

# **Sensitivitätsanalyse von passiven Insassenschutzsystemen im Frontalcrash**

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# Occupant Safety Systems

## Frontal crash test




Quelle: EURO NCAP

### Legal requirements

- FMVSS 208
- ECE-R94
- ...

### Consumer ratings

- US NCAP
- EURO NCAP
- ...

- Test setups (rigid barrier, ODB, ... )
  - Dummies (5%ile female, 50%ile male, ... )
  - Crash velocities (40km/h, 56km/h, ... )
-  Basis of ratings: Dummy criteria

## Design of Restraint System

Adjustment of belt + airbag systems for best overall performance

# Safety system components for frontal crash



## Airbag systems

- Driver airbag (single / dual stage)
- Passenger airbag (single / dual stage)
- Knee airbag



## Seat belt system

- Seat belt webbing
- Retractor
- Buckle
- Anchor
- D-ring
- Pretensioner (retractor, buckle, anchor)
- Load Limiter (Constant, Degressive, Switchable)

# Aim of sensitivity analysis

## Restraint system parameters

- Belt:
  - pretensioner
  - D-Ring friction
  - ...
- Airbag:
  - generator
  - time to fire airbag
  - ...



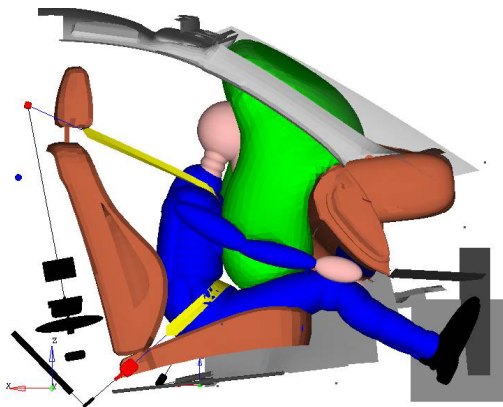
## Correlations

Parameters – Dummy criteria  
Dummy criteria – Dummy criteria

## Sensitive system parameters

## Dummy criteria

- $a_{\text{head, max}}$ , HIC36, ...
- neck tension,  $N_{ij}$ , ...
- chest deflection, ...
- femur forces, ...



- Passenger simulation model (Madymo)
- US-NCAP (Rating) / FMVSS 208 (Law)
- Hybrid III 5%ile female dummy
- Adjusted restraint system

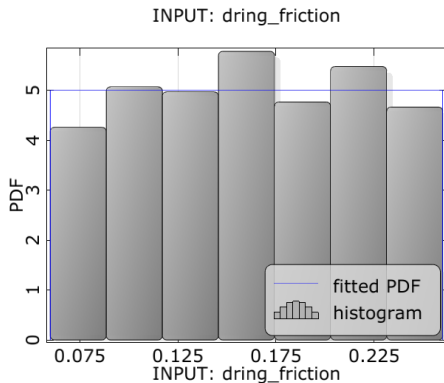
# Definition of input and output parameters

## Inputs

RS design parameters

- 1. Pretensioner
- 2. D-ring friction
- ...
- 12. ...

uniformly distributed



LHS sampled

user defined design parameter intervals

$[\mu_{\min}; \mu_{\max}]$

$[\mu_{\min}; \mu_{\max}]$

⋮

## Outputs

Dummy criteria

- 1. HIC36
- 2.  $F_{t,neck}$
- ...
- 24. ...

36 variables

## Special Example

- Specific inputs + input intervals
- Results meaningful only for this analysis

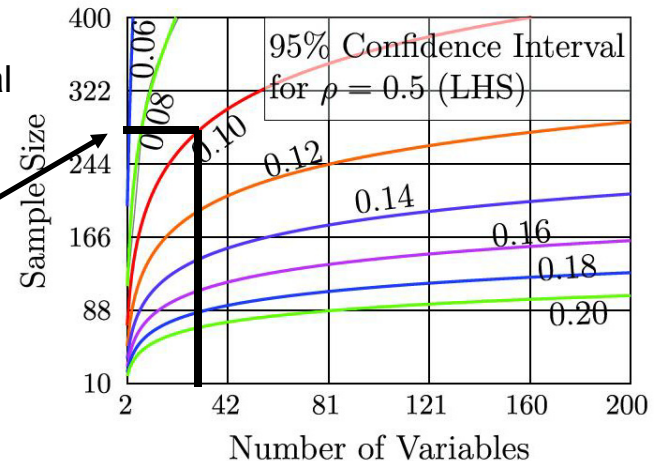
## Latin Hypercube Sampling (LHS)

**Aim:**

95% Confidence Interval  
 $\rho = 0.5 [-0.05; +0.05]$

Identification of sample size

chosen: 350 samples



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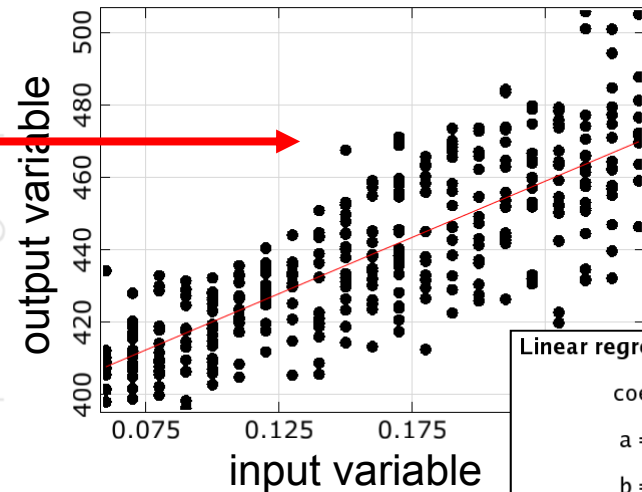
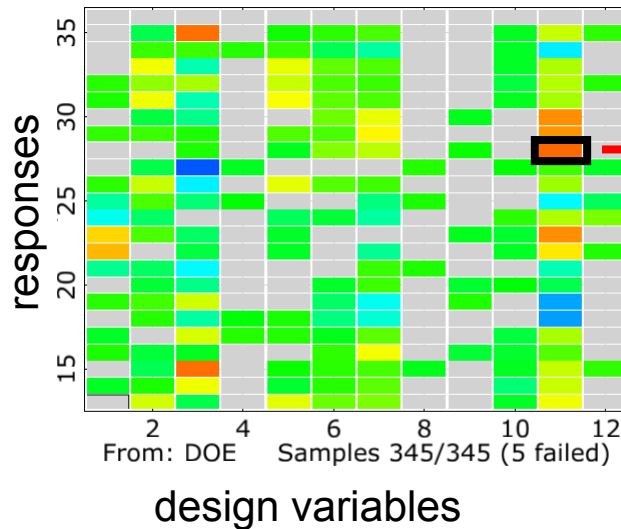
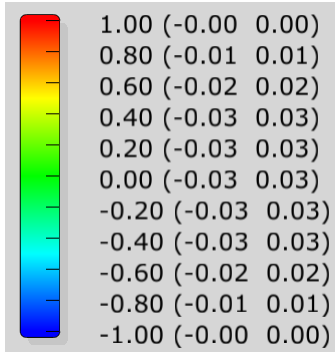
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# Linear correlation matrix

Linear correlation matrix  $C_{xx}$   
Input – Output parameters

Anthill plot – linear correlation

Significance filter limit = 95%



Linear regression  $y = a \cdot x + b$   
coefficients:  
 $a = 310.787$   
 $b = 389.063$

- Degree of linear relationship between two characteristic parameters
- Linear regression model
- High correlation  $\rightarrow$  not necessarily causal relationship
- Correlation may be affected by other variables

relevant linear correlation

$0.5 < \rho \leq 0.7$  low

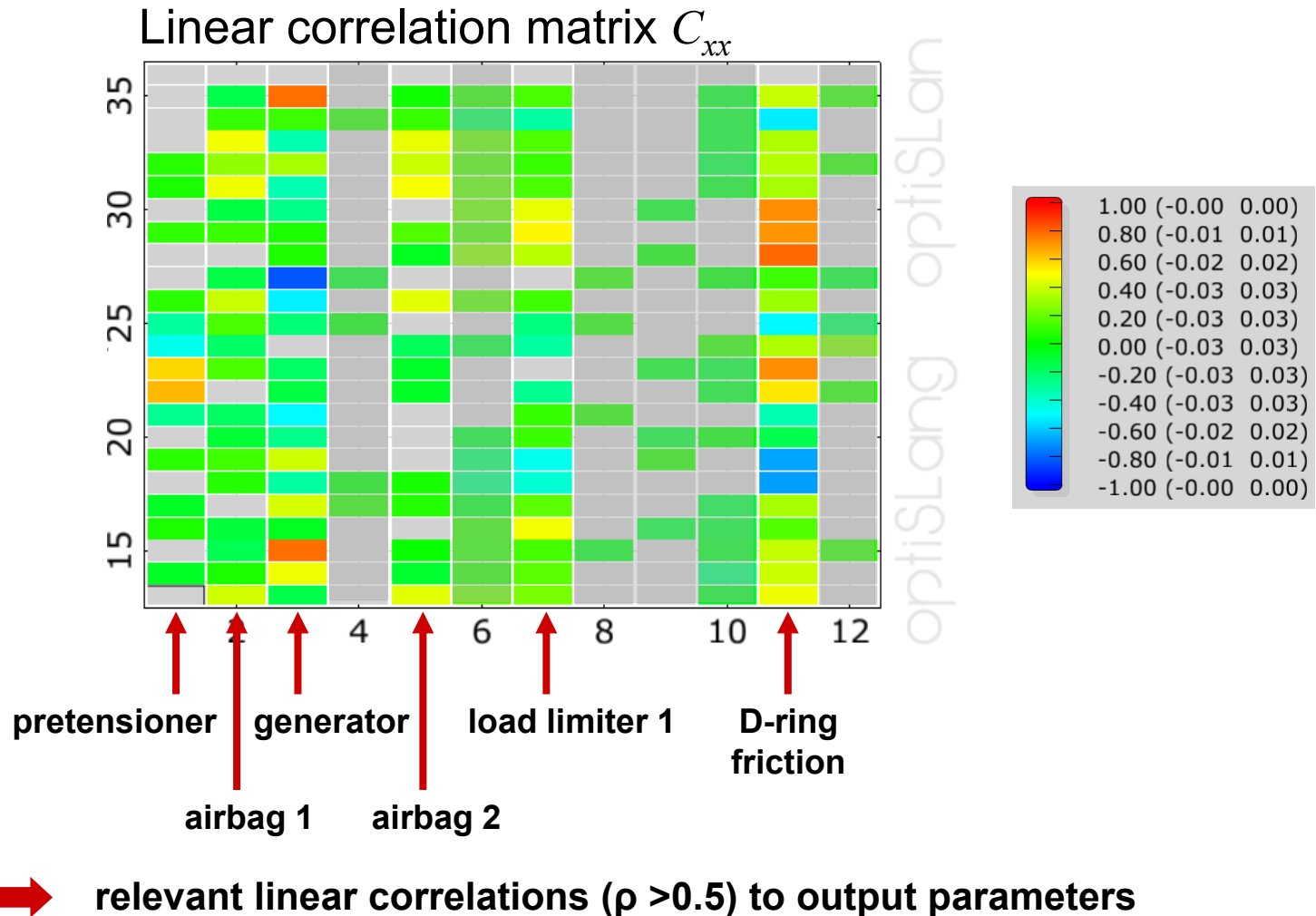
$0.7 < \rho \leq 0.9$  medium

$0.9 < \rho \leq 1.0$  high



# Identifying relevant input parameters

## Linear correlations



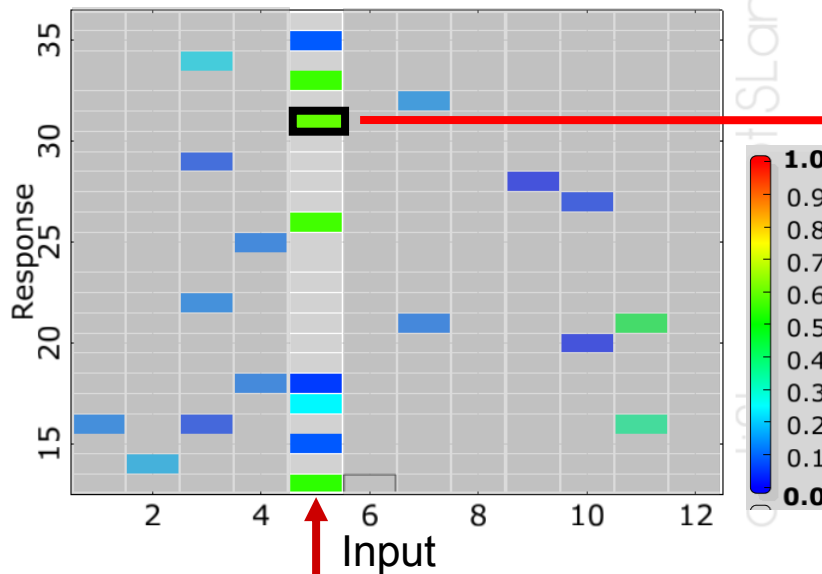
# Identifying relevant input parameters

## Quadratic correlations

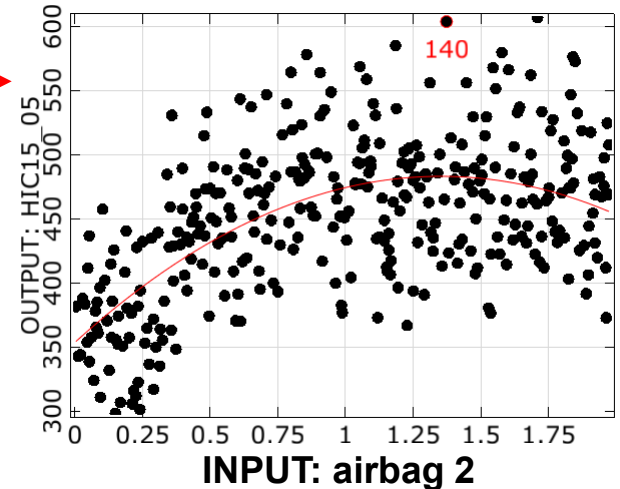
Quadratic correlation matrix  $C_{XX}$

Anthill plot – linear correlation

Quadratic – linear correlation coefficients



INPUT: airbag 2 vs. OUTPUT: HIC15\_05, quadratic  $r=0.596$



quadratic correlation

$0.5 < \rho \leq 0.7$  low

$0.7 < \rho \leq 0.9$  medium

$0.9 < \rho \leq 1.0$  high

Quadratic regression  $y = a \cdot x^2 + b \cdot x + c$

coefficients:

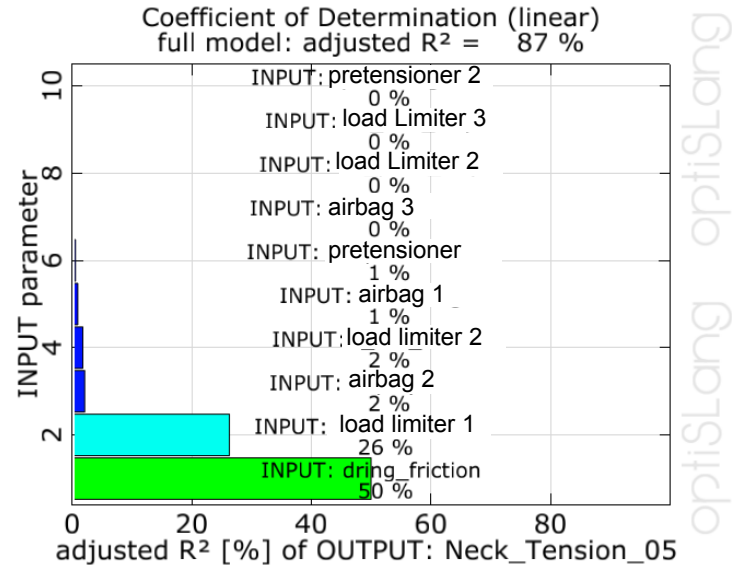
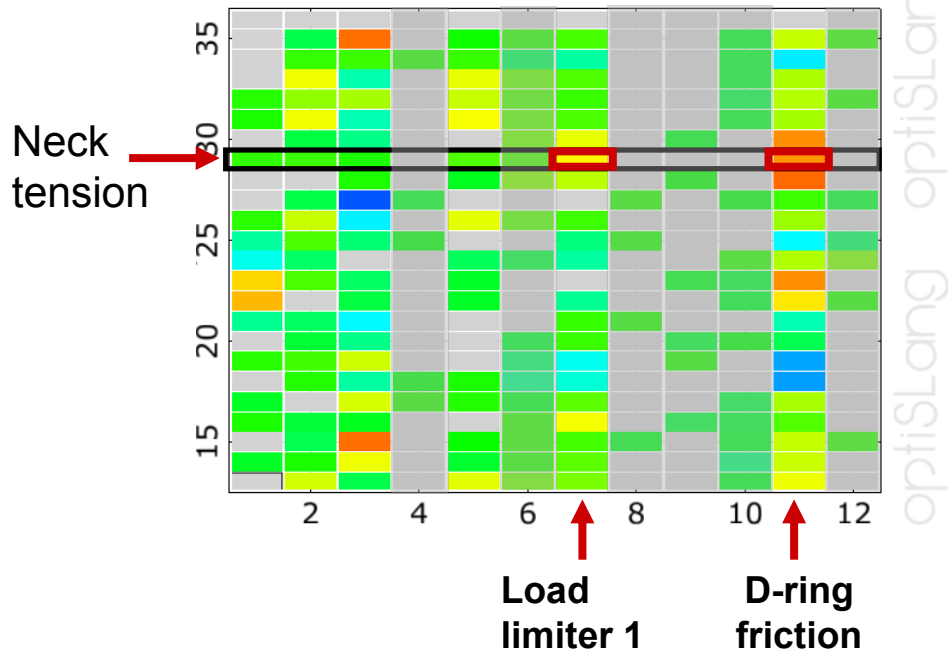
$a = -70.8635$

$b = 191.588$

$c = 353.606$

➔ relevant quadratic correlations ( $\rho > 0.5$ ) only for airbag 2

# Important Input – Output correlations

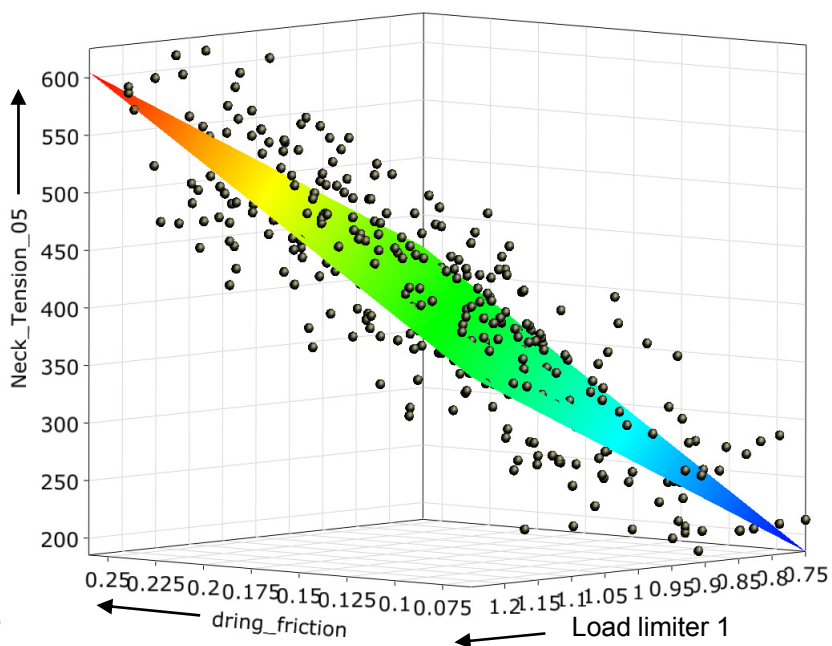


	Load limiter 1	D-ring friction	lin. corr.
$\rho$	0.52	0.71	low
R <sup>2</sup>	26% (87%)	50% (87%)	med
			high

- ➔ Dummy criterion: Neck tension
- Two important linear correlations
  - Most important: D-ring friction (medium correlation)
  - Load limiter 1 (low correlation)

# Response surface

## Linear regression for criterion: Neck Tension

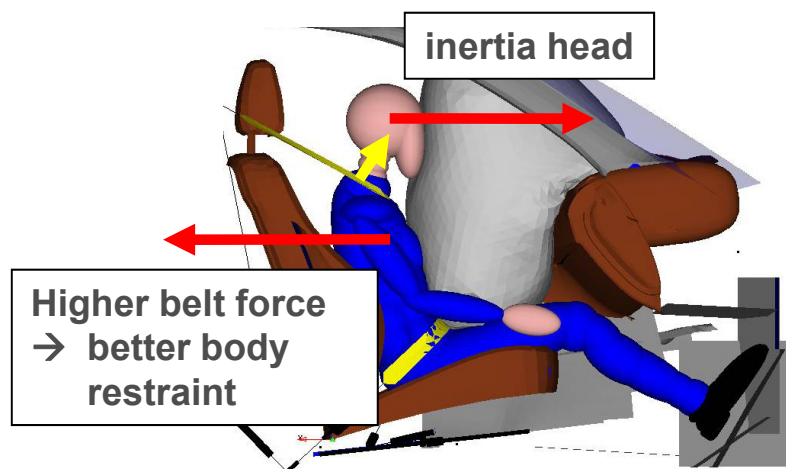


Simultaneous increase in

- D-ring friction
- Load limiter 1

Increase in belt force

Increase in Neck Tension



# Results for Neck criteria



		Load limiter 1	D-Ring friction	
NTE	$\rho$	0.48		lin. corr.
	$R^2$	23% (28%)		
NTF	$\rho$			low
	$R^2$			med
NCE	$\rho$		-0.69	high
	$R^2$		48% (85%)	
NCF	$\rho$	-0.47	-0.68	
	$R^2$	22% (90%)	46% (90%)	
Neck tens.	$\rho$	0.52	0.71	
	$R^2$	26% (87%)	50% (87%)	
Neck compr.	$\rho$	0.46	0.72	
	$R^2$	20% (87%)	52% (87%)	
IRF Neck	$\rho$		-0.53	
	$R^2$		28% (45%)	

Neck criteria correlate linear with belt parameters

- D-Ring friction\*
- Load limiter 1\*

\* Basis: interval approach for input parameters

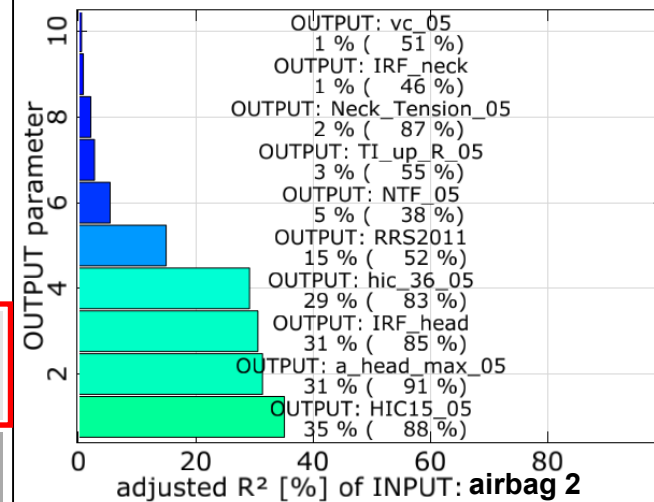
# Results for Head injury values



airbag 2      D-Ring friction      airbag 1      generator

HIC36	$\rho$	0.54	0.47	
	$R^2$	29% (83%)	22% (73%)	
HIC15	$\rho$	0.60		0.47
	$R^2$	35% (88%)		22% (76%)
IRF <sub>head</sub>	$\rho$	0.56		0.47
	$R^2$	31% (85%)		22% (75%)
$a_{\text{head,max}}$	$\rho$	0.56		-0.53
	$R^2$	31% (91%)		28% (80%)
$t_{a_{\text{head,max}}}$	$\rho$			-0.83
	$R^2$			69% (71%)

Coefficient of Determination (quadratic)



lin. corr.      quad. corr.

low	low
med	med
high	high

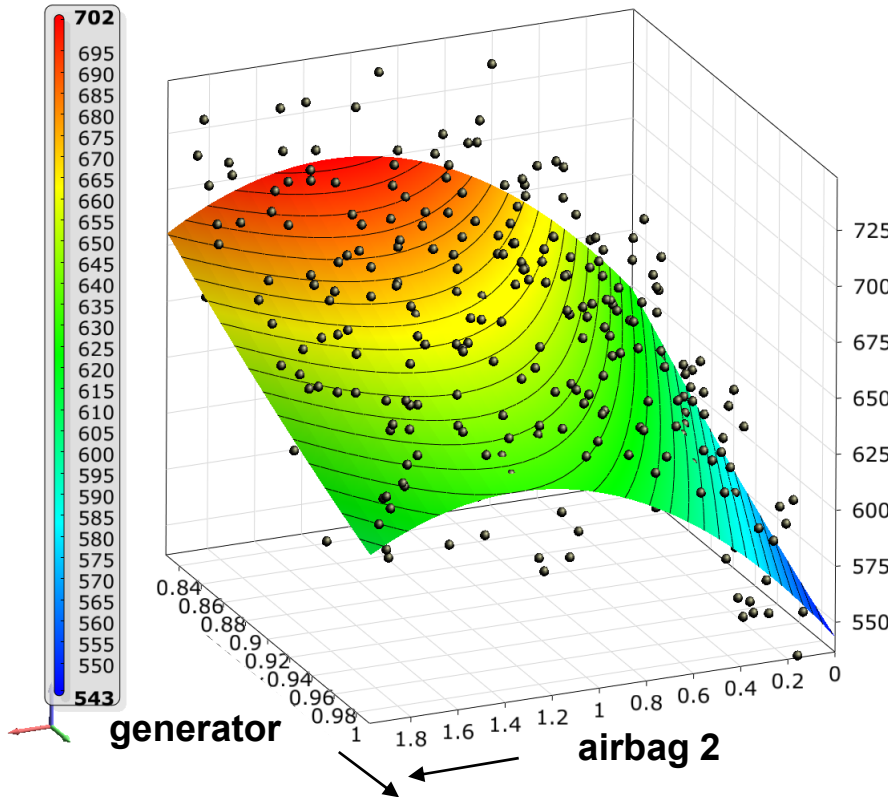
important correlations (quadr.) of  
airbag 2 with head injury values

➔ Head criteria influenced by airbag parameters

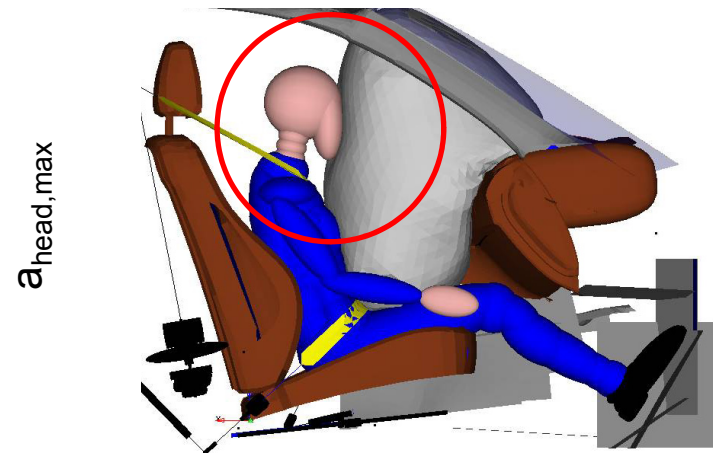
# Response surface

## Quadratic regression for head deceleration $a_{\text{head,max}}$

Quadratic regression of  $a_{\text{head,max}_05}$



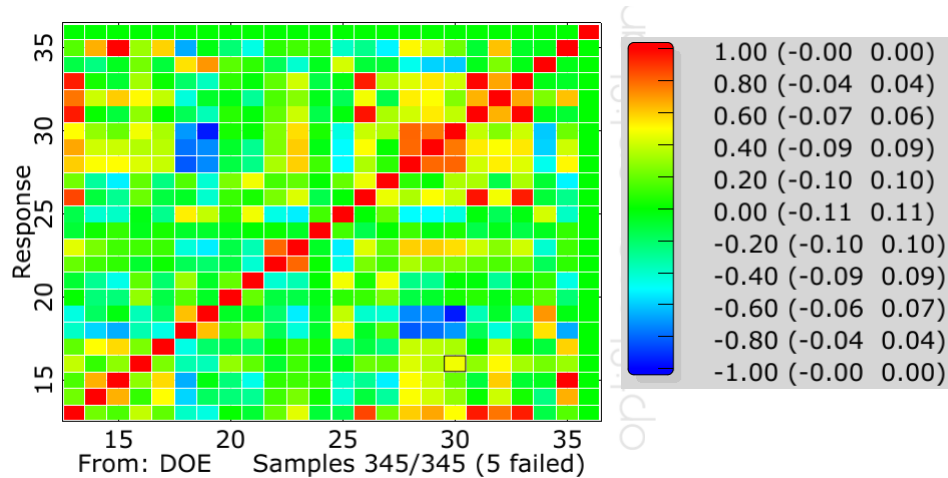
Contact head - airbag



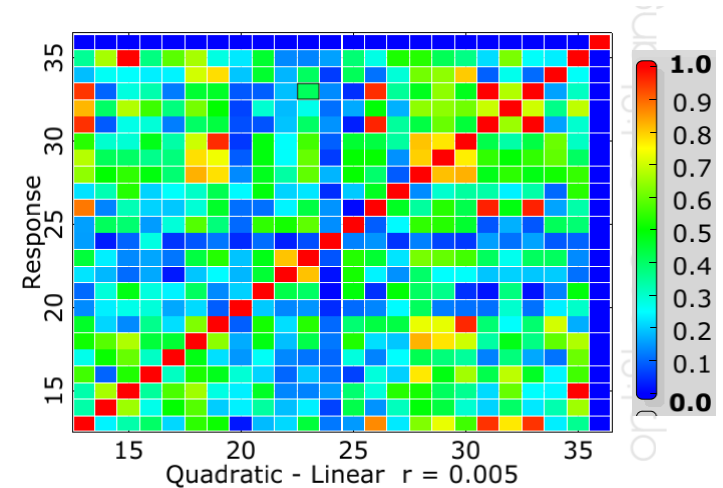
**→ early coupling head - airbag → low head deceleration**

# Output – Output correlations

## Linear correlation matrix



## Quadratic correlation matrix



- ➔ **Detection of correlations between dummy criteria of different body regions**
- ➔ **influencing certain body regions affects other parts of the body**

Criterion for regression model: magnitude of correlation coefficient + anthill plot



# Correlations between dummy criteria

## Correlations between different body regions

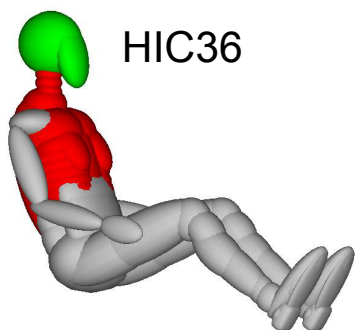
HIC36

		$\rho_{lin}$	$\rho_{quad}$
Neck	NTE		0.56
	NCE		0.51
	$F_{c,neck}$		0.54
	$F_{t,neck}$	0.67	
Thorax	$a_{3ms}$		0.64

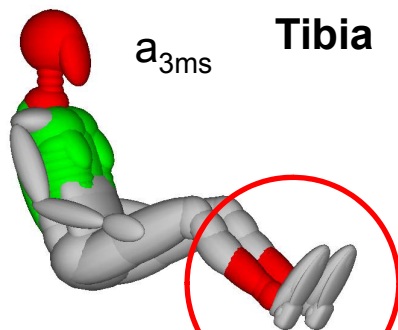
Thorax\_a3ms

		$\rho_{lin}$	$\rho_{quad}$
Head	HIC36		0.63
	NTE		0.77
	NCE	-0.83	
Neck	NCF	-0.73	
	$F_{c,neck}$	0.80	
	$F_{t,neck}$	0.80	
	$TI_{low,R}$		0.55
Tibia	$TI_{low,L}$		0.62

Body regions with correlating dummy criteria



HIC36



$a_{3ms}$

Tibia

**Correlation Tibia – Thorax?**  
**Causal relationship?**

- Identification of relevant input parameters → reduction of input parameters (e.g. for optimizations)
- Correlations reveal tendencies (only linear and quadratic correlations)
- Visualisation of correlations → helpful for system understanding
- Important for meaningful results → choice of input parameters + definition of input parameter intervals