CCS project

Published: 12 Jun 2009 21:54 CET

The US Energy Department said it will restart a programme aimed at building a CCS plant in Illinois.

The Next Generation of Alternative Energy

Venture capitalists flirt with solar thermal, algae, and wave power

By Katy Marquardt
Posted July 25, 2008

Cold Science

Study finds glaciers melting faster than believed

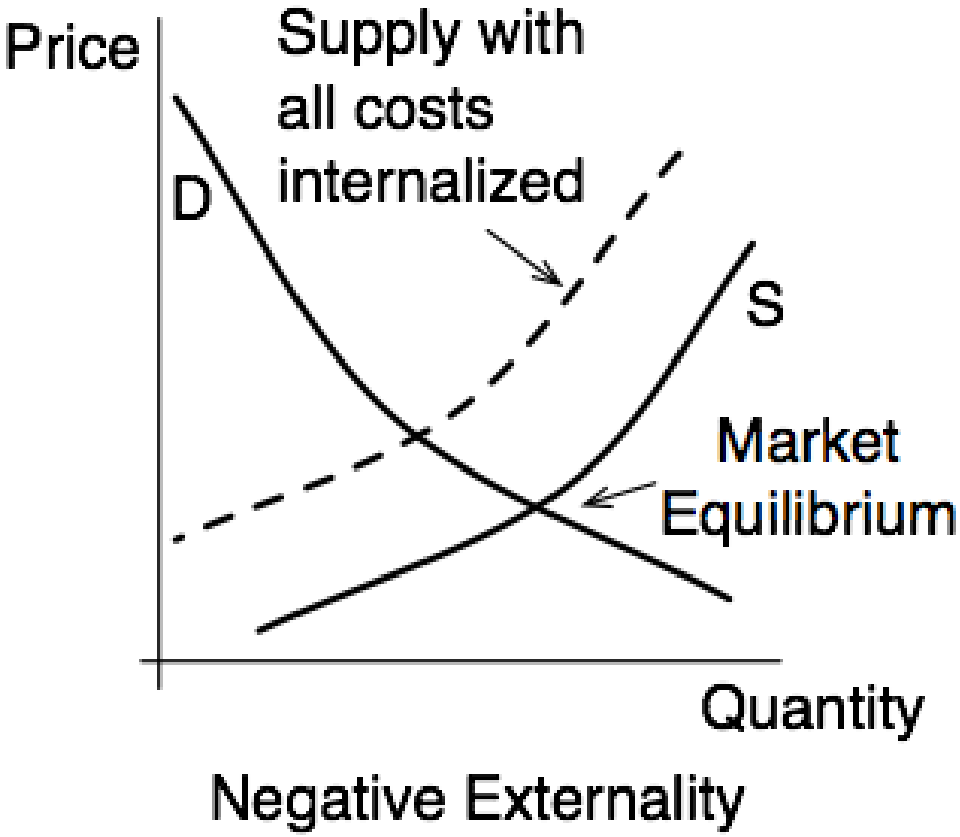
US wants China to act on carbon emissions

Public goods and negative externalities

Economic Externalities:
When consumers and producers do not explicitly consider all costs and benefits associated with their choices, as observed by society.

Negative Externality:
Occurs when a decision maker does not bear the full cost of a decision and over-produces or over-consumes.

Public goods and negative externalities



Negative Externality

Public objectives of society conflict with private objectives of firms due to externalities

How can design decisions impact…

Automakers?

Consumers?

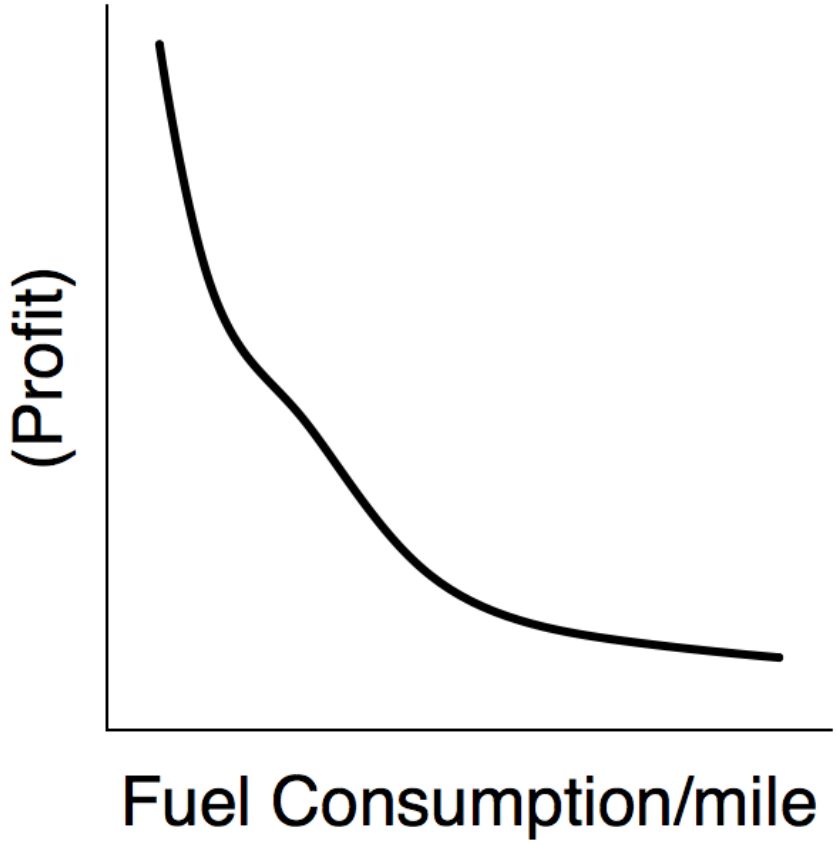
How can design decisions impact…

Society?

A Pareto set approach is used to quantify competition between objectives

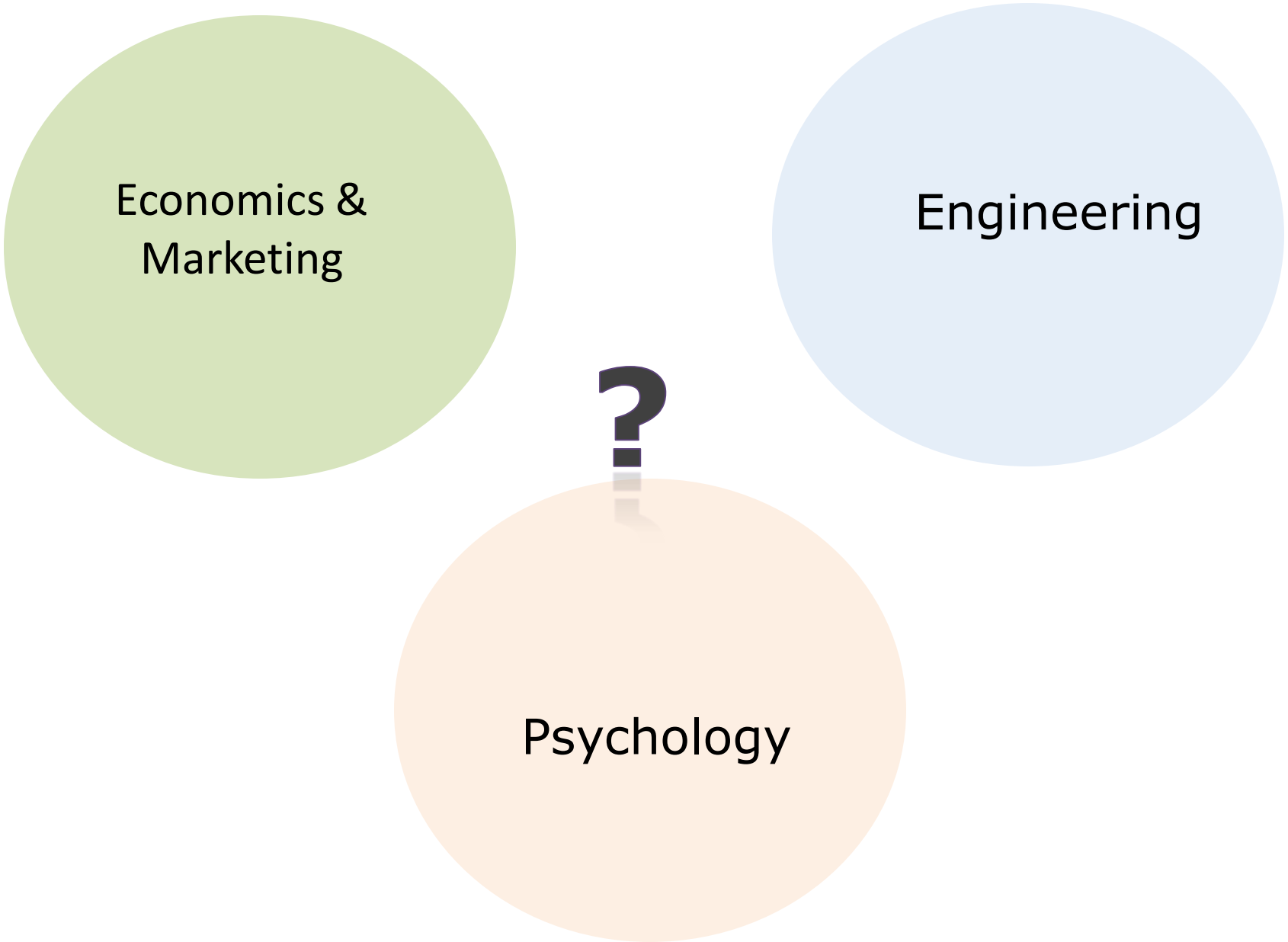
$$\mathbf{f} = \begin{bmatrix} f_{-profit} \\ f_{fuelconsump} \end{bmatrix}$$

$$\begin{aligned} \min_{\mathbf{x}} \quad & \mathbf{f}(\mathbf{x};\mathbf{p}) \\ \text{subject to:} \quad & \mathbf{h}(\mathbf{x};\mathbf{p}) = \mathbf{0} \\ & \mathbf{g}(\mathbf{x};\mathbf{p}) \leq \mathbf{0} \\ & \mathbf{x} \in \mathcal{X} \end{aligned}$$

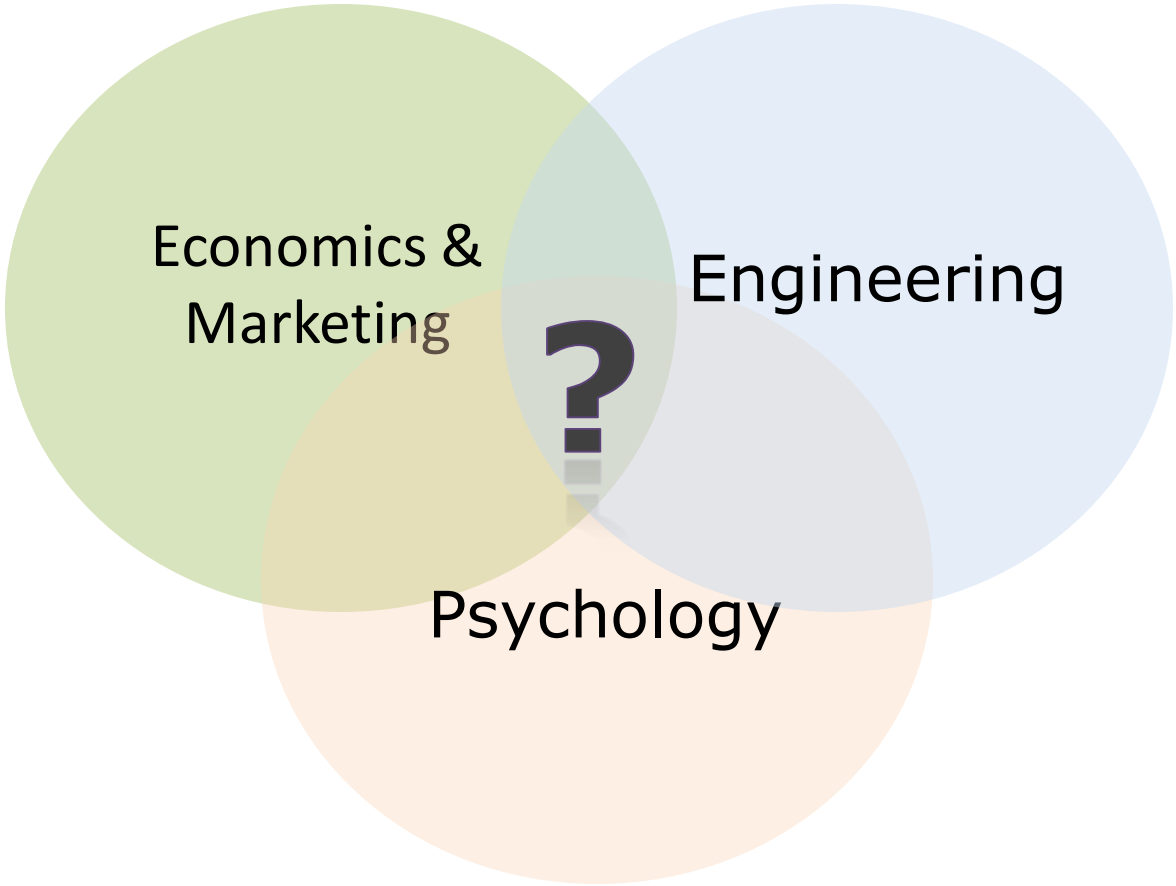


Frischknecht, B. and Papalambros, P., 2008, **A Pareto Approach to Aligning Public and Private Objectives in Vehicle Design**, Proceedings of the ASME 2008 IDETC/CIE 2008, August 3-6, 2008, Brooklyn, NY DETC-49143

Approach



Approach

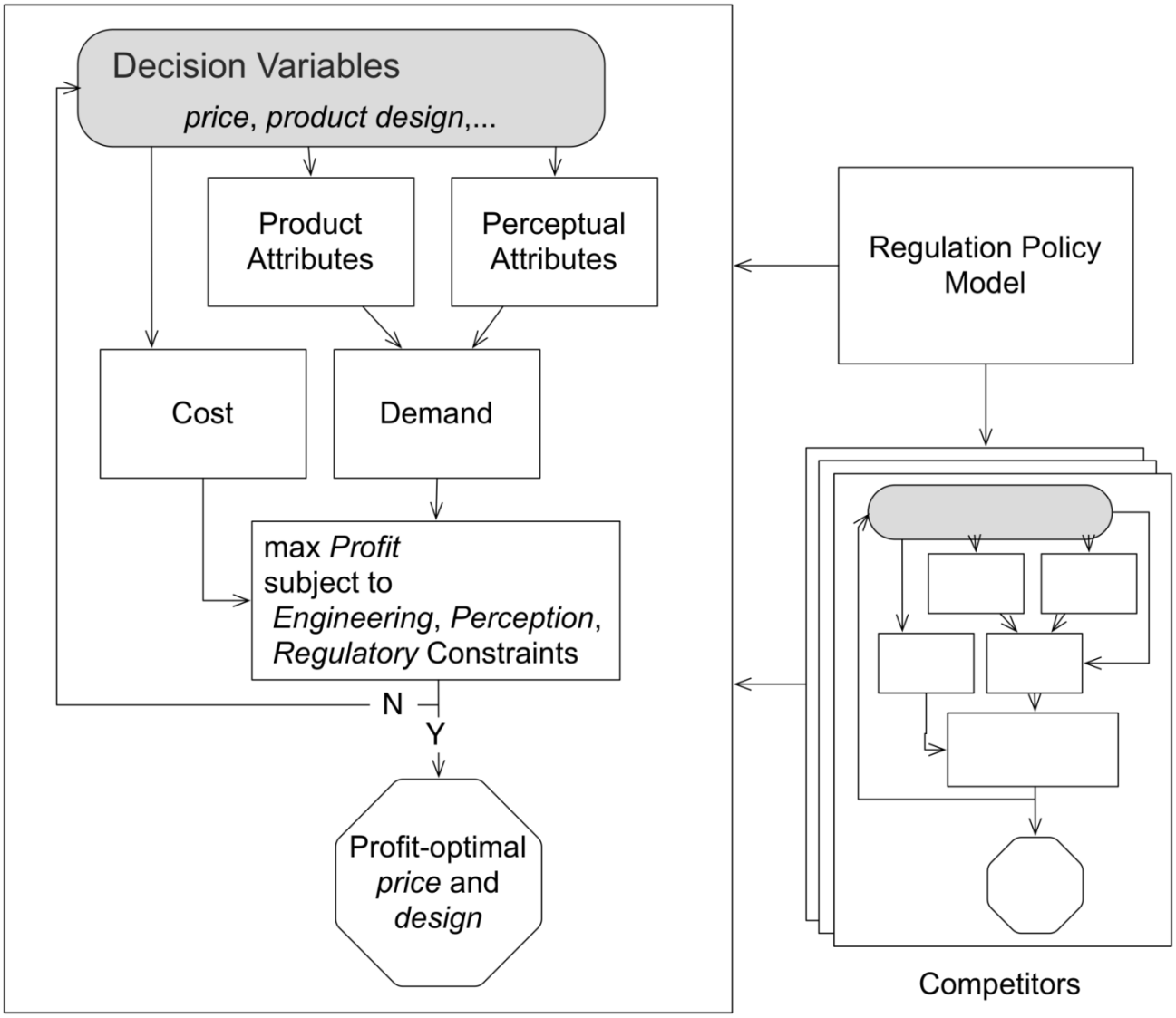


Where we're going

Discuss the overall framework that was developed to integrate methods from these disciplines

Present 2 case studies: look at tradeoffs between profit and fuel economy and safety and fuel economy

Present a study that examined the perceptions about safety and environmental friendliness



Frischknecht, B. and Papalambros, P. Y., "A Pareto Approach to Aligning Public and Private Objectives in Vehicle Design", *2008 ASME Design Engineering Technical Conference*, New York, NY, August 3-6, 2008, DETC2008-49143.

Michalek, J., Papalambros, P. Y., and Skerlos, S., "A Study of Fuel Efficiency and Emission Policy Impact on Optimal Vehicle Design Decisions". *Journal of Mechanical Design*, Vol. 126, No. 6, 2004, pp. 1062-1070.

Georgiopoulos, P., Jonsson, M., and Papalambros, P. Y., "Linking Optimal Design Decisions to the Theory of the Firm: The Case of Resource Allocation", *ASME Journal of Mechanical Design*, Vol. 127, 2005, pp.358-366.

Profit vs. fuel economy vehicle design case study

Demand Model

$$U_{ij} = \delta' \mathbf{z}_j + \beta' \mathbf{x}_{ij} + \mu_i' \mathbf{w}_{ij} + \epsilon_{ij}$$

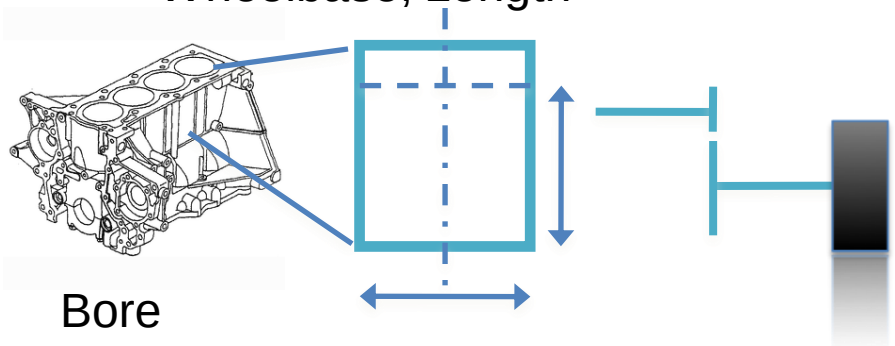
$Europe$	$mvan \cdot child$	$Price/inc$
$Japan$	$SUV \cdot child$	hp/wt
$Chrysler$	$pickup \cdot rural$	$gal/mile$
GM		$L \times W$
$Korea$		$2Seat$ or $mini$
		$minivan$
		SUV
		van
		$pickup$
		$hybrid$

Decision variables

$

MSRP

Width, Height,
Wheelbase, Length



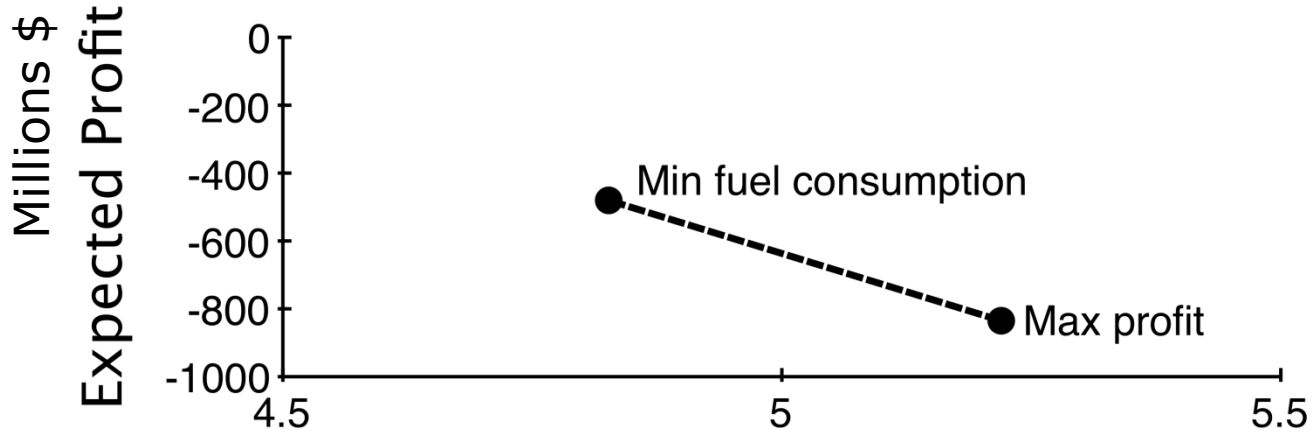
Bore
Bore/Stroke

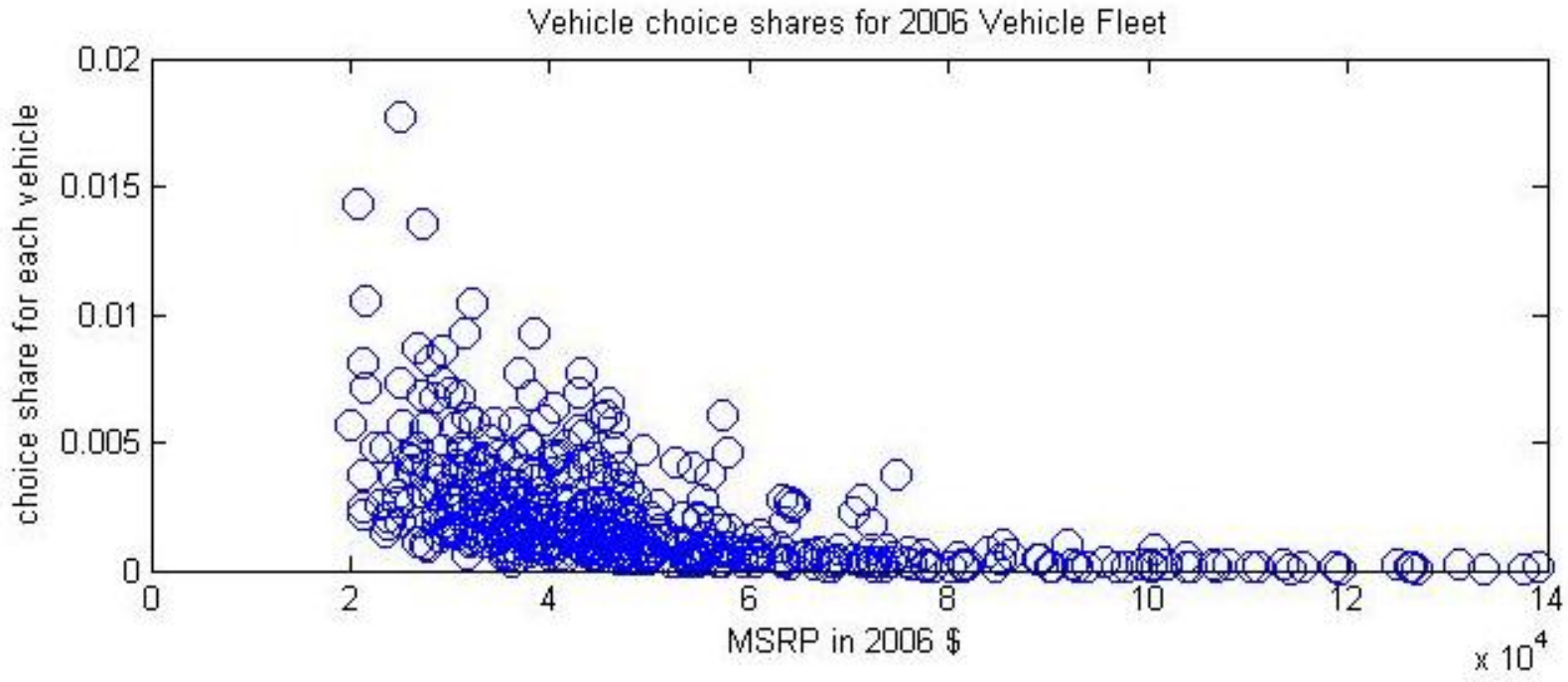
Final drive ratio

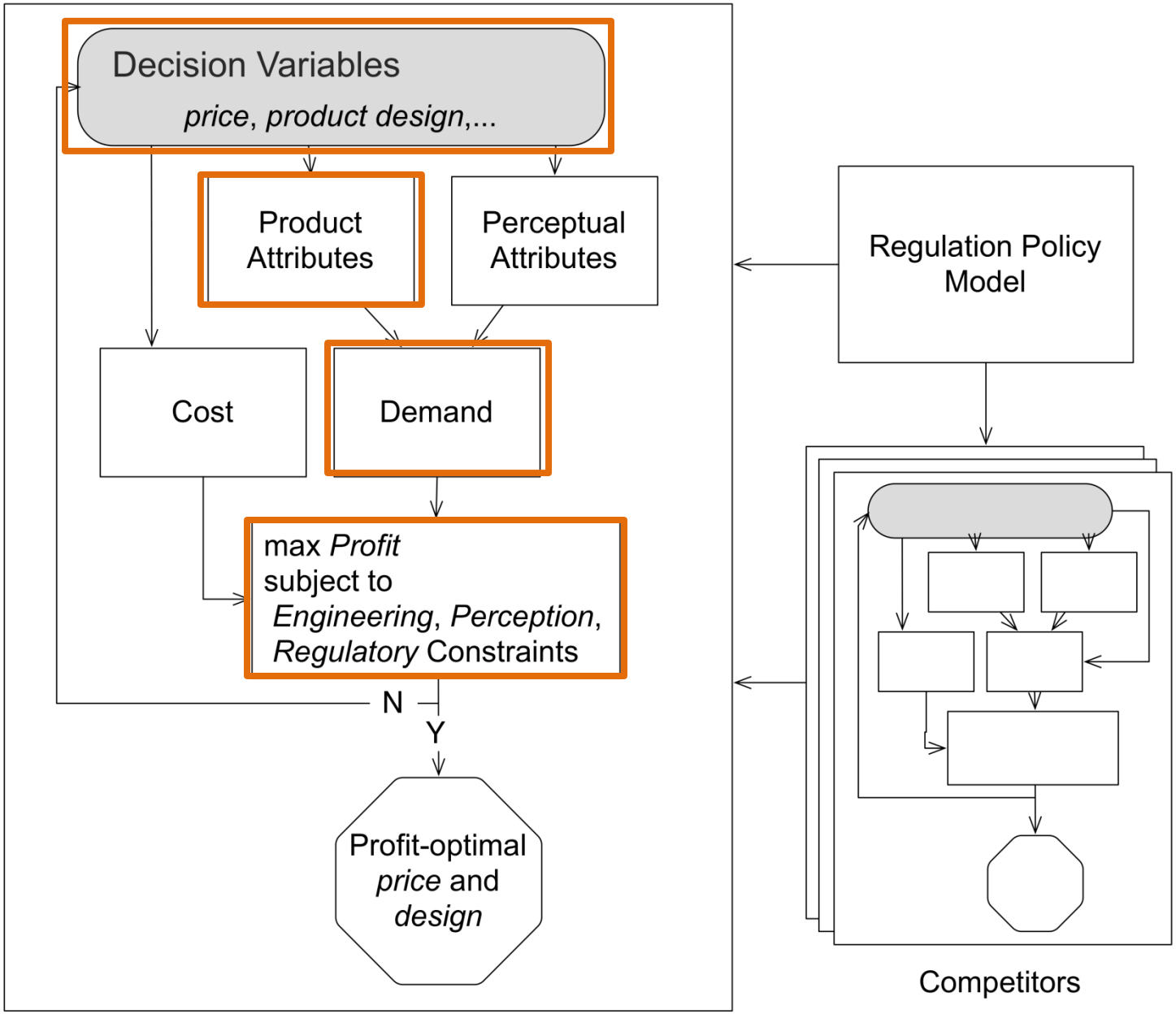
Constraints for midsize crossover

- Top Speed
- Towing grade
- Passing acceleration
- Cargo volume
- Rollover score
- Crush space
- Curb clearance

Market simulations



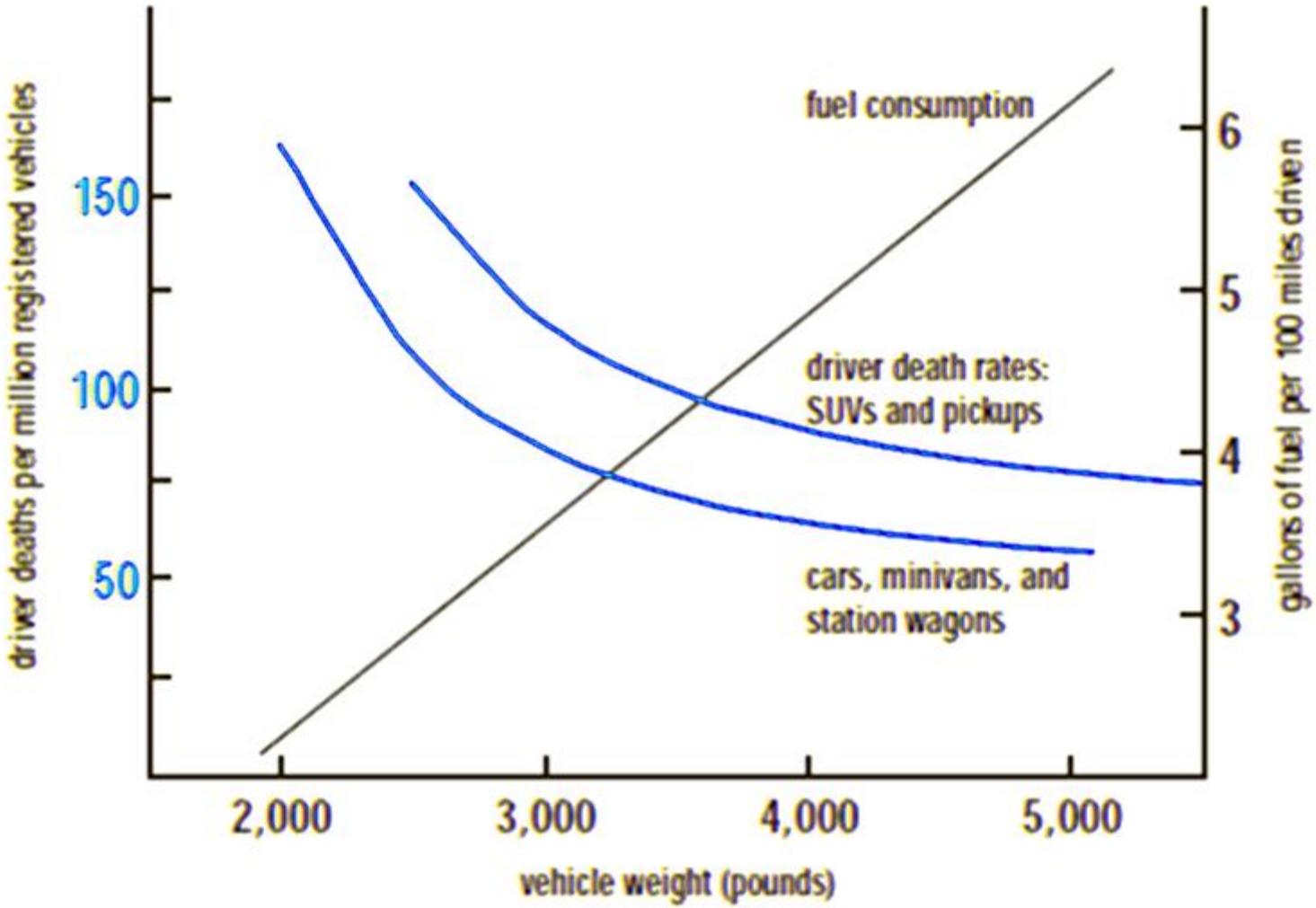




Simulation-Based Case Study

A look at the role of safety and fuel economy in vehicle performance

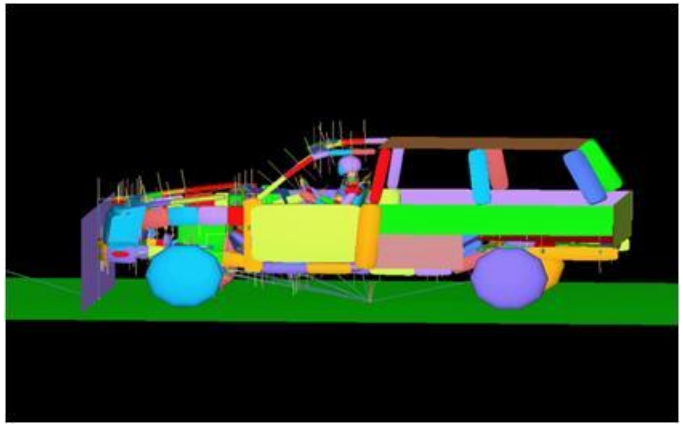
Driver Risk & Fuel Consumption vs. Weight



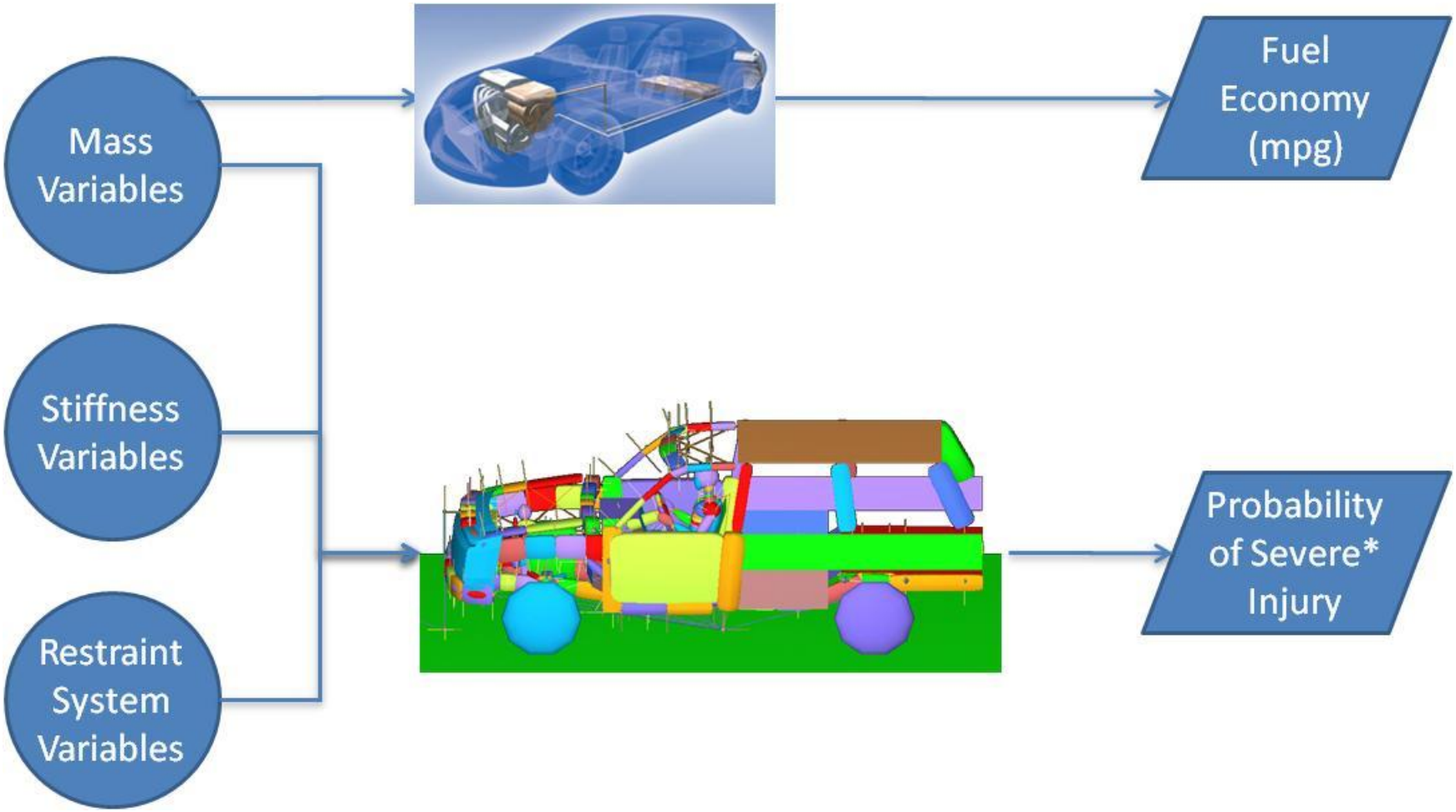
Insurance Institute for Highway Safety, Improve Fuel Economy without Negative Safety Consequences, *IIHS Status Report*, 37(4) 2002.

Objectives

- To develop a simulation-based approach for evaluating and optimizing vehicle designs
- To consider occupant safety and fuel economy outcomes concurrently
- To simultaneously optimize over structure and restraint system design decisions



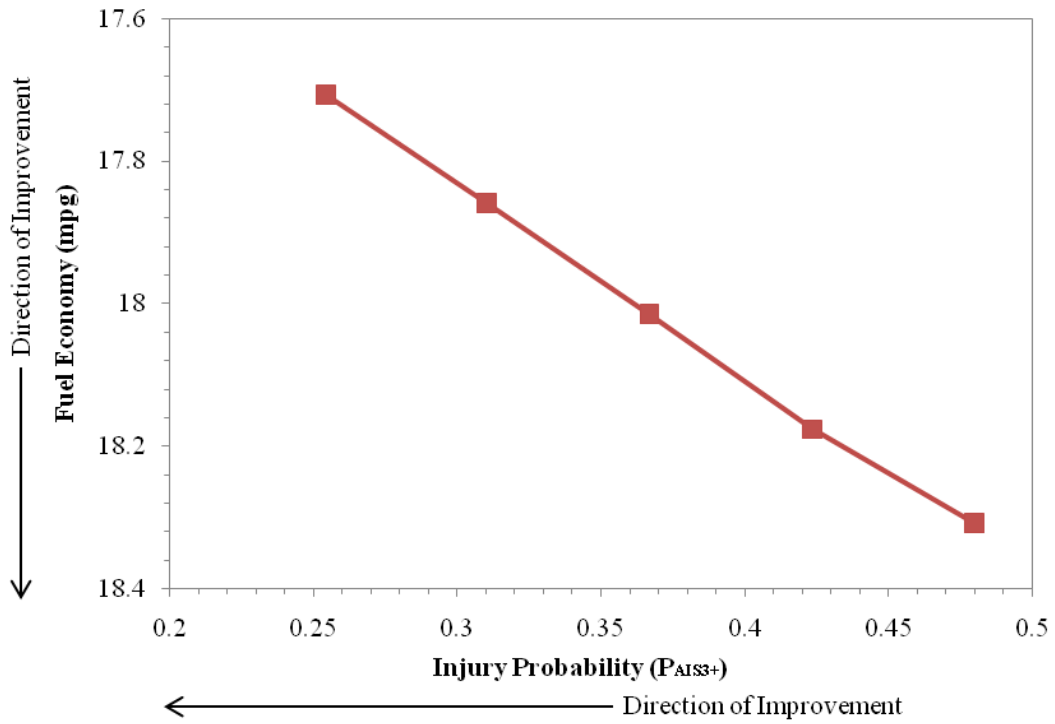
Model Calculation Flow



*Severe indicates 3 or higher on the Abbreviated Injury Scale (AIS)

Results of Three-Variable Study

Using results of a three-variable DoE, a bi-linear response surface was used for a multi-objective optimization study



Variables:

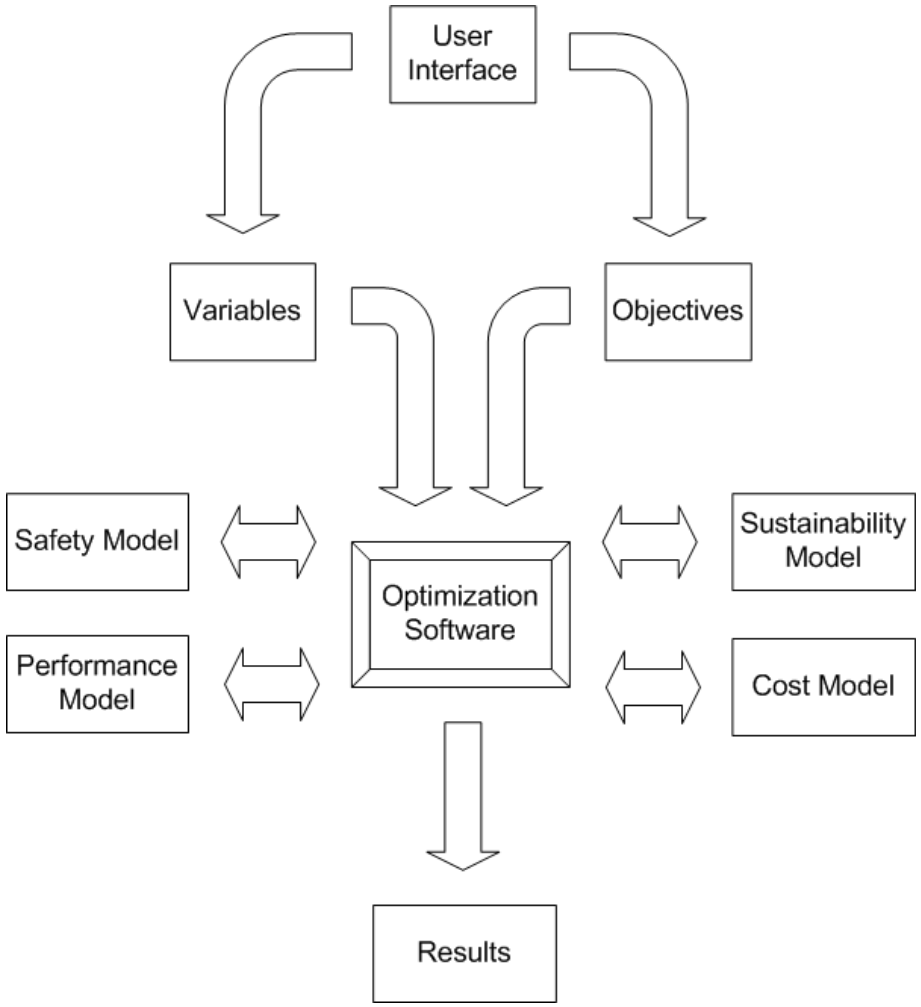
1. Rear body mass
2. Front rail stiffness
3. Airbag release time

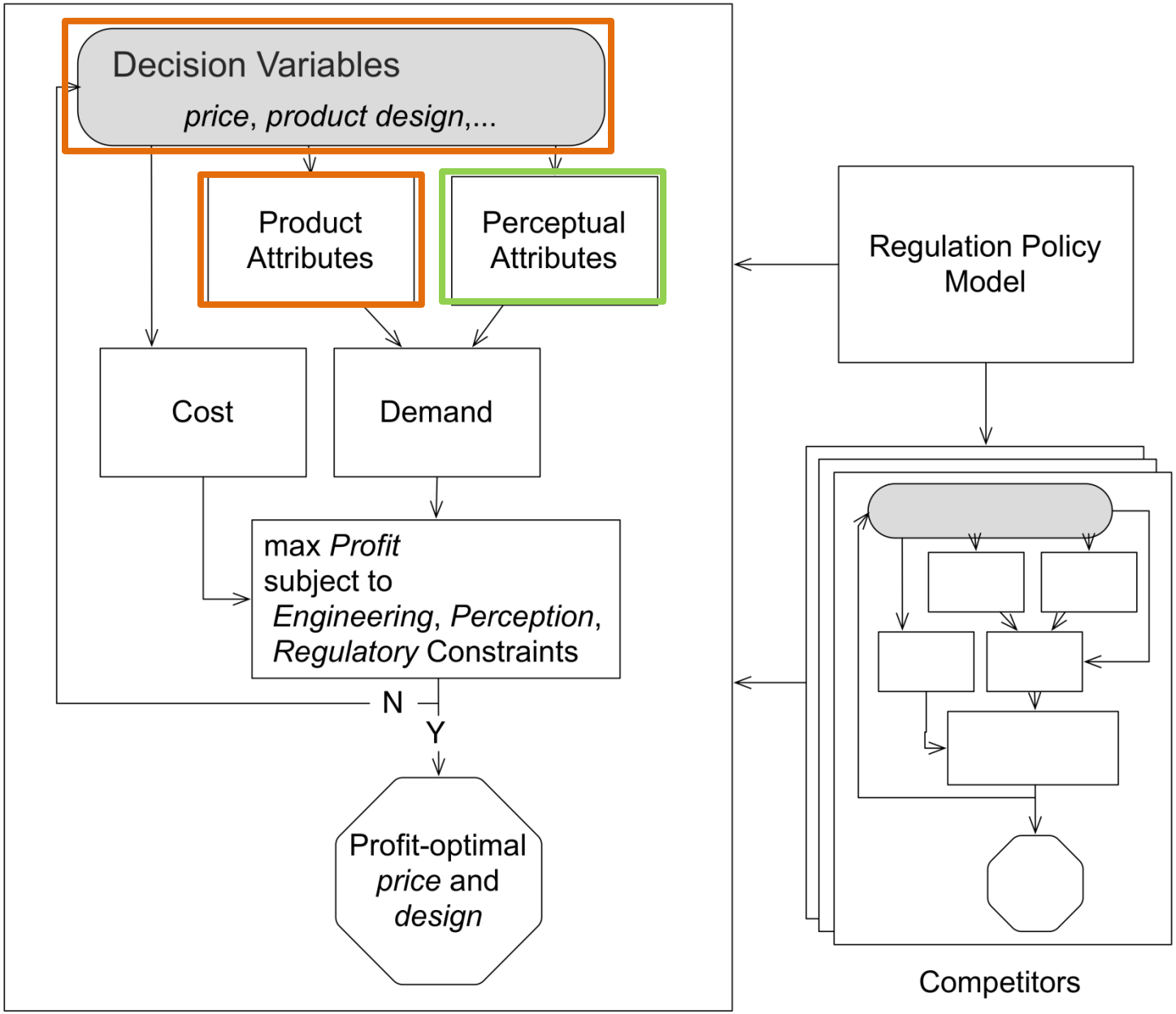
Objectives:

1. Minimize probability of occupant injury
2. Maximize fuel economy

Future Model Development

- Add structure and restraint system variables
- Adapt model to other vehicle classes
- Diversify crash scenarios and weight them by frequency of occurrence
- Add performance and cost models to better assess feasibility





Quantifying Perceptions

A look at perceived environmental friendliness (PEF) and perceived safety of vehicles

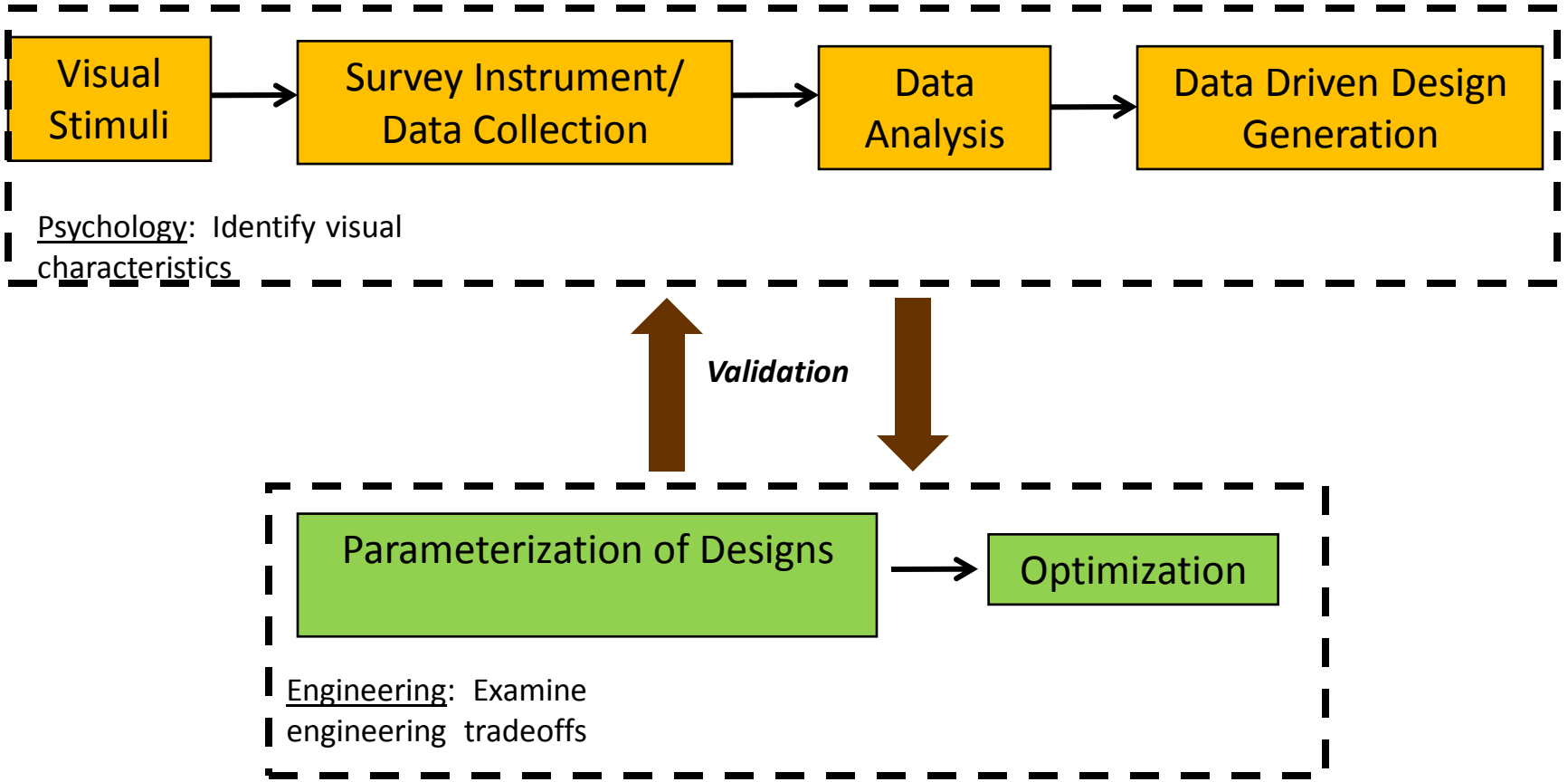
Main Research Questions

1. What physical attributes relate to one's perception of vehicle greenness?

2. What visual/aesthetic characteristics are related to perception of greenness?

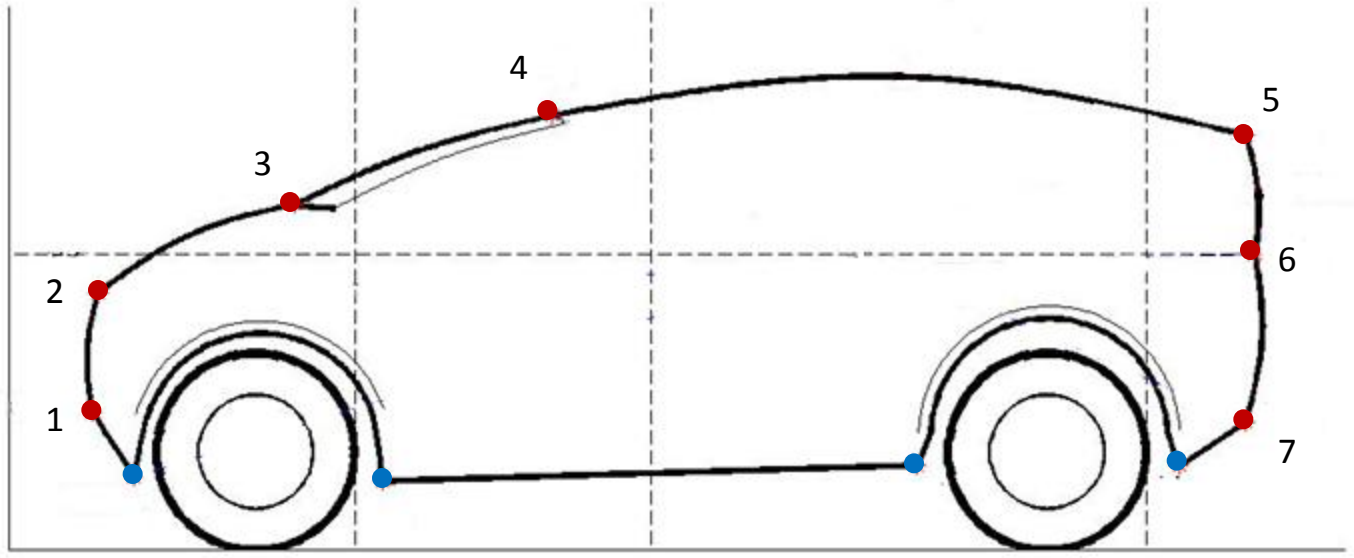
3. What are the tradeoffs that exist between the factors that influence perception of greenness and other critical engineering parameters?

Methodology



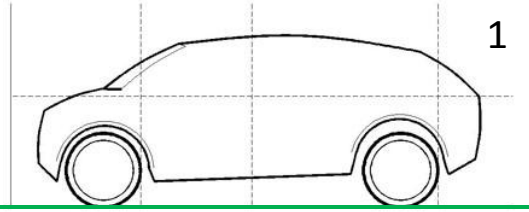
Reid, T., Gonzalez, R and Papalambros, P., 2009, **A Methodology for Quantifying the Perceived Environmental Friendliness of Vehicle Silhouettes in Engineering Design**, Accepted to ASME 2009 IDETC/CIE , August 30 – September 2, 2009 DETC-87095

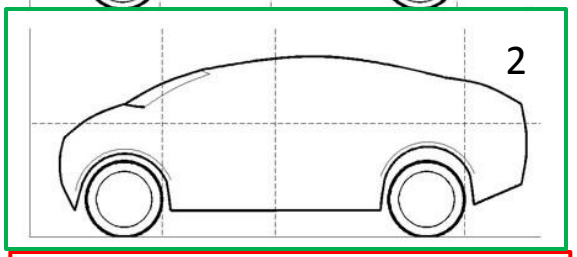
Stimuli Creation

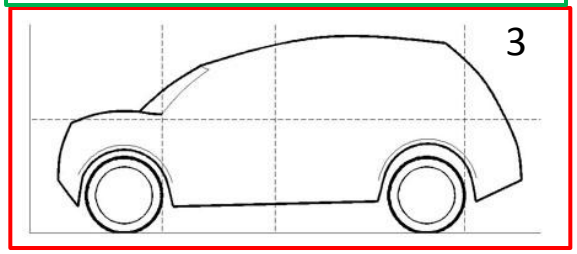


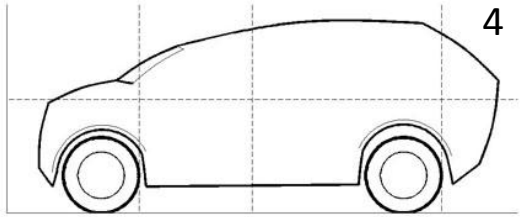
Taguchi Method to provide a DOE with minimal options to survey respondents

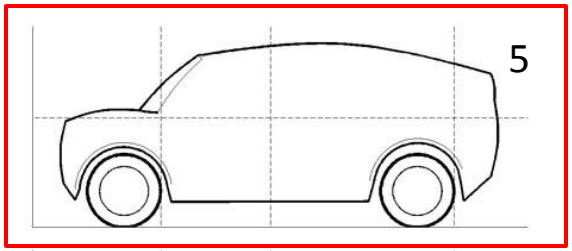
16 experiments = 16 possible vehicle shapes

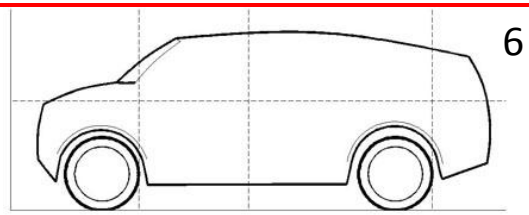


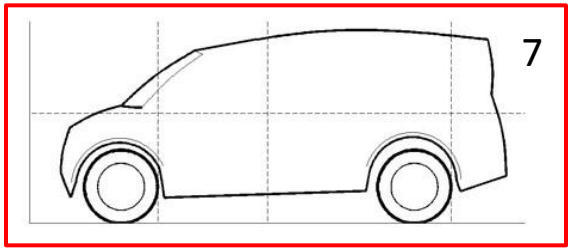


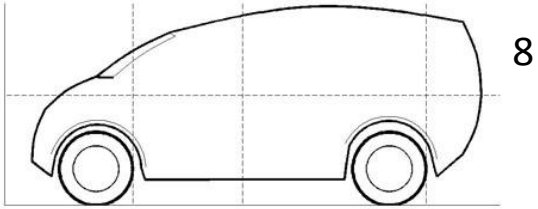


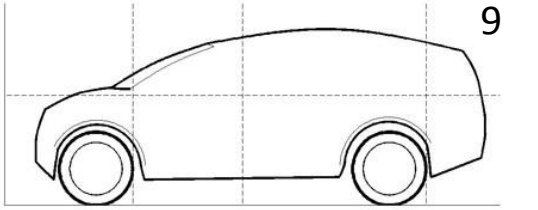


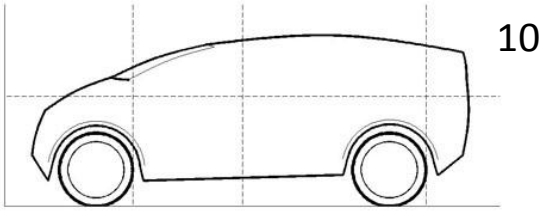


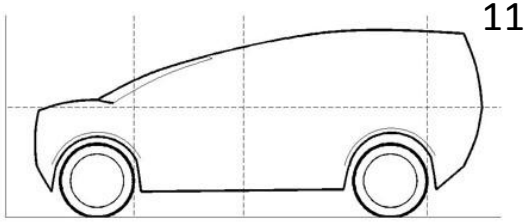


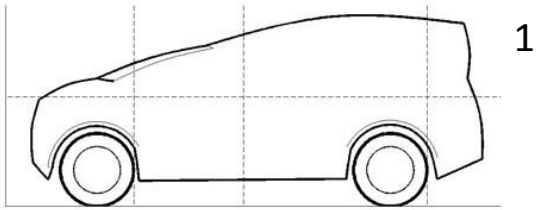


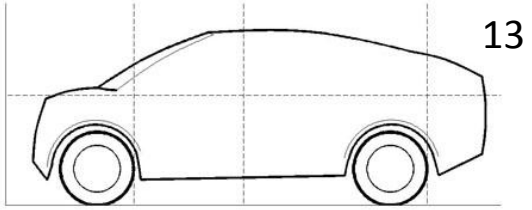


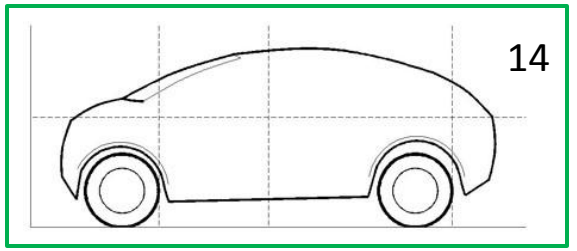


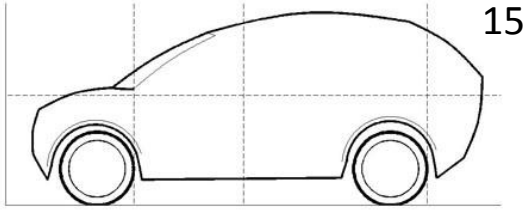


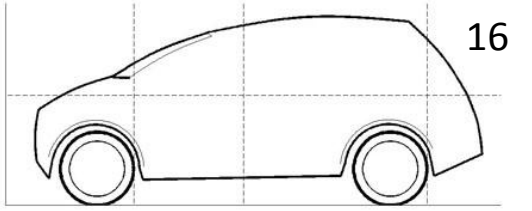


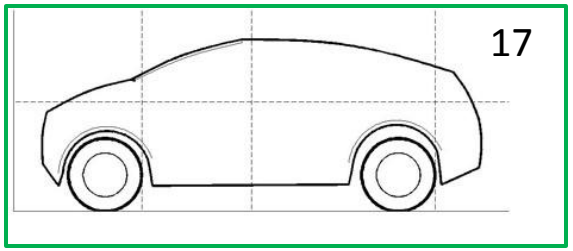






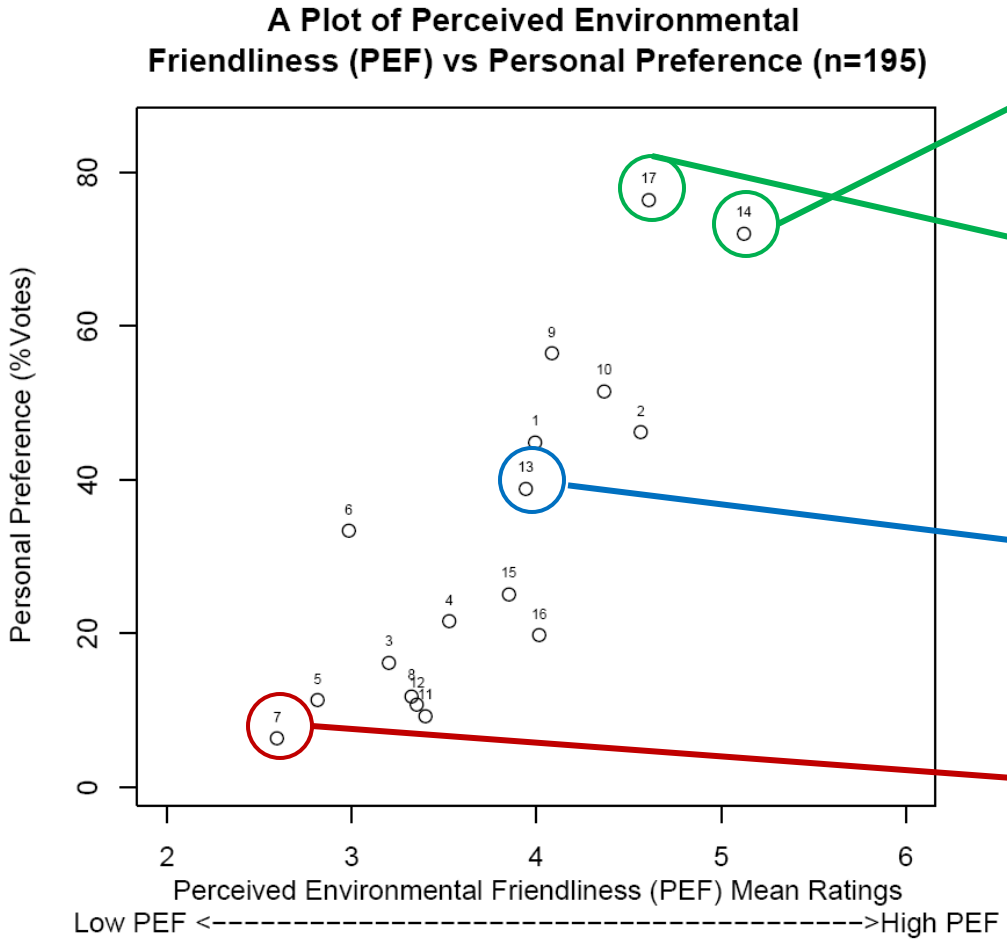


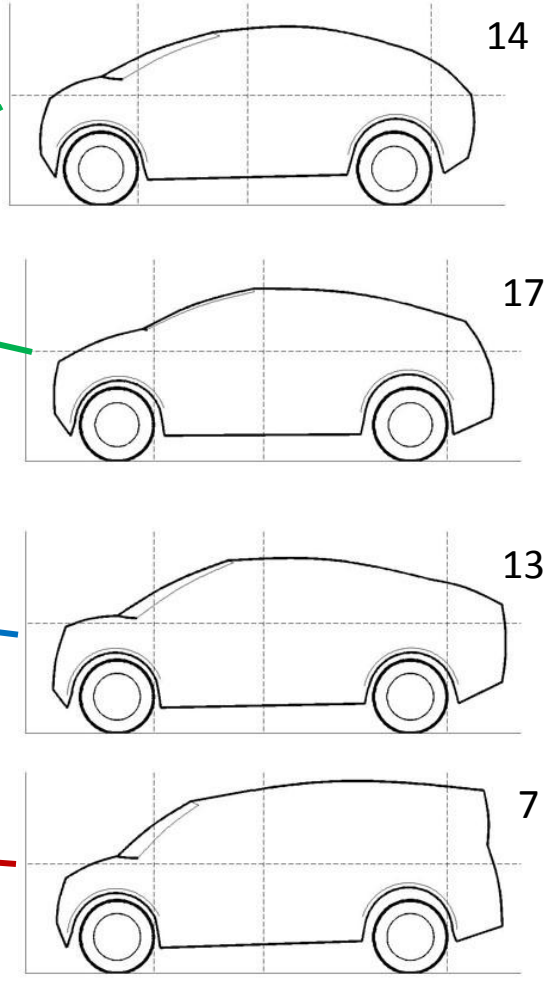




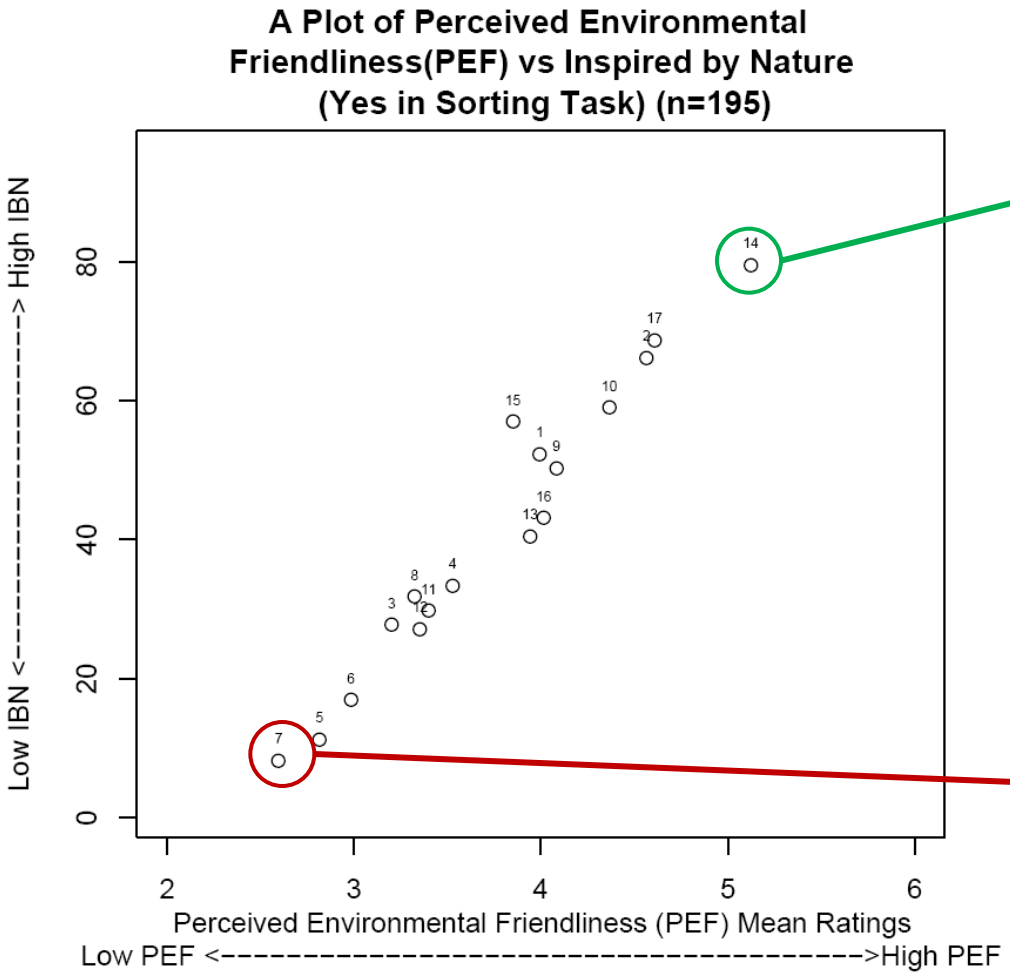
“plant”

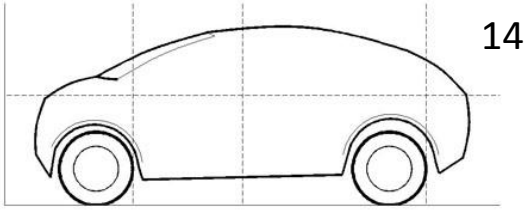
Results: Perceived EF vs. Preference

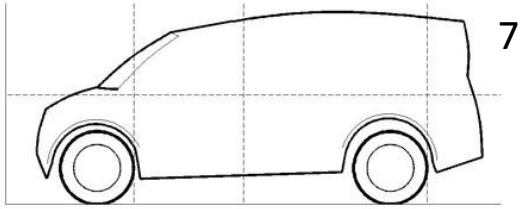




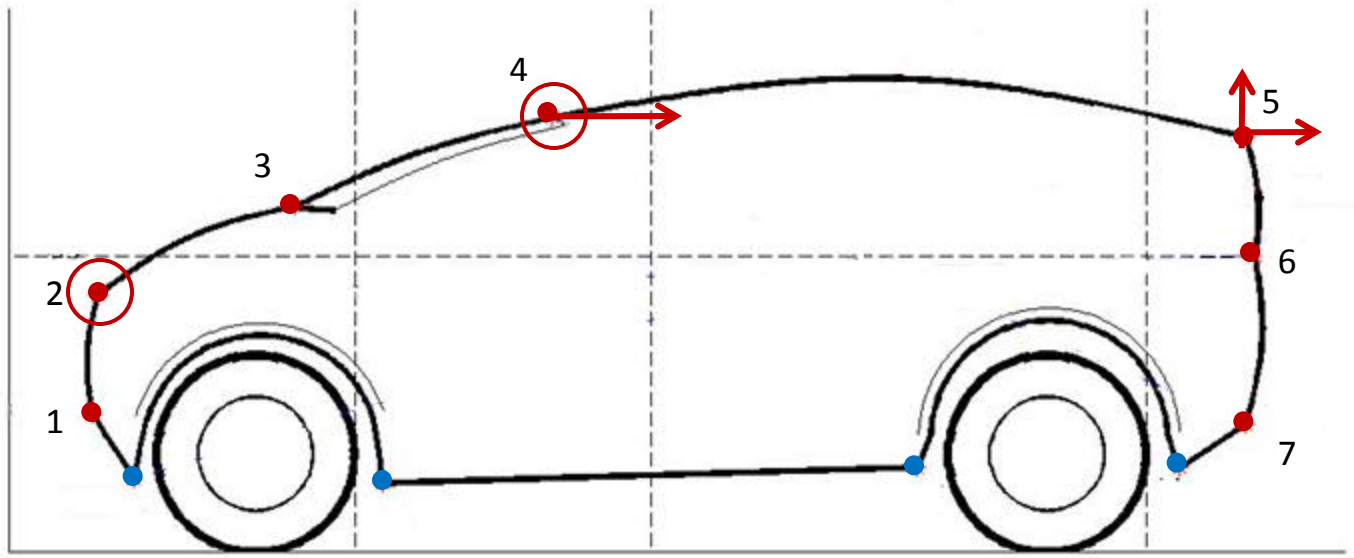
Results: Perceived EF vs. IBN





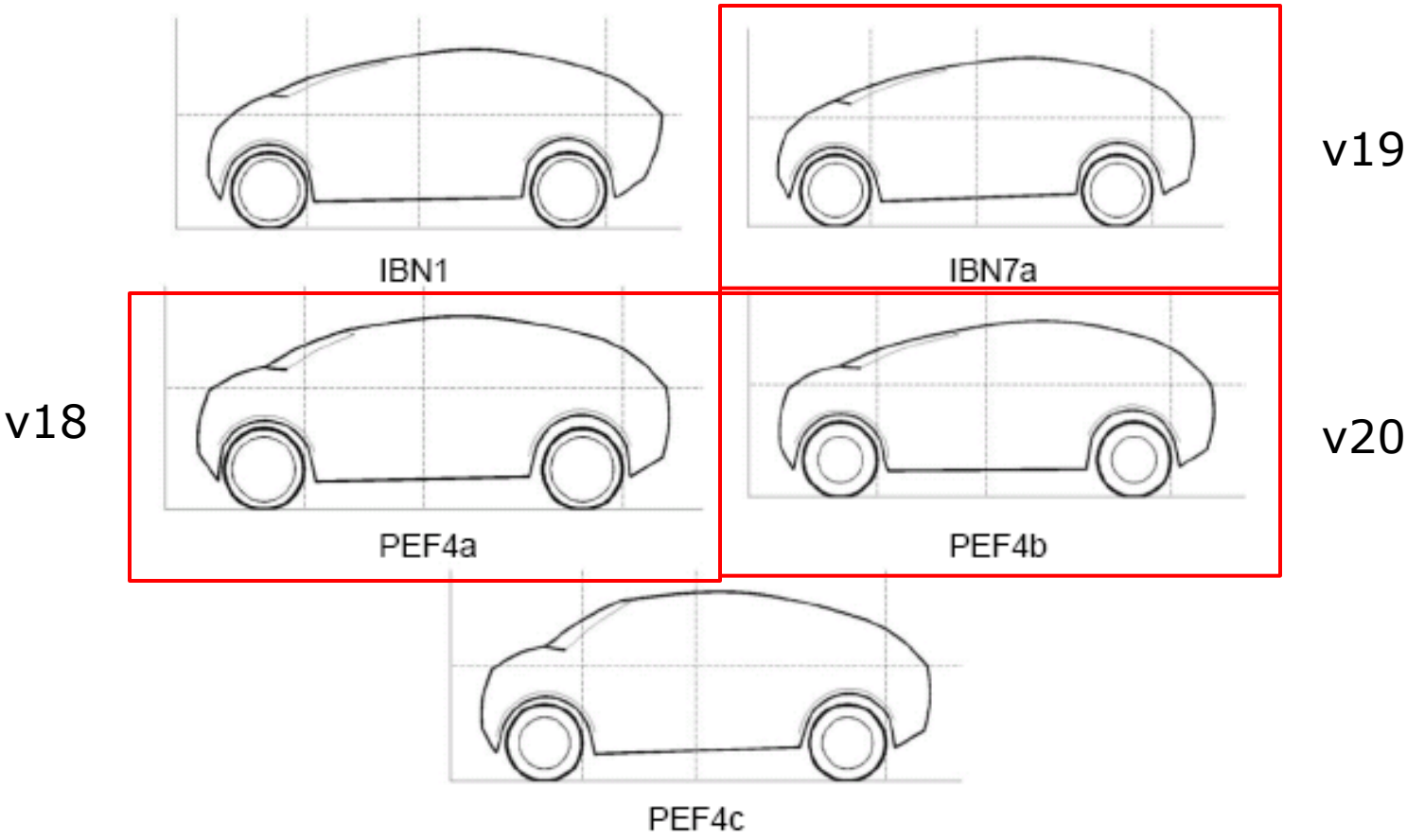


Factors: Perceived EF vs. IBN

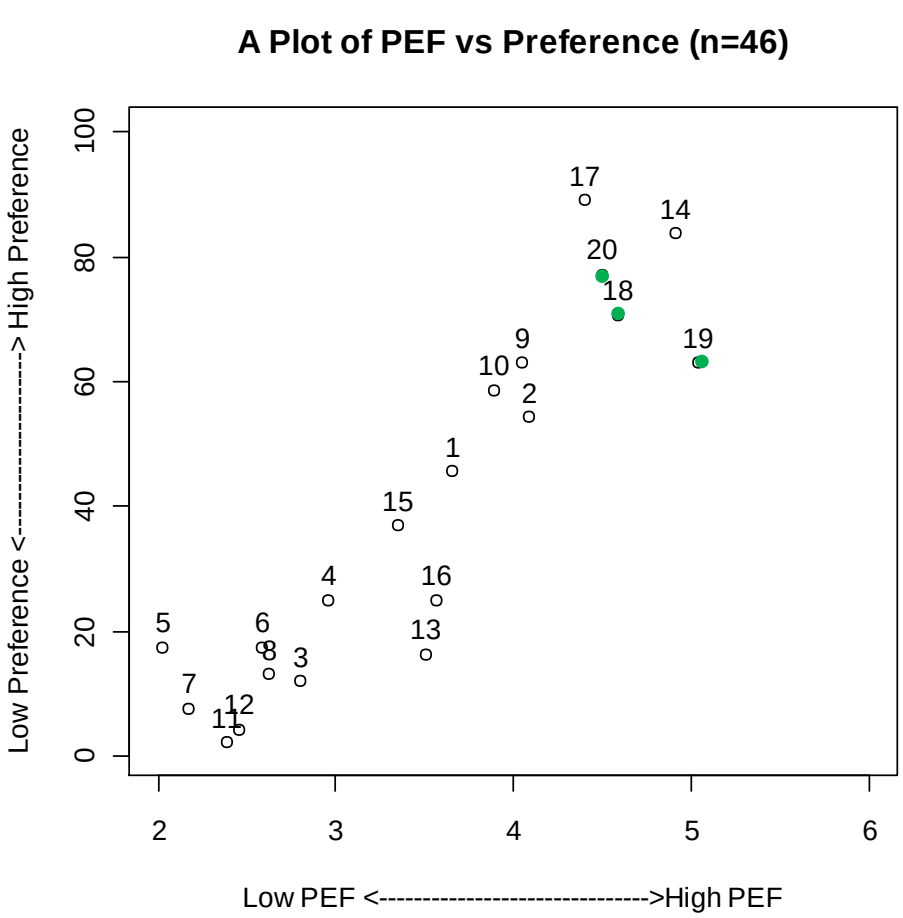


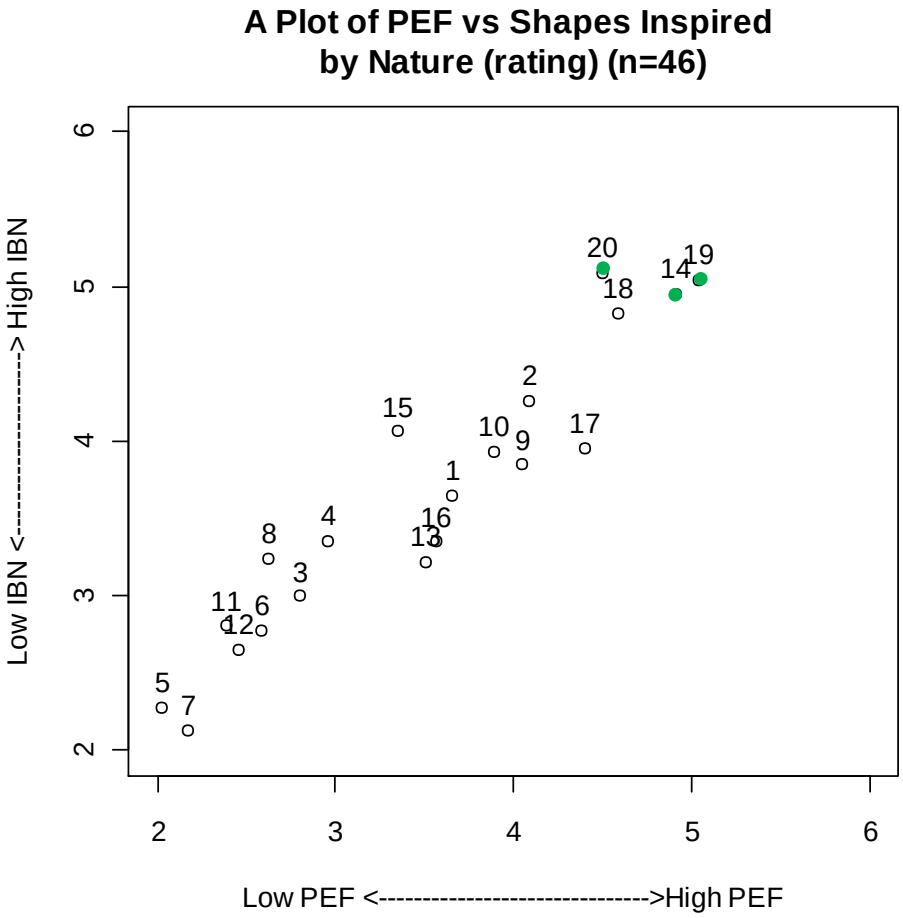
Point 2 – interactions between x and y coordinates
Point 4 – main effect on x coordinate; interactions between x and y coordinate
Point 5 – main effects on x and y coordinate only

Examples of new designs based on user data

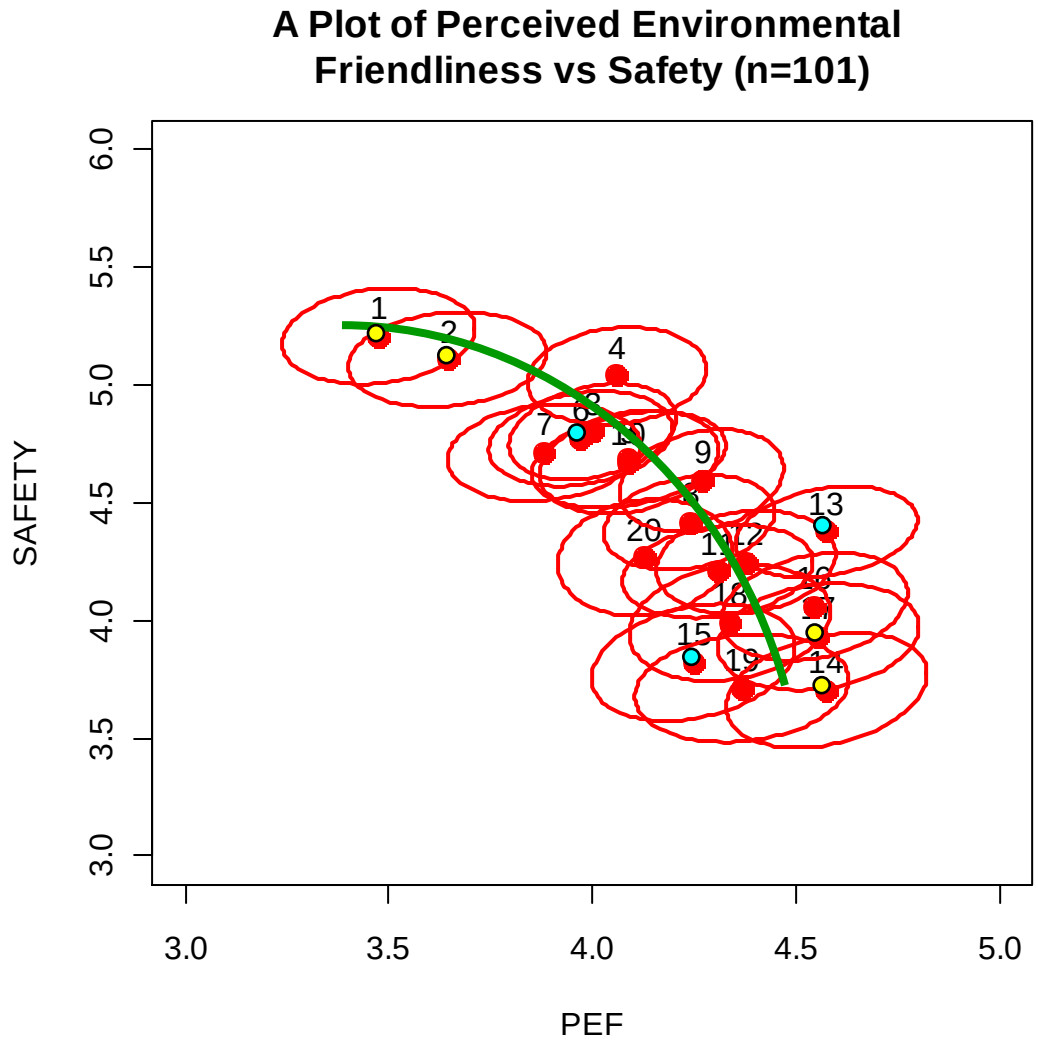


Results of validation study





Additional Study: A Look at Safety



Perception Study Conclusions

- The data indicate that silhouettes that have smoother curves/more continuous lines and have a less boxy backend correlate with perceived environmental friendliness
- Perceptions about safety and environmental friendliness are inversely related

Summary

A scenario based framework was presented that can integrate both objective and subjective considerations in the design process

A method for analyzing tradeoffs between fuel consumption and profit from the perspective of the firm was presented

A model for simulation based analysis of tradeoffs between safety and fuel economy was discussed

A method for quantifying perception environmental friendliness and safety was presented

Acknowledgments

Colleagues:

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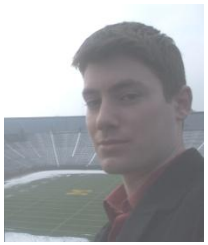

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Yi Ren (Max) and members of the Optimal Design Lab

Faculty Advisors:

Richard Gonzalez, Psychology & Statistics Dept.
Panos Papalambros, Mechanical Engineering Dept.

Sponsors:

Ford Motor Company
Rackham Graduate School

What questions do you have?