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Nov 13, 2013

modeFRONTIER在汽车安全及设计优化中的应用

modeFRONTIER in Automotive Safety: Stochastic Model Extrapolation and Robustness Design

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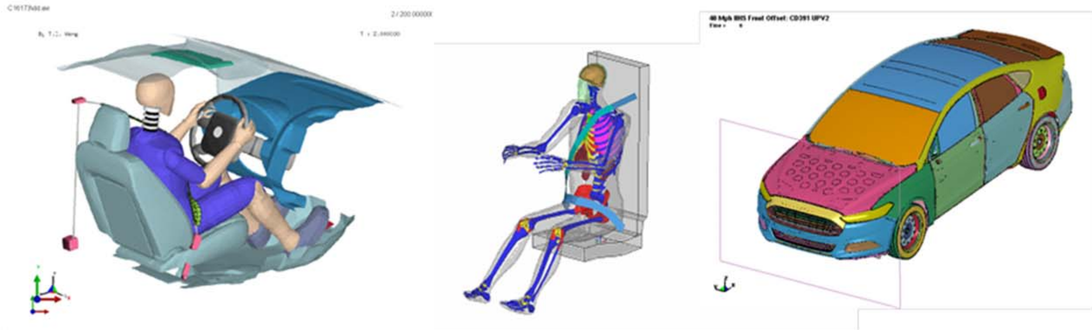

About Me

Professional Experiences

- 2013/07- present
  - Researcher & Associate Professor, Chongqing University

- 2008- 2013
  - Research engineer, PhD Intern, passive safety, Ford Research Laboratory
  - Postdoctoral & PhD research fellow, University of Michigan (U of M)

Education

- 2005-2011, **Ph. D.** Mechanical Engineering, UM-SJTU (Shanghai Jiao Tong University) -Joint program
- 2001-2005, **B. E.** ME (UM-SJTU Joint class)
- 2001-2005, **B. A.** International Economy & Commerce, SJTU

Research Interests

- 模型验证与校核理论及方法 Model Validation & Verification
- 稳健设计与基于可靠性设计方法 Robust/Reliability Based Design
- 多学科优化设计理论与方法 Multidisciplinary Design Optimization
- 车辆安全耐撞性优化设计 Vehicle Safety Crashworthiness Optimization
- 动态系统统计数据分析 Statistical analysis techniques on dynamic time histories

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  - Ford Motor Company
- **Dr. Sumeet Parashar, Dr. Zengdan Xue**
  - ESTECO North America

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公路交通安全：世界和中国



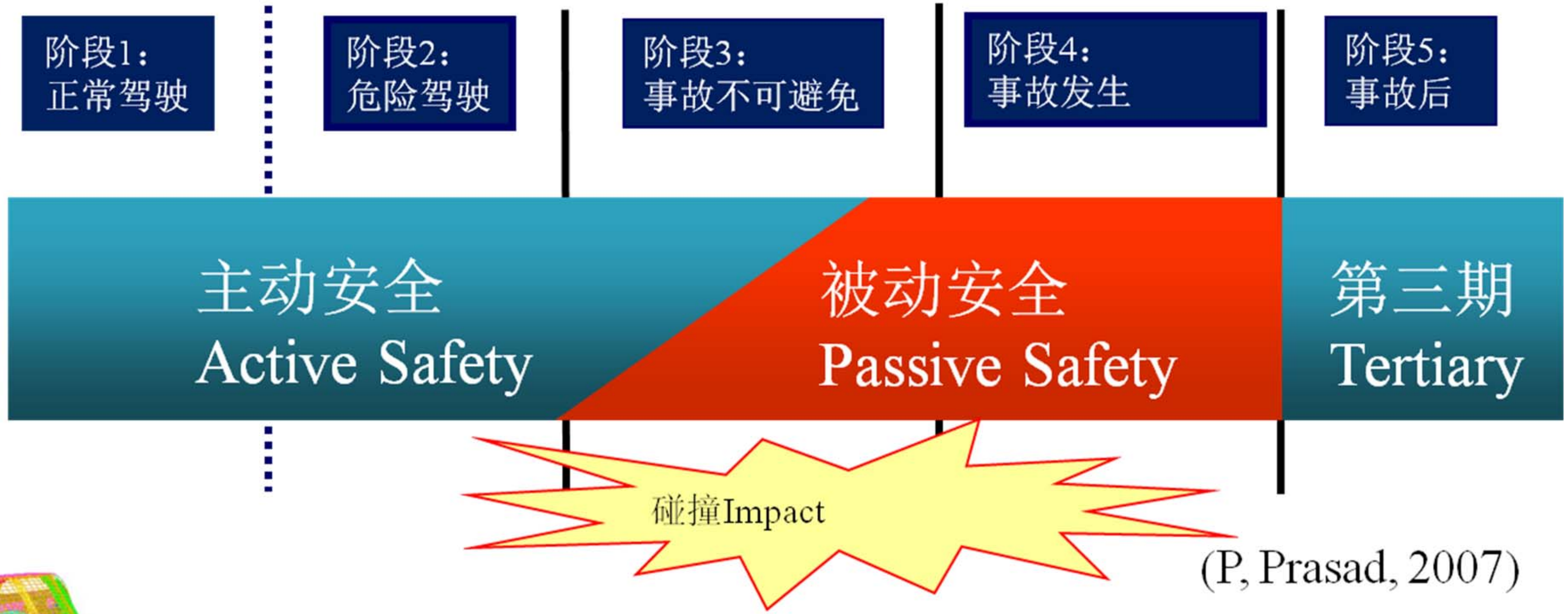

每年全世界

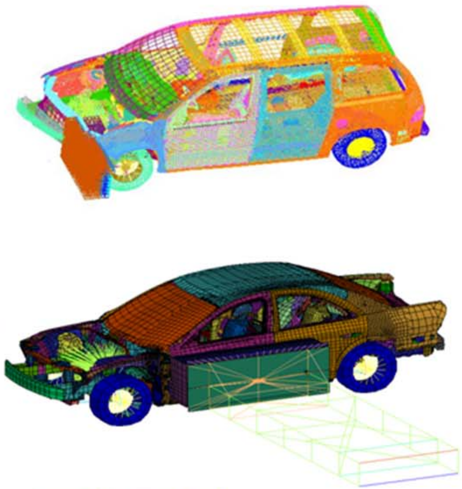
- 120万人：死于车祸
- 2500万人：受伤或致残
- 23%：车祸占全球伤害总死亡比例
- 5000亿美元：车祸相关经济损失
- WHO Report 2004

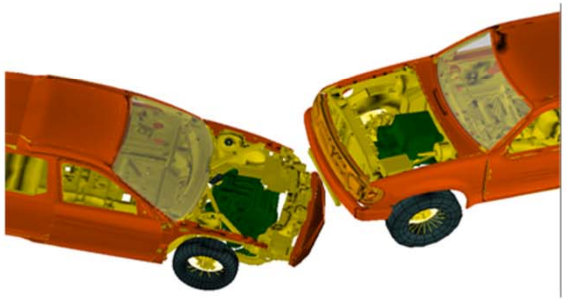
2012年中国

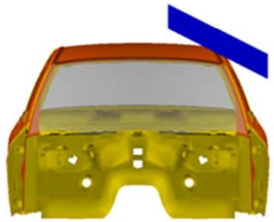
- 20.4万：交通事故
- 6.0万人：死于车祸
- 25.4万人：受伤或致残
- 9.3亿元：车祸直接经济损失
- 中国交通技术网

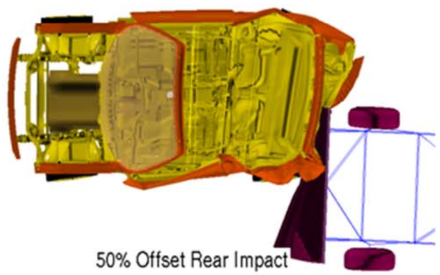
汽车安全研究综述


阶段1：
正常驾驶
阶段2：
危险驾驶
阶段3：
事故不可避免
阶段4：
事故发生
阶段5：
事故后
主动安全
Active Safety
被动安全
Passive Safety
第三期
Tertiary
碰撞Impact
(P, Prasad, 2007)







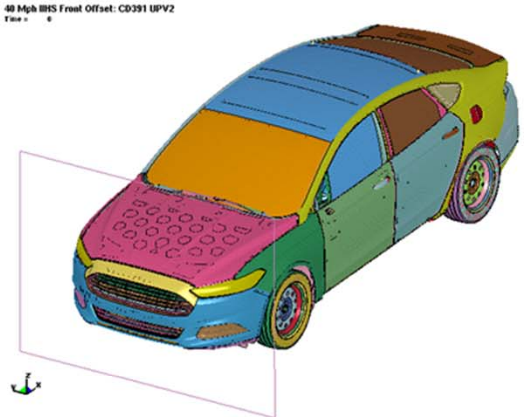

50% Offset Rear Impact

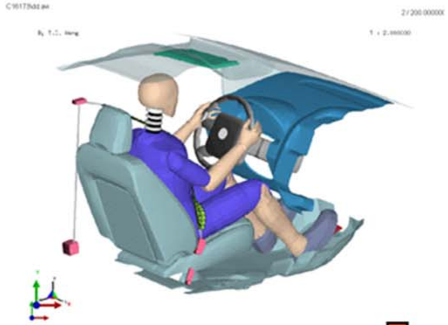
被动安全研究

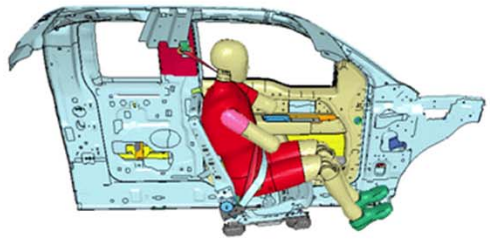
Global Safety Regulations

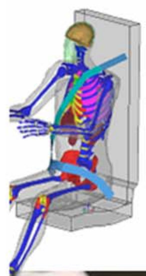
Public Domain

Real World Considerations







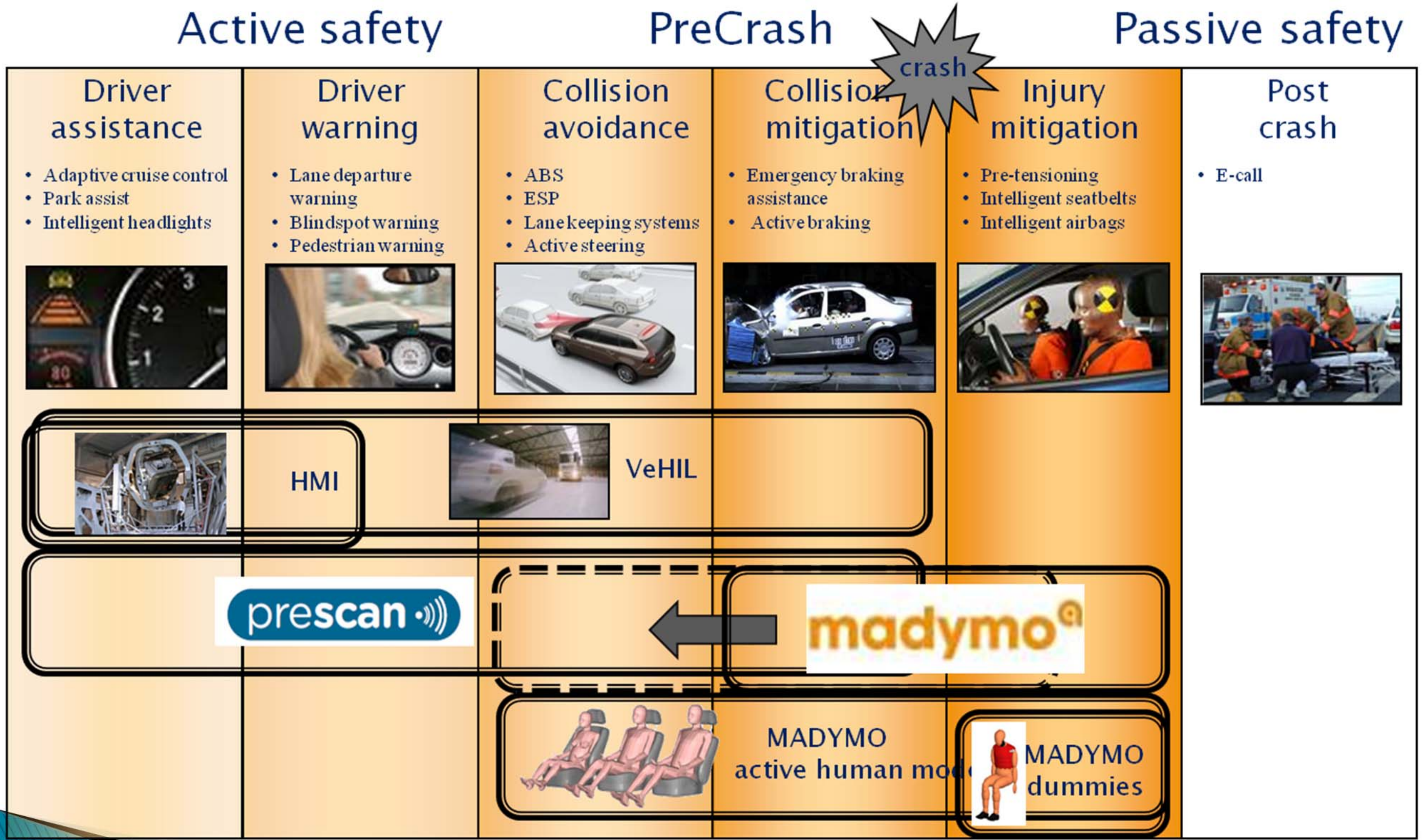


Optimization & Robustness Designs

Greater Products, Stronger Business, A better World !

(J Cheng, 2012)

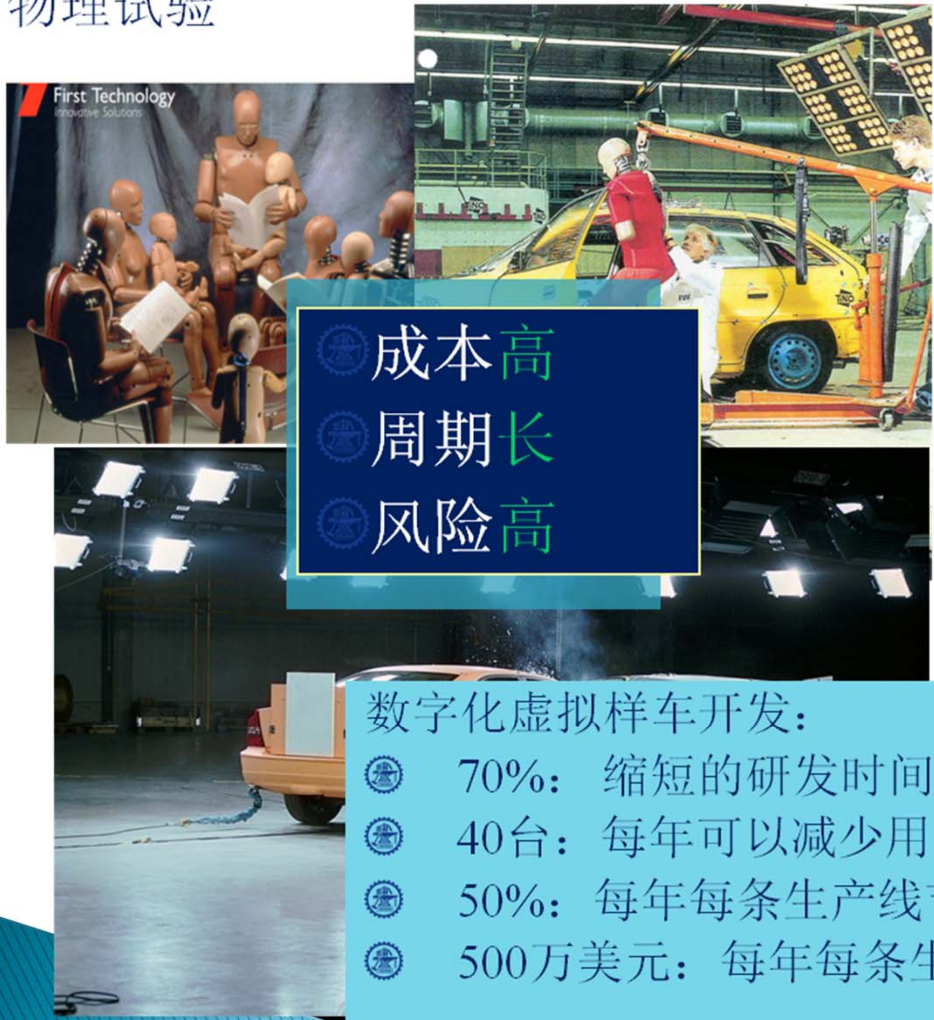
趋势：集成安全



(Courtesy of TASS, 2012)

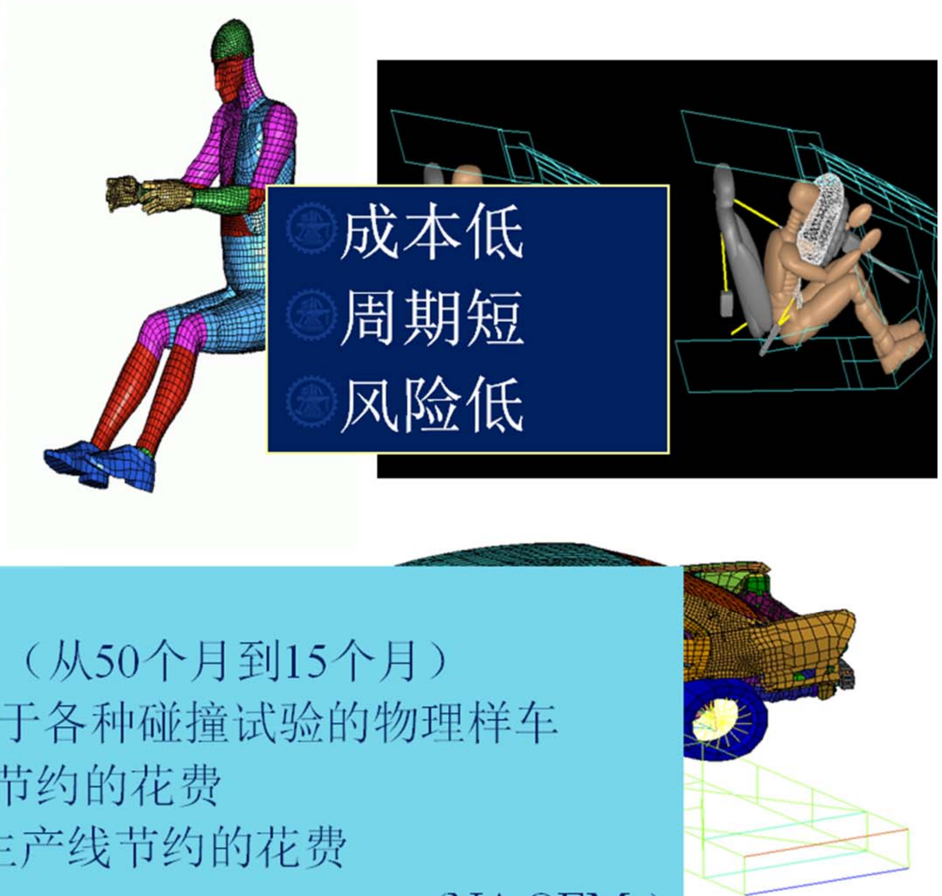
物理试验 vs. 仿真模型

物理试验



- 成本高
- 周期长
- 风险高

仿真模型



- 成本低
- 周期短
- 风险低

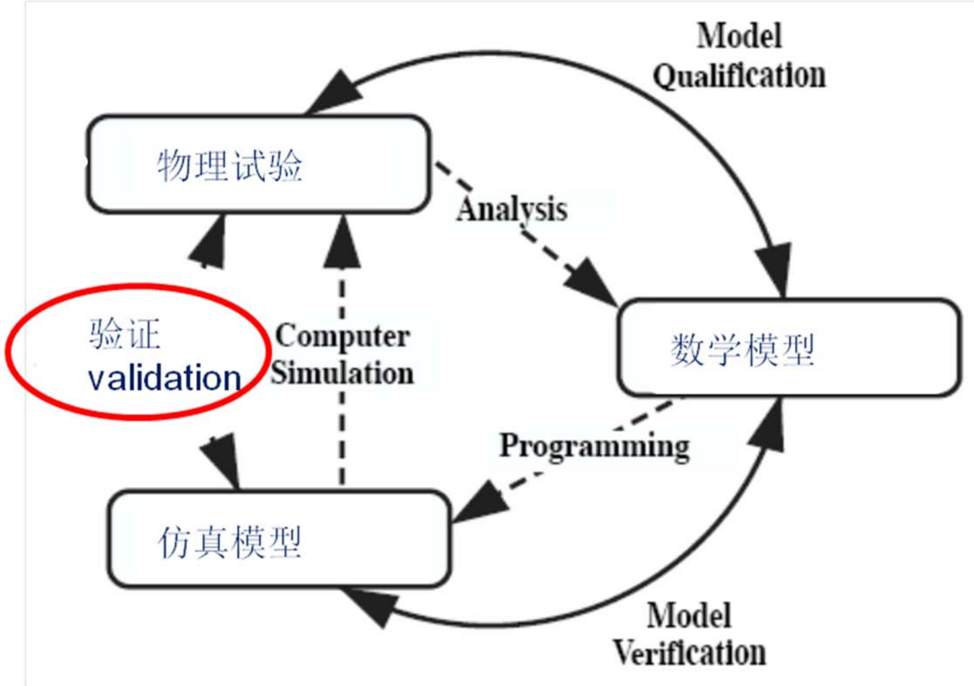
数字化虚拟样车开发：

- 70%：缩短的研发时间（从50个月到15个月）
- 40台：每年可以减少用于各种碰撞试验的物理样车
- 50%：每年每条生产线节约的花费
- 500万美元：每年每条生产线节约的花费

(NA OEMs)

模型验证 Model Validation

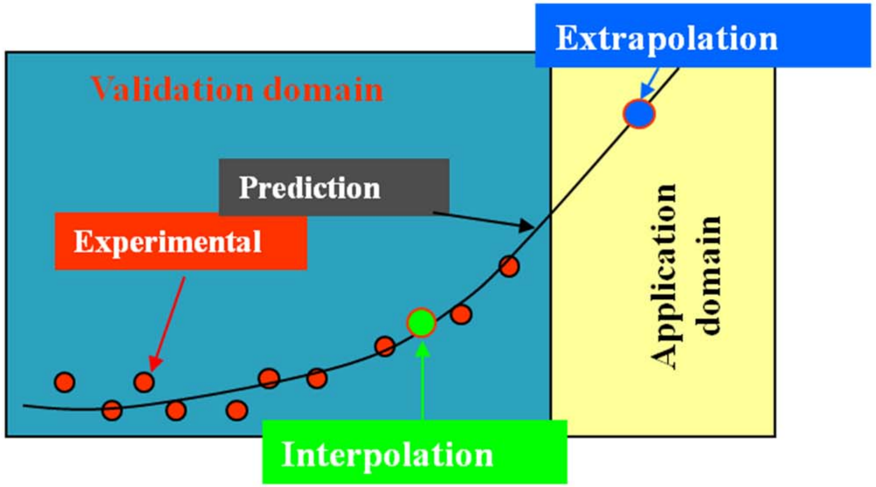
福特Explorer 2003 整车正碰试验



模型验证 Model Validation

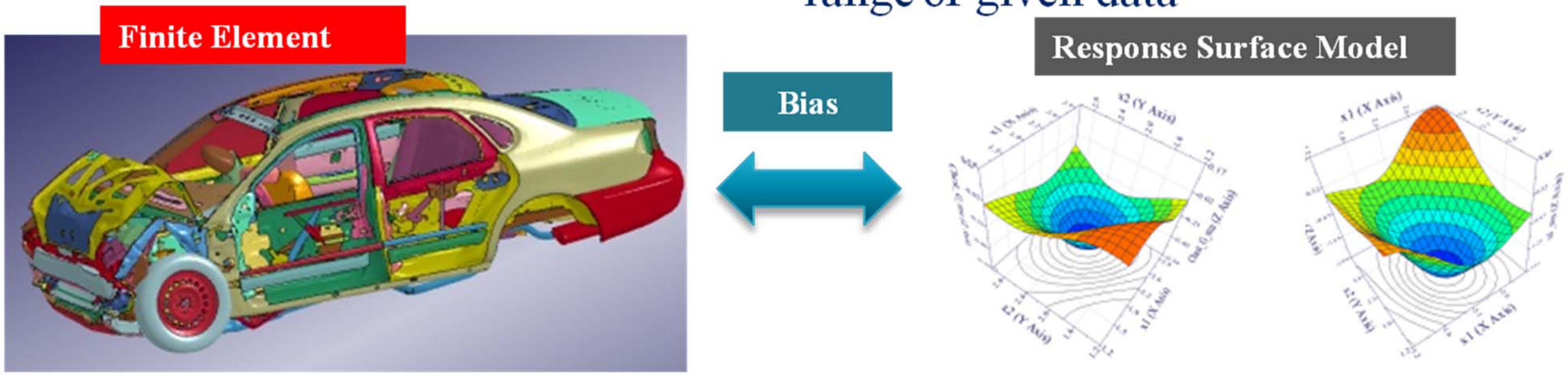
- 确定计算机仿真模型在拟定用途上与其模拟的物理事实吻合程度的过程。

模型内插与外推
Model Interpolation and Extrapolation

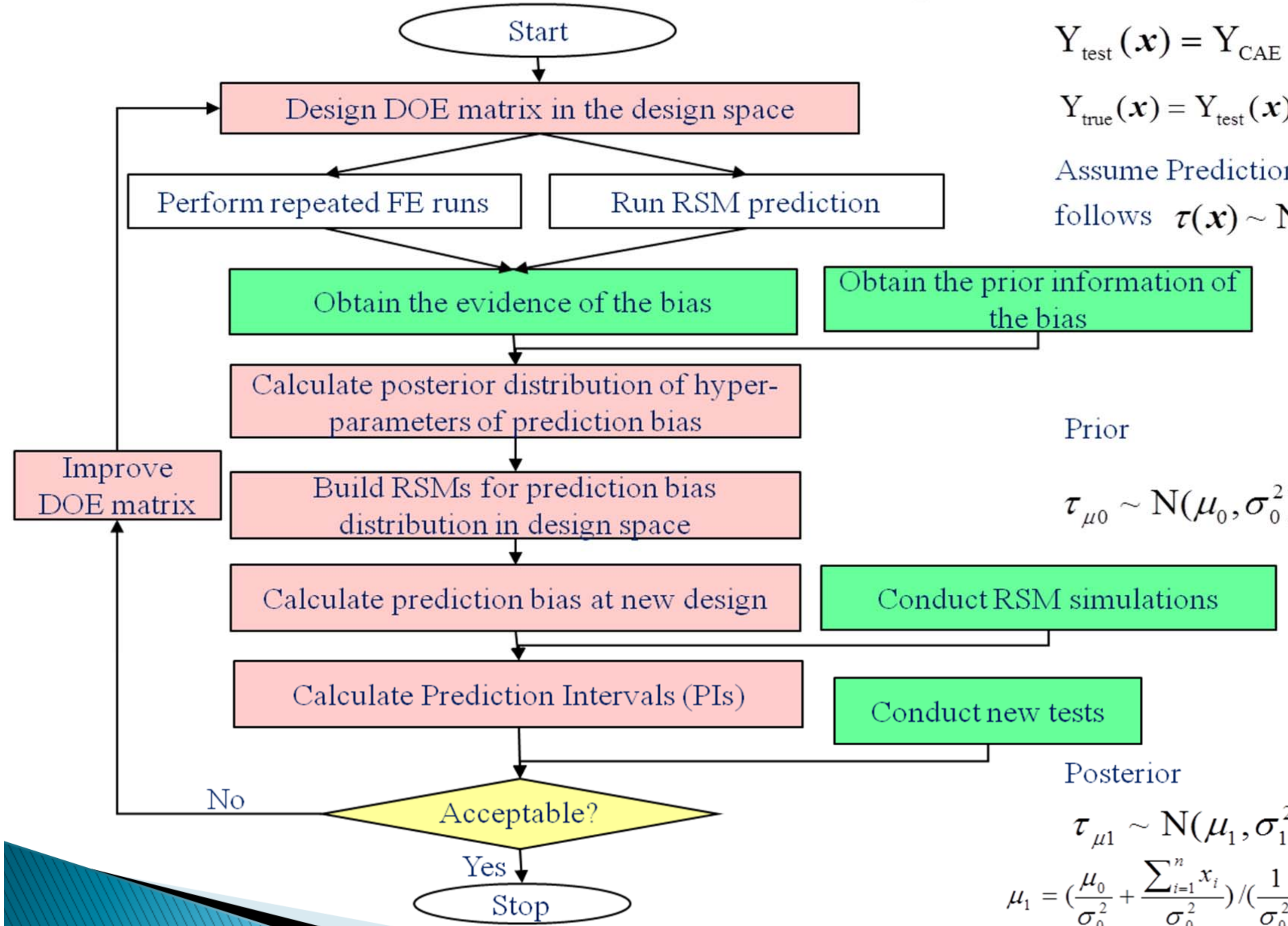


Model Interpolation is a method of evaluating new data points within the range of a discrete set of known data points.

Model Extrapolation is a method of estimating the model predictive capability of a new data point which is beyond the range of given data



Bayesian Inference based Model Interpolation and Extrapolation



$$Y_{test}(\boldsymbol{x}) = Y_{CAE}(\boldsymbol{x}) + \delta(\boldsymbol{x}) + \varepsilon(\boldsymbol{x})$$

$$Y_{true}(\boldsymbol{x}) = Y_{test}(\boldsymbol{x}) - \varepsilon(\boldsymbol{x}) = Y_{CAE}(\boldsymbol{x}) + \delta(\boldsymbol{x})$$

Assume Prediction bias $\tau(\boldsymbol{x}) = \delta(\boldsymbol{x}) + \varepsilon(\boldsymbol{x})$

follows $\tau(\boldsymbol{x}) \sim N(\tau_{\mu}(\boldsymbol{x}), \tau_{\sigma^2}(\boldsymbol{x}))$

Prior

$$\tau_{\mu 0} \sim N(\mu_0, \sigma_0^2) \quad p(\theta \mid x) = \frac{p(x \mid \theta)p(\theta)}{\int p(x \mid \theta)p(\theta)d\theta}$$

Posterior

$$\tau_{\mu 1} \sim N(\mu_1, \sigma_1^2)$$

$$\mu_1 = \left(\frac{\mu_0}{\sigma_0^2} + \frac{\sum_{i=1}^{n} x_i}{\sigma_0^2}\right) / \left(\frac{1}{\sigma_0^2} + \frac{n}{\sigma_0^2}\right) \qquad \sigma_1^2 = \left(\frac{1}{\sigma_0^2} + \frac{n}{\sigma_0^2}\right)^{-1}$$

Case Study: Vehicle Design Problem

2001 Ford Taurus model from National Crash Analysis Center (NCAC) for Frontal Impact

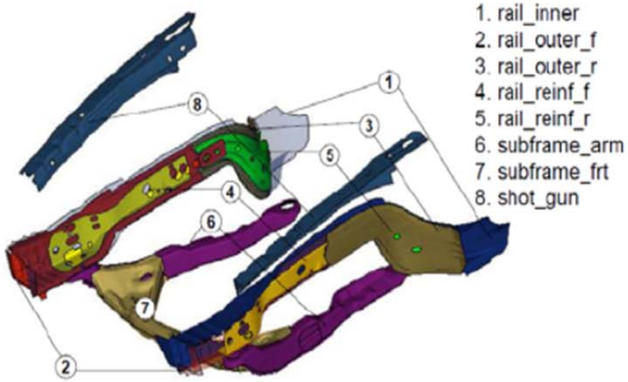


Fig. 4 Design variable selection for main front-end structure

	Design variables	Lower bound	Upper bound	Baseline
x1	rail_inner	1.4	2.8	1.9
x2	rail_outer_front	1.2	2.8	1.91
x3	rail_outer_rear	1.6	4.0	2.51
x4	rail_reinf_front	1.5	4.0	2.4
x5	rail_reinf_rear	1.6	4.0	2.55
x6	subframe_arm	1.5	3.5	2.55
x7	subframe_front	1.5	3.5	2.25
x8	shot_gun	1.2	3.0	1.5

Case Study: Interpolation and Extrapolation

80 uniform DOEs

3 repeated FE runs and 1 RSM at each design

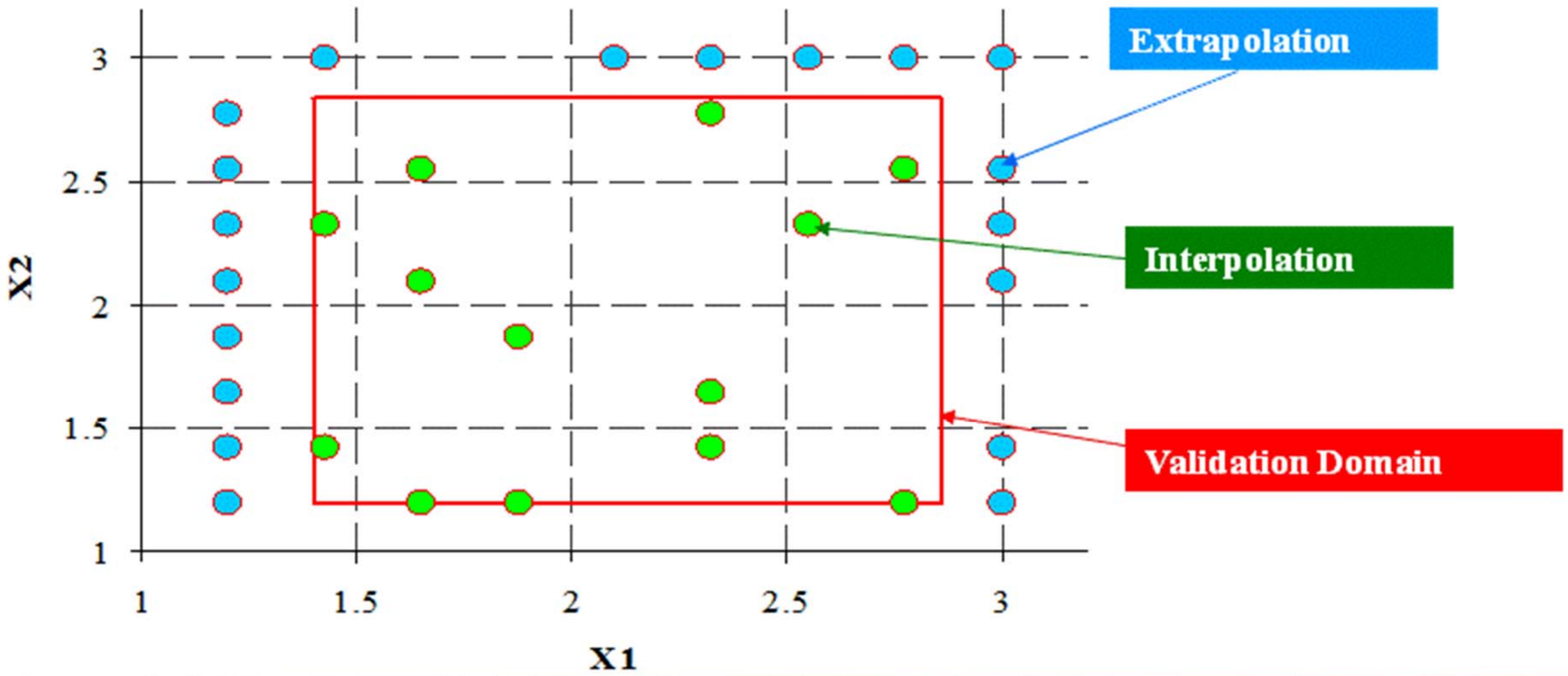
65 DOE samples are used to construct the Kriging RSMs

15 DOE samples to validate the interpolation capability

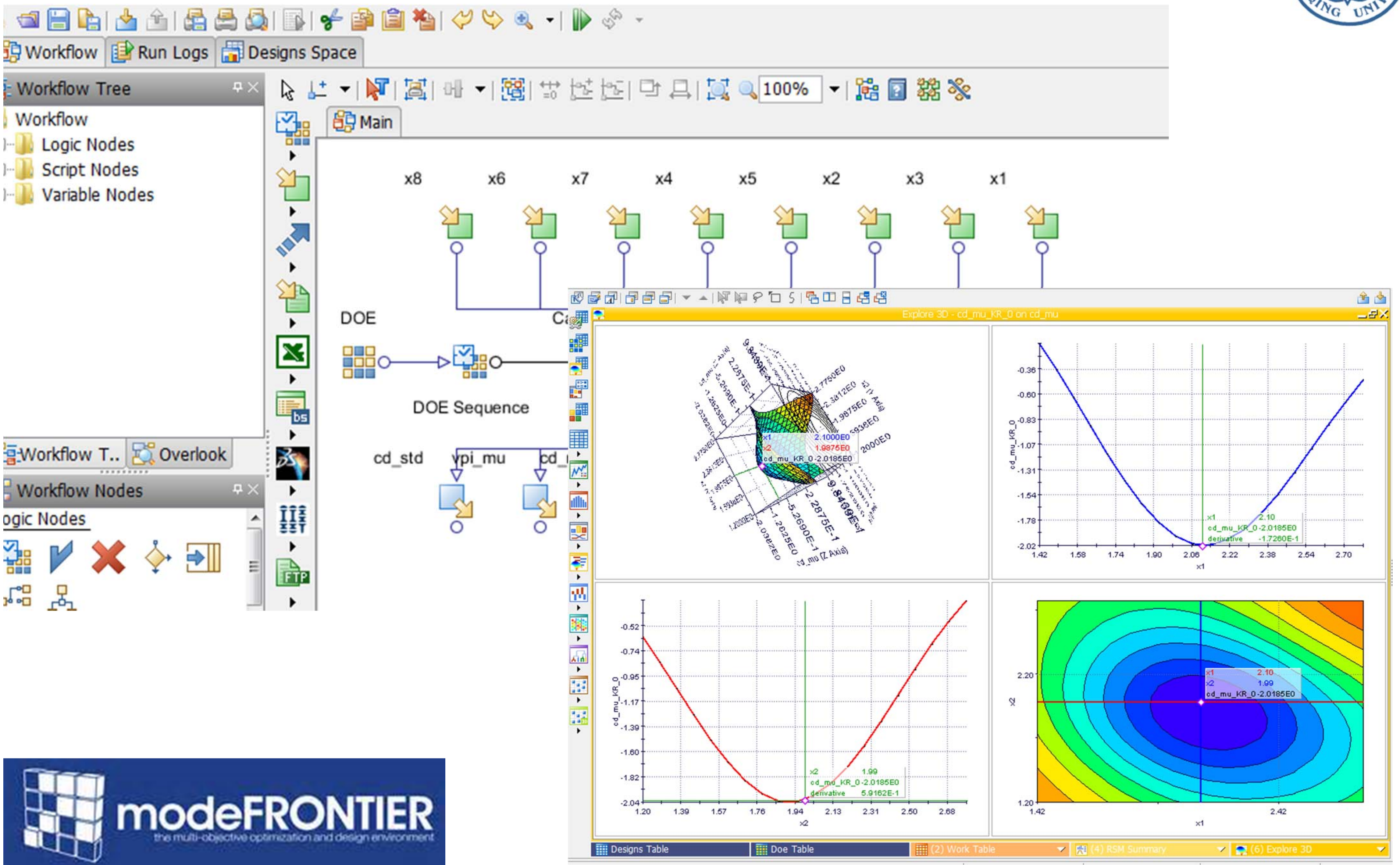
25 for extrapolation

Key Performance Output Responses:

Chest G, Crush distance



Case Study: RSM modeFRONTIER Flowchart



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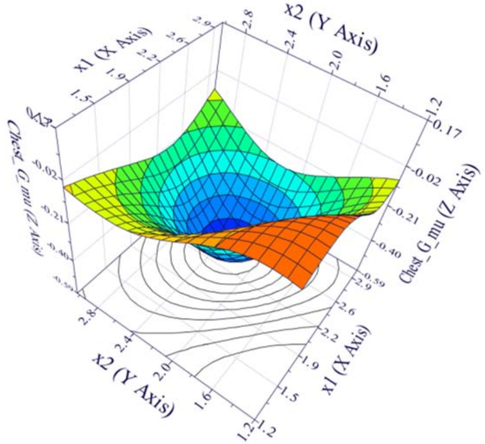
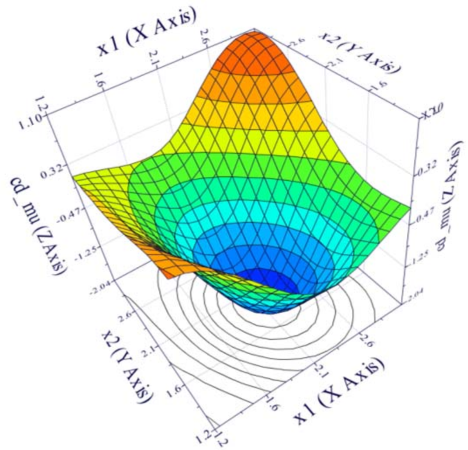
Case Study: Kriging RSMs of Prediction Bias

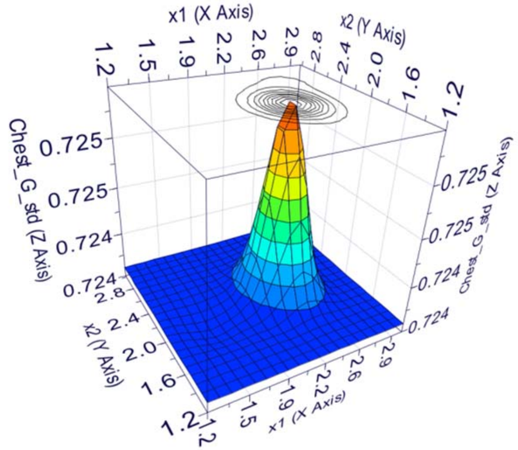
- Chest G bias mean $\tau_{\mu}(x_a)$



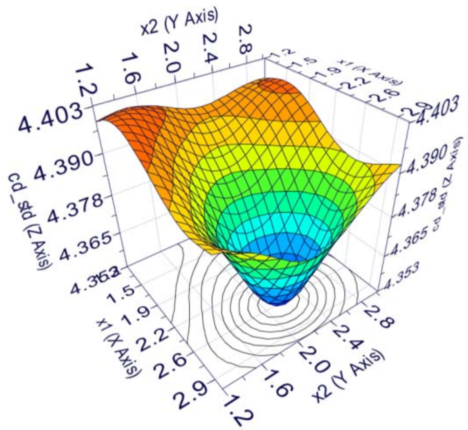
Crash Distance bias mean $\tau_{\mu}(x_a)$



- Chest G bias Standard Deviation $\tau_{\sigma}(x_a)$



Crash Distance bias Standard Deviation $\tau_{\sigma}(x_a)$



Case Study II: Taurus Example Interpolation Evaluation Results

Chest G			
Interpolation	Area Metric	Reliability Metric	Bayesian Confidence Metric
Bayesian Inference-based Method	0.0102	0.4703	0.6888
GPM-based Method	0.0131	0.4106	0.6208
Copula-based Method	0.0081	0.5550	0.7874
Crush Distance			
Interpolation	Area Metric	Reliability Metric	Bayesian Confidence Metric
Bayesian Inference-based Method	0.0069	0.7208	0.9302
GPM-based Method	0.0082	0.6841	0.8650
Copula-based Method	0.0117	0.4833	0.7208

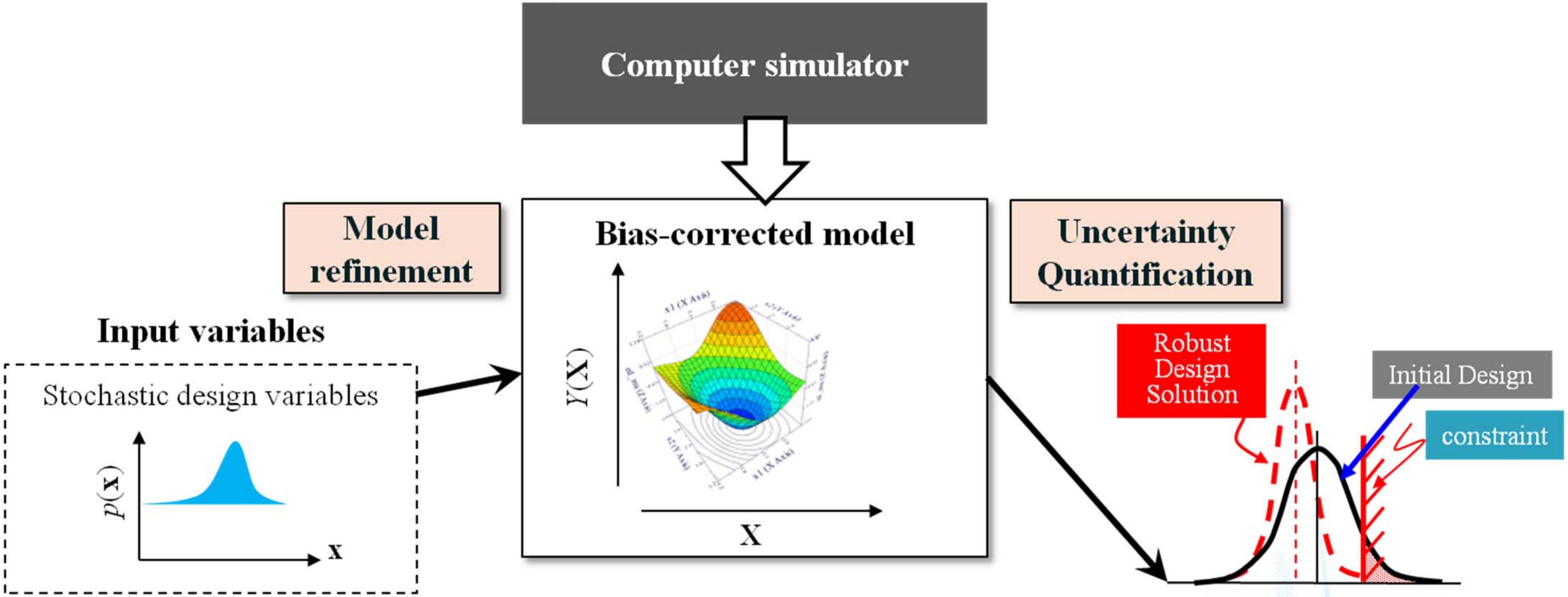
- Copula-based method is rated best in chest G prediction while worst in crush distance prediction. In general, crush distance interpolation prediction results have higher credibility than chest G.

Case Study II: Taurus Example Extrapolation Evaluation Results

Chest G			
Extrapolation	Area Metric	Reliability Metric	Bayesian Confidence Metric
Bayesian Inference-based Method	0.0174	0.3513	0.5650
GPM-based Method	0.0166	0.3527	0.5196
Copula-based Method	0.0289	0.2160	0.3390
Crush Distance			
Extrapolation	Area Metric	Reliability Metric	Bayesian Confidence Metric
Bayesian Inference-based Method	0.0077	0.6682	0.8925
GPM-based Method	0.0127	0.4577	0.7188
Copula-based Method	0.0125	0.4468	0.7005

- The ranking of the three methods are not exactly the same according to different validation metrics,
- For the chest G extrapolation, the evaluation results of Bayesian inference based method and GPM based method are similar, and both methods are rated better than the Copula-based method.
- For the crush distance extrapolation, GPM based method and Copula-based method are rated similar by all three metrics while both are outperformed by Bayesian inference method.

基于可靠性的设计优化
Reliability Based Design Optimization (RBDO)



$$\min \mu_Y(X), \text{s.t.} \Pr\{g_i(X) \le 0\} \ge \alpha_i\%, i = 1, \ldots, k$$

Reliability-Based Design Optimization (RBDO)

Obtain an improved while reliable design, regardless of input variable variations

Case Study: Reliability Based Design Optimization

RBDO problem formulation

Find $\mu_{x_i}, i = 1, 2, \ldots, 8$

to minimize μ_{Weight}

subject to

$$\Pr\{CG \le CG_{\text{Target}}\} \ge 99\%, CG_{\text{Target}} = 65;$$

$$\Pr\{CD \le CD_{\text{Target}}\} \ge 99\%, CD_{\text{Target}} = 750;$$

$$L_{x_i} \le \mu_{x_i} \le U_{x_i}, i = 1, 2, \ldots, 8.$$

where

$$Weight = 6.012x_1 + 3.166x_2 + 2.078x_3 + 1.237x_4 + 1.463x_5 + 4.369x_6 + 3.547x_7 + 2.306x_8,$$

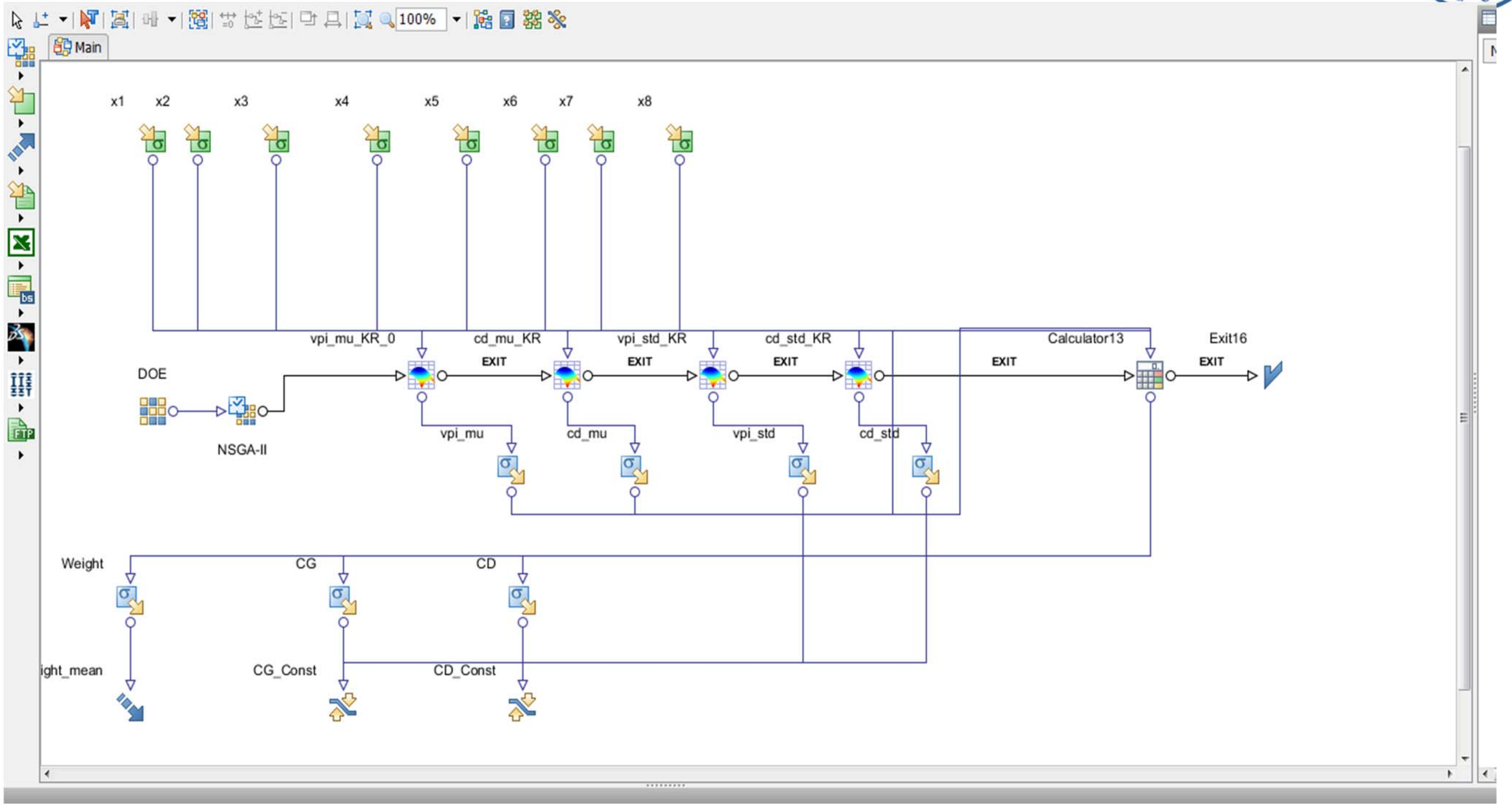
$$CG = 84.699 - 7.7668x_6 + 0.7635x_5x_8 + 0.9809x_7 - 13.133x_1 - 0.999x_2x_5 + 4.0889x_1x_6 - 0.3187x_4x_8 + 0.2922x_1x_5,$$

$$CD = 922.51 - 2.5605x_6x_7 + 0.6625x_4 - 88.269x_1 + 13.929x_1^2 - 1.2664x_3x_6 + 0.4711x_4x_5 - 8.2049x_2x_6 - 4.6859x_4x_8,$$

where

$$x_i \sim N\left(\mu_{x_i}, \left(0.05x_{i\_\text{Baseline}}\right)^2\right), i = 1, 2, \ldots, 8$$

Case Study: RBDO modeFRONTIER Flowchart



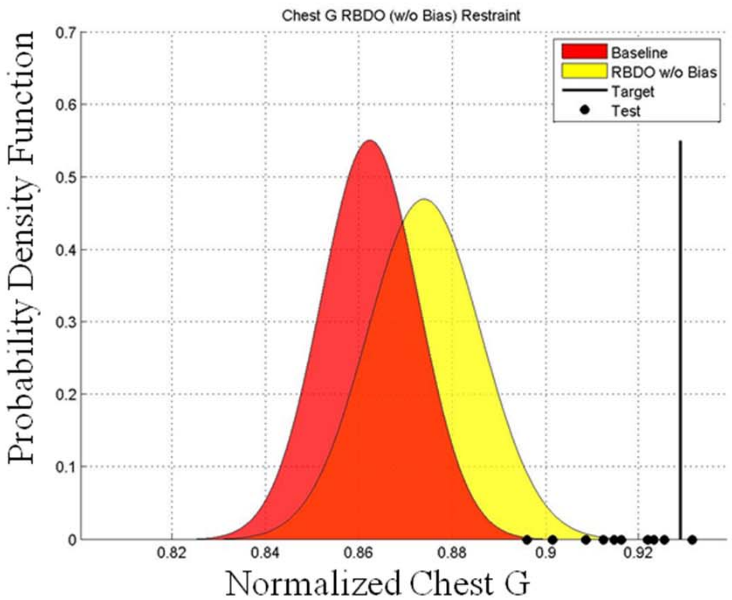
modeFRONTIER
the multi-objective optimization and design environment

RBDO result: optimal design without bias correction

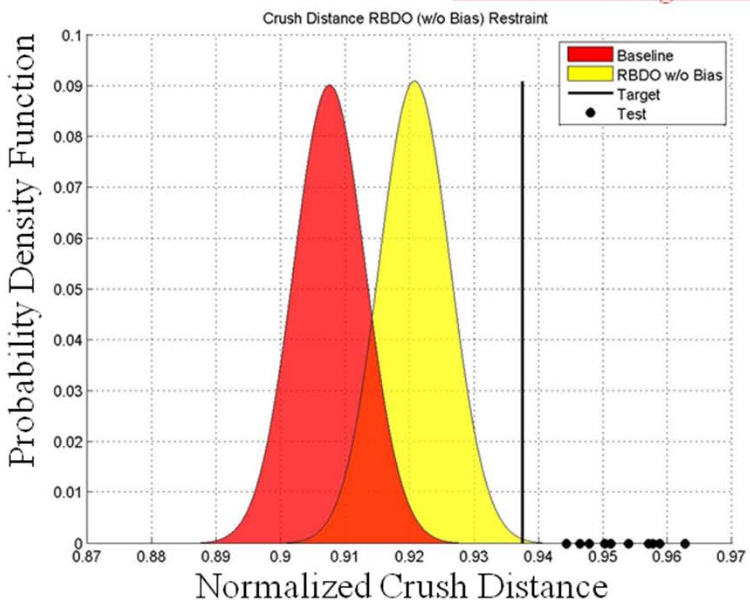
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	Weight
Baseline	1.90	1.91	2.51	2.40	2.55	2.55	2.25	1.50	51.97
RBDO w/o bias	1.715	1.212	1.614	3.966	1.560	1.595	1.559	2.988	44.08

Design target
Baseline design
RBDO w/o bias design

RBDO

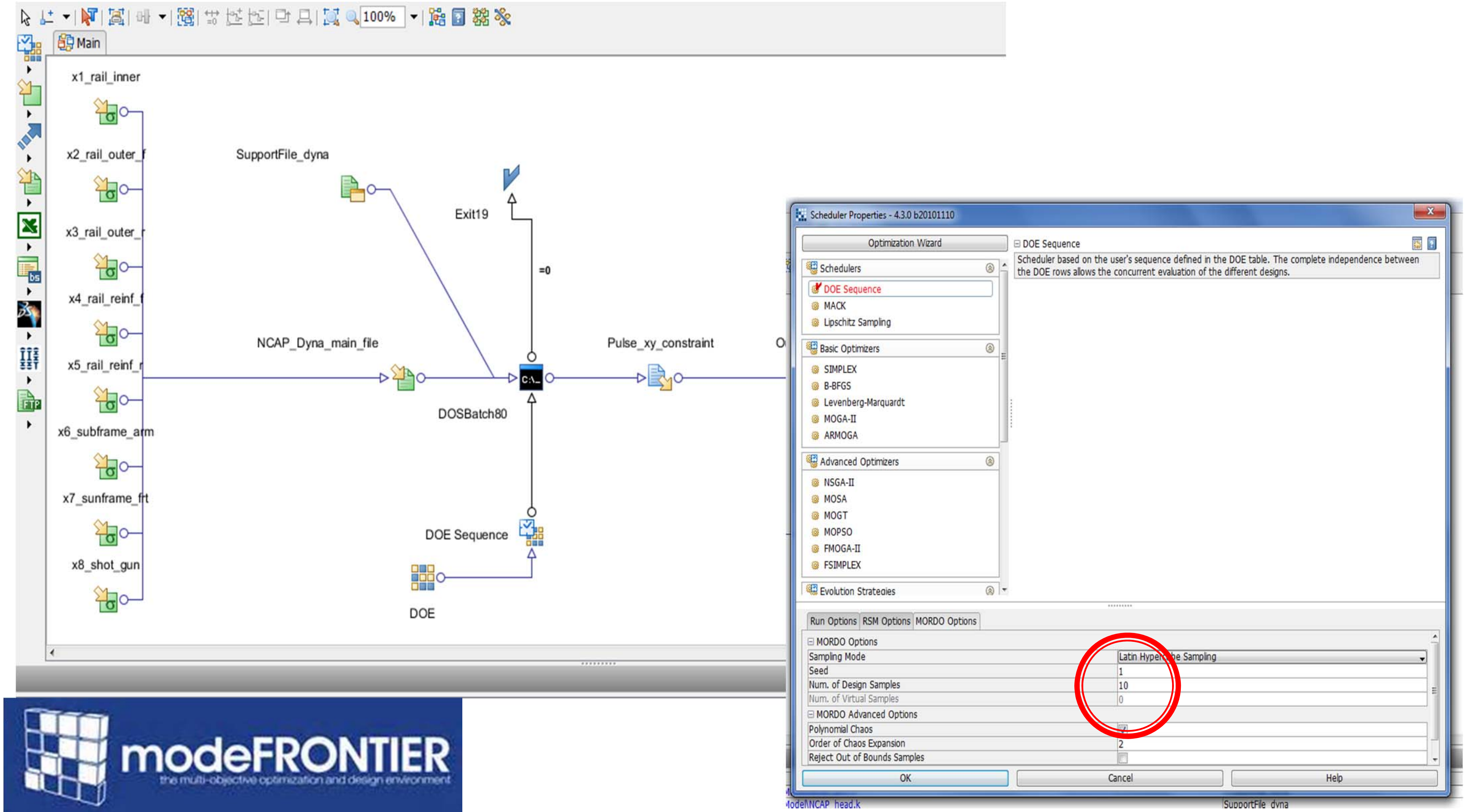


Chest G



Crush Distance

Case Study: FE Confirmation modeFRONTIER Flowchart

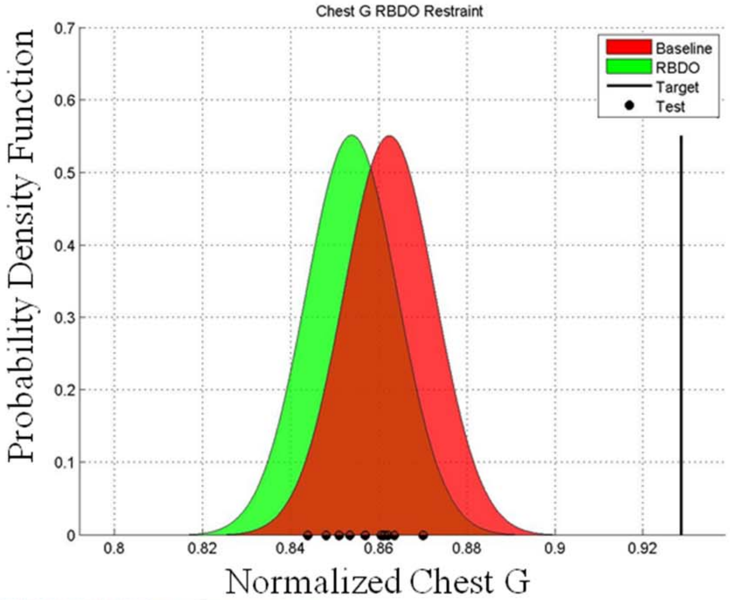


RBDO result: optimal design

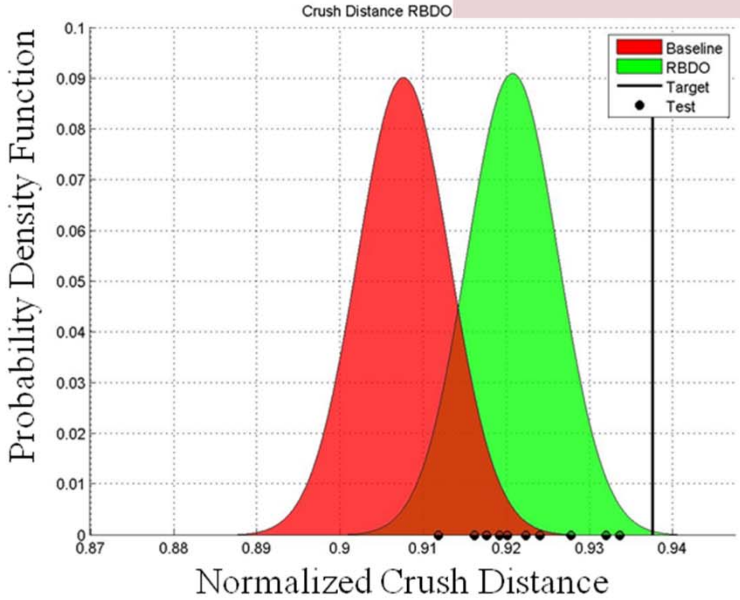
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	Weight
Baseline	1.90	1.91	2.51	2.40	2.55	2.55	2.25	1.50	51.97
RBDO w/o bias	1.715	1.212	1.614	3.966	1.560	1.595	1.559	2.988	44.08
RBDO	1.918	2.270	1.600	1.500	1.601	2.379	1.700	1.497	46.21

Design target
Baseline design
RBDO design

RBDO



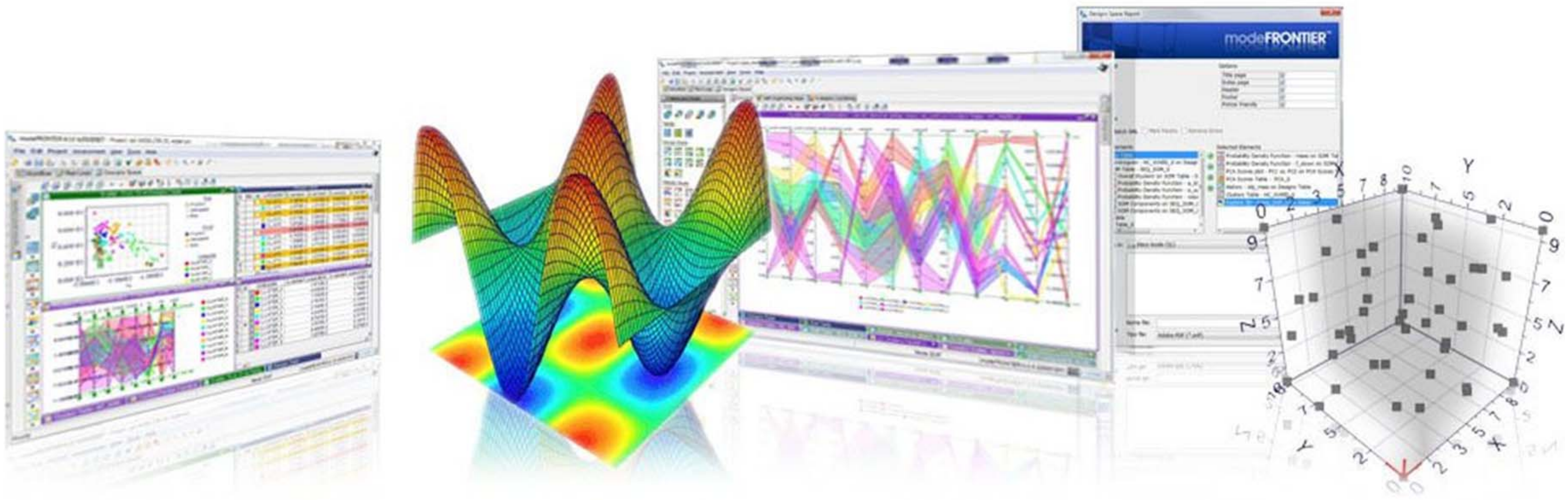
Chest G



Crush Distance

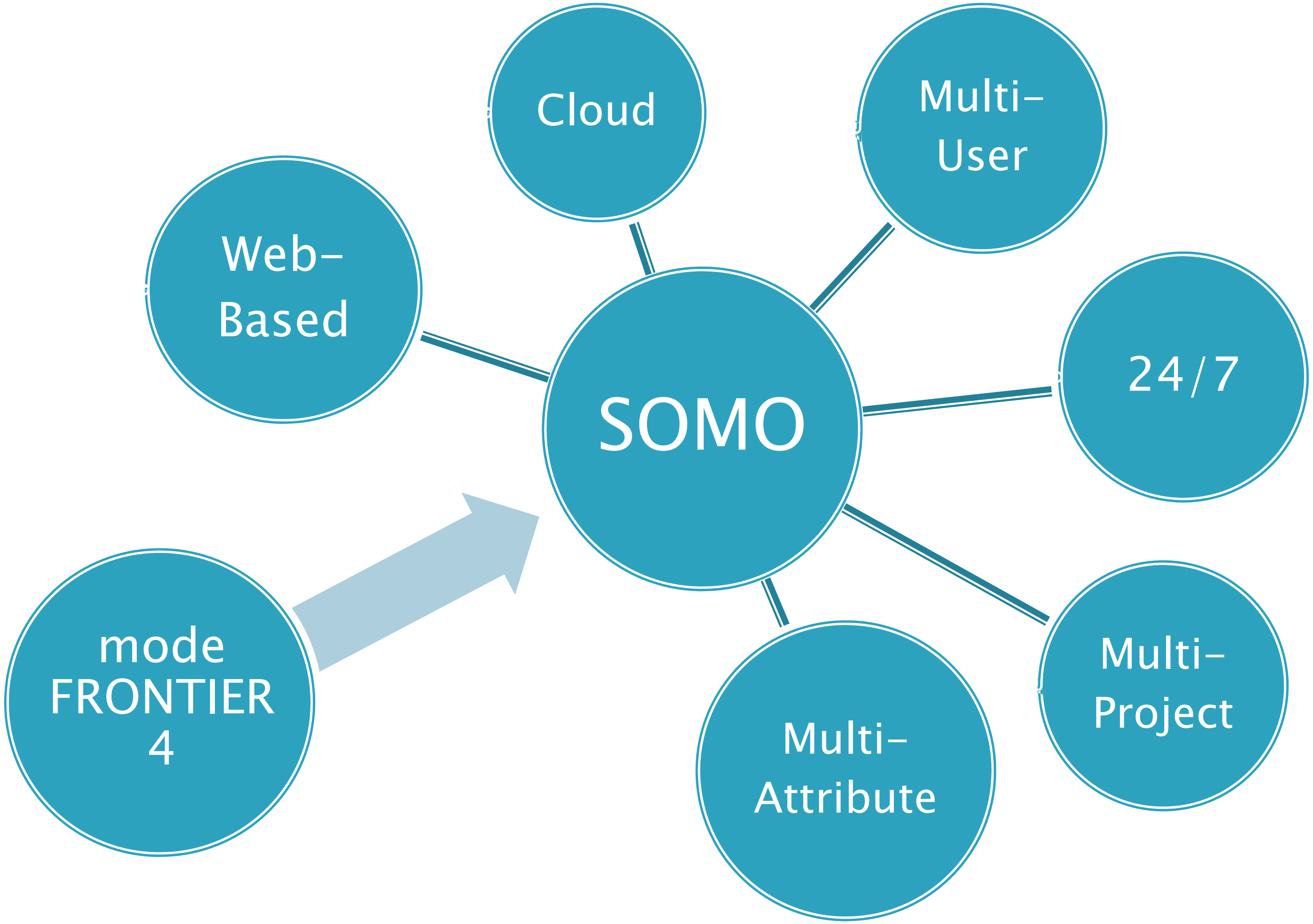
modeFRONTIER

is a **multidiciplinary** and **multi-objective optimization** and **design environment**, written to allow easy coupling to almost any computer aided engineering (CAE) tool, whether commercial or in-house.



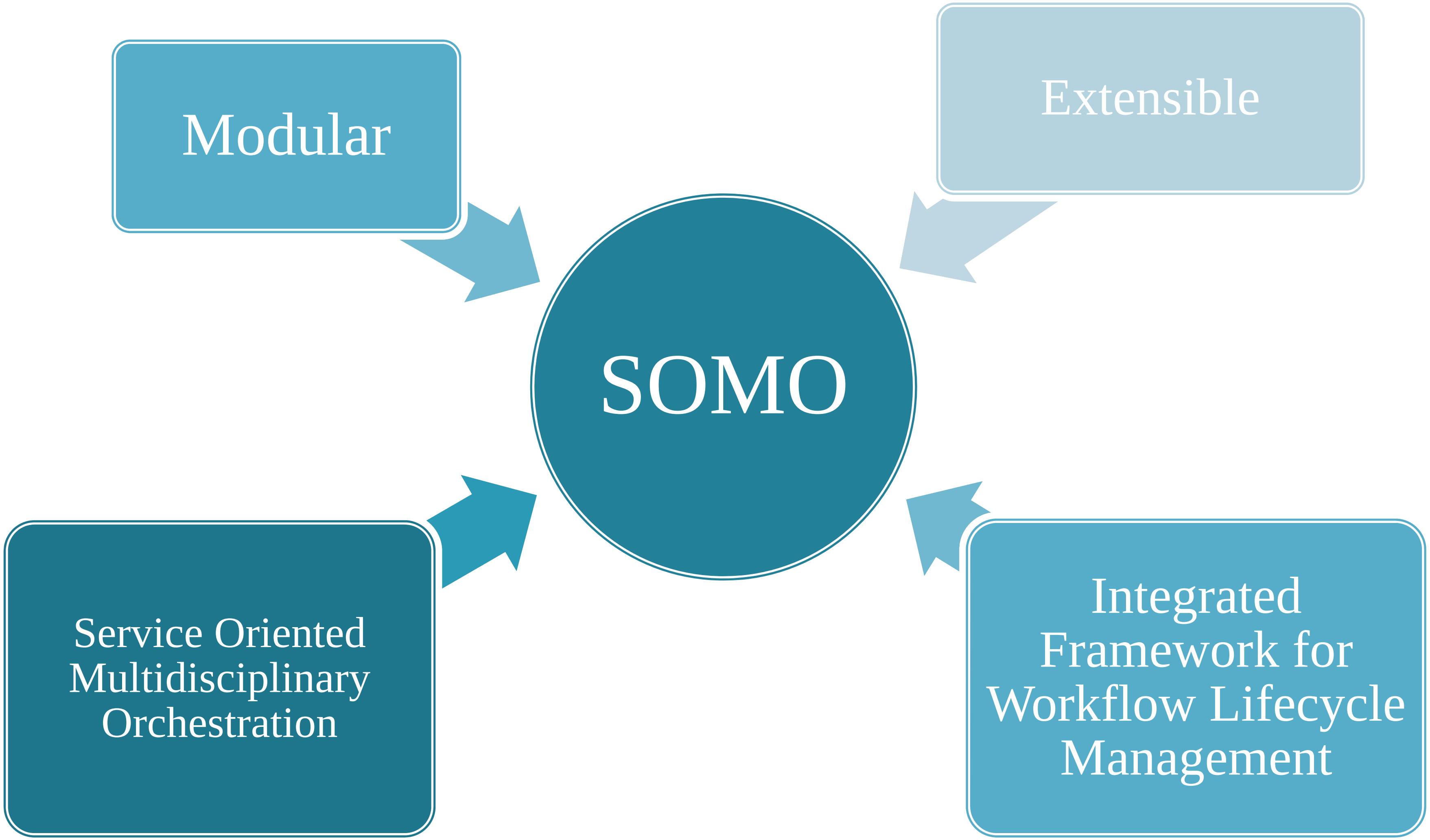
(Courtesy of ESTECO, 2011)

Next Generation Design Optimization



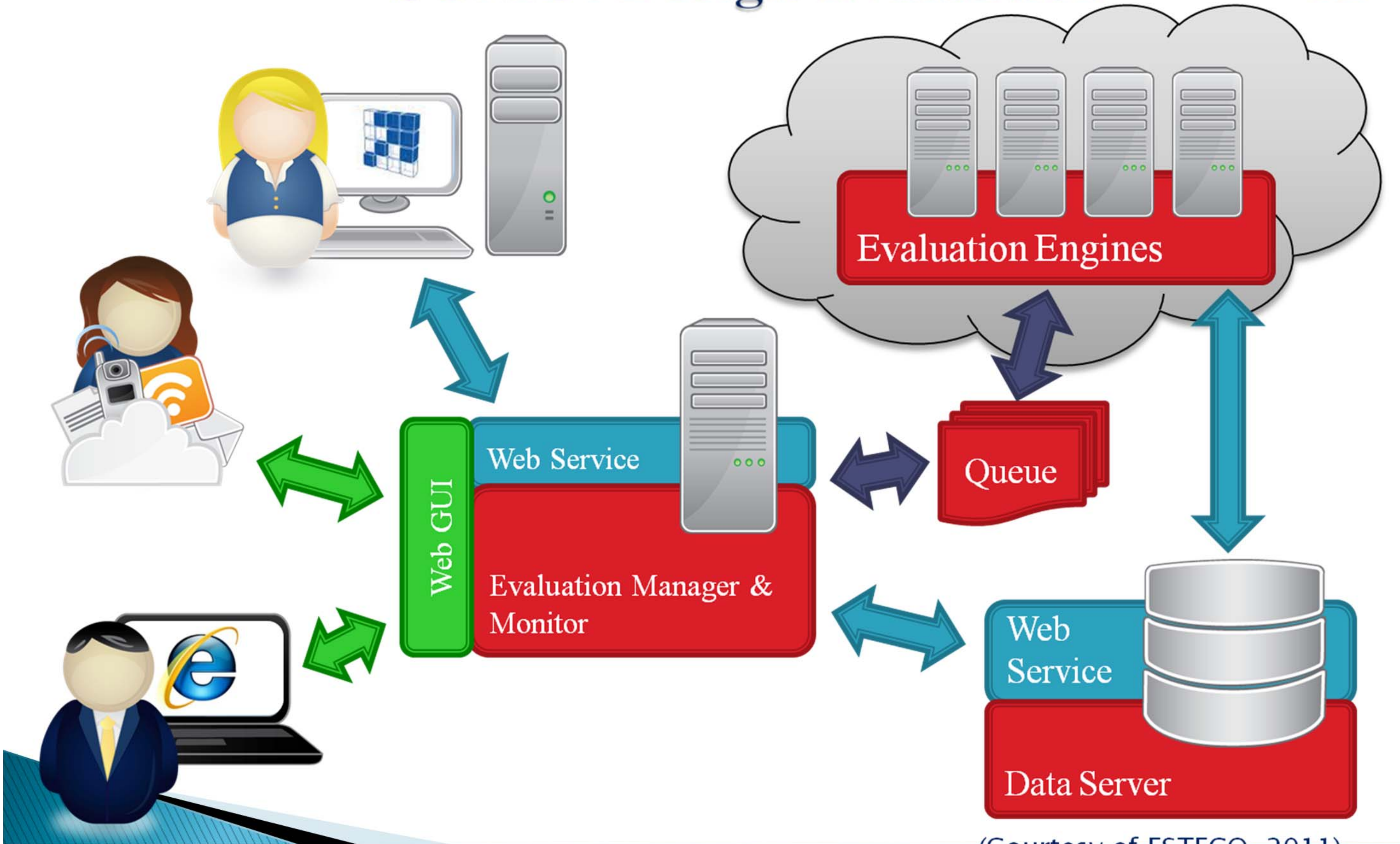
(Courtesy of ESTECO, 2011)

What Is SOMO?



(Courtesy of ESTECO, 2011)

SOMO: Design Evaluation



(Courtesy of ESTECO, 2011)

SOMO vs. modeFRONTIER

	SOMO	modeFRONTIER
Design process approach	Batch	Interactive/Batch
Computing resources	Remote	Local/Grid
Control over resources	Share	Total
Multidisciplinary	Different departments	Different applications
Deployment	Community	Single user
Platform	Web	Desktop
Availability	Intranet, Internet	Office
Architecture	Modular for extensibilty	Monolithic for perfomance
Target	Engineers, Managers, Executives	Engineers
Optimization	Through library modules	Native

(Courtesy of ESTECO, 2011)

Thank you!

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