Sensitivitätsanalyse von passiven Insassenschutzsystemen im Frontalcrash

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Weimarer Optimierungs- und Stochastiktage 6.0
15.10.2009

Table of content

- **Introduction: Occupant Safety Systems**
- **Safety system components for frontal crash**
- **Aim of sensitivity analysis**
- **Definition of input and output parameters**
- **Results of sensitivity analysis**
  - Input – Output correlation analysis
  - Output – Output correlation analysis
- **Summary**

Occupant Safety Systems

Frontal crash test

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
  - …

Identification

Correlations

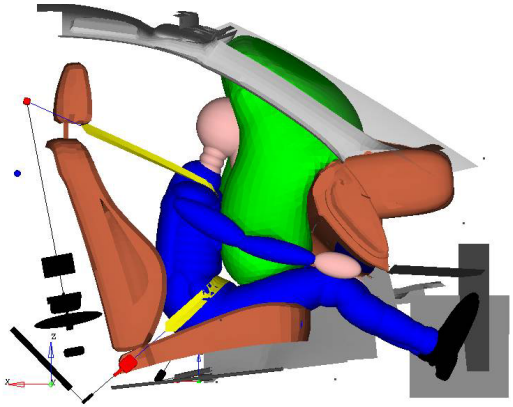
Parameters – Dummy criteria

Dummy criteria – Dummy criteria

Sensitive system parameters

Dummy criteria

- $a_{head,\ max}$, HIC36, …
- neck tension, Nij, …
- 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. …

user defined design parameter intervals

[$pret_{min}$; $pret_{max}$]

[μ_{min}; μ_{max}]

⋮

Outputs

Dummy criteria

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

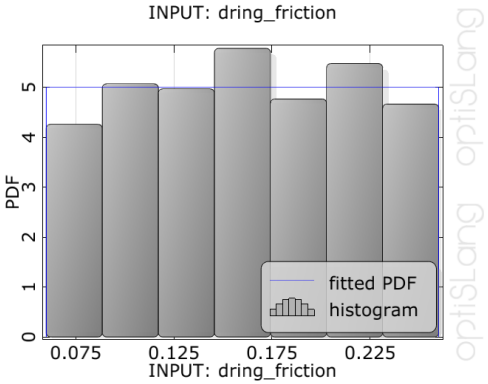
24. …

36 variables

Special Example

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

uniformly distributed



LHS sampled

Latin Hypercube Sampling (LHS)

Aim:

95% Confidence Interval

ρ = 0.5 [-0.05; +0.05]

Identification of sample size

chosen: 350 samples

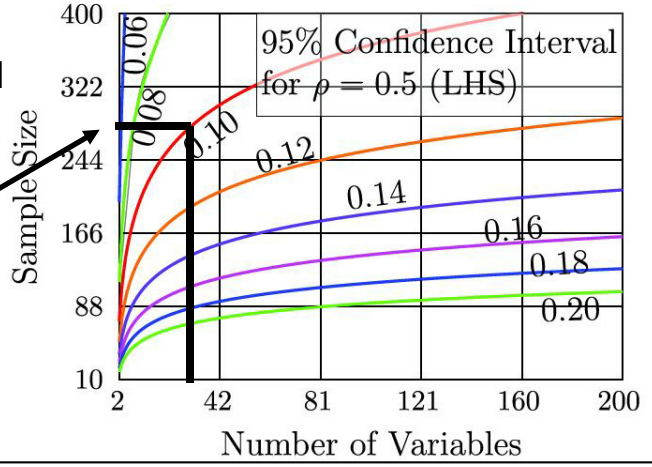
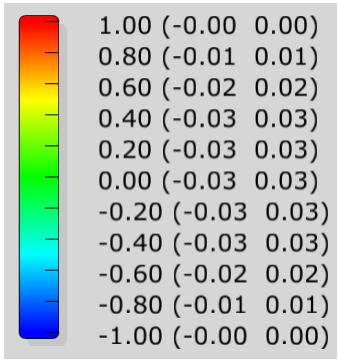


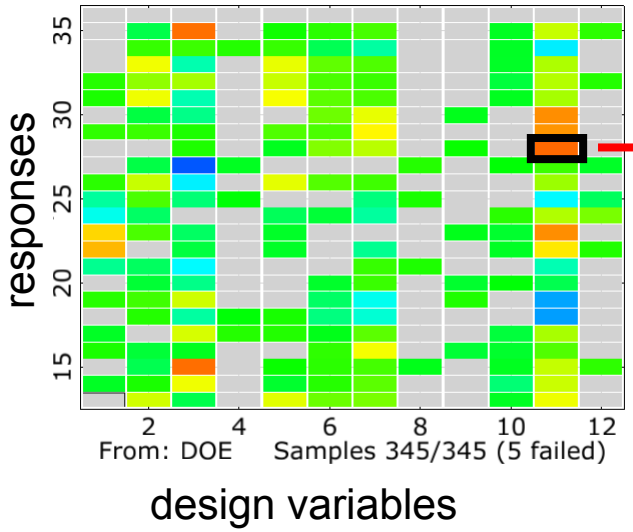
Table of content

Linear correlation matrix

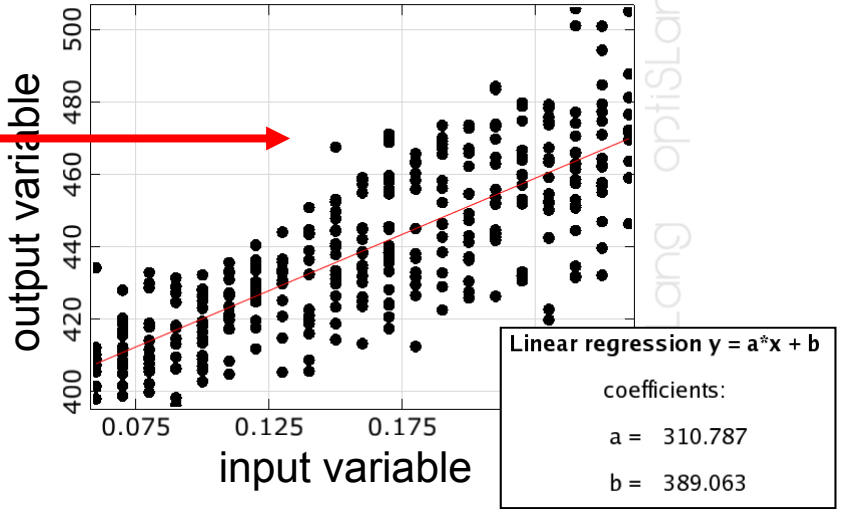
Linear correlation matrix C_{xx}
Input – Output parameters

Significance filter limit = 95%





Anthill plot – linear correlation



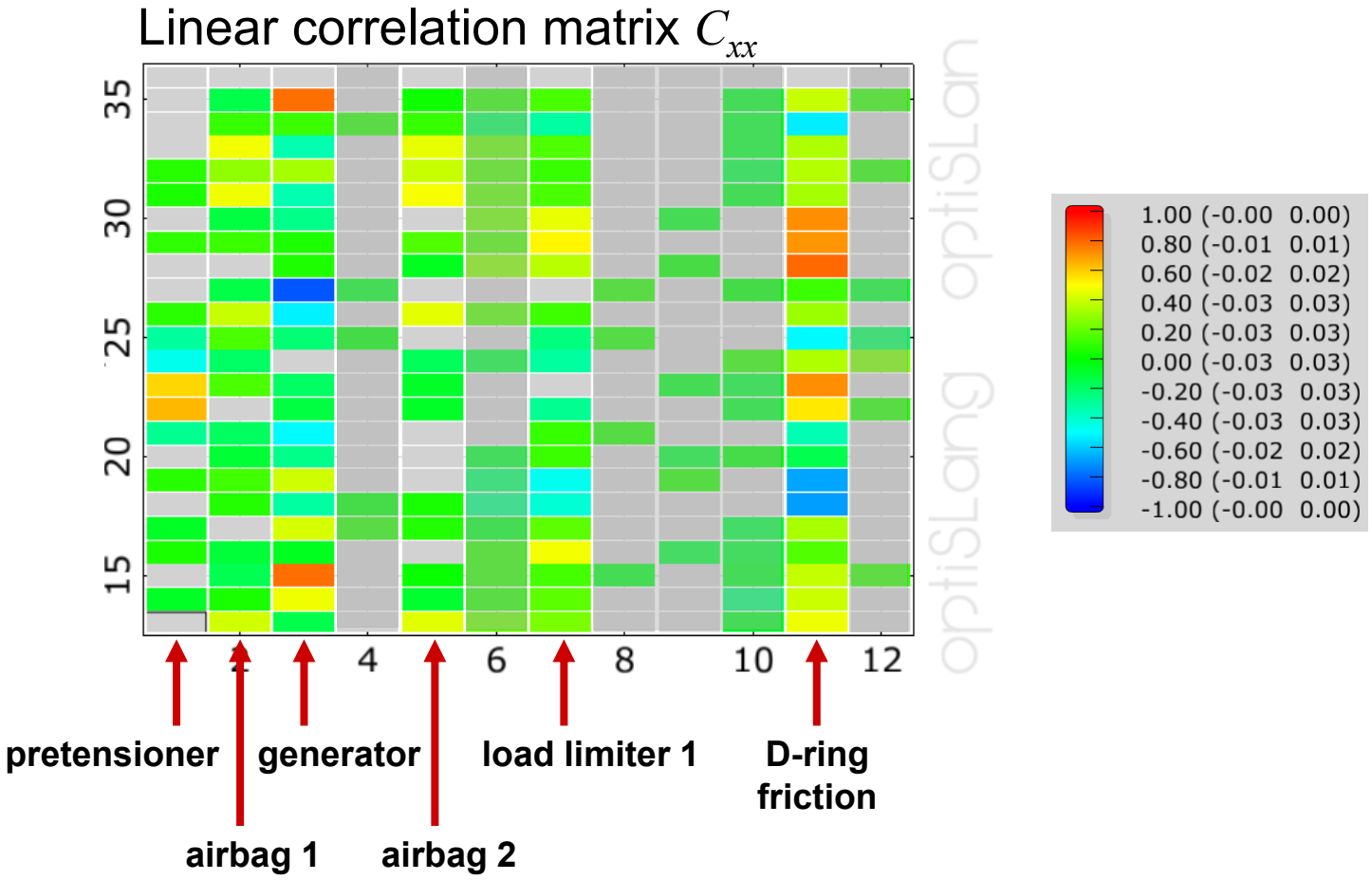
- **Degree of linear relationship between two characteristic parameters**
- **Linear regression model**
- High correlation → not necessarily causal relationship
- Correlation may be affected by other variables

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



➡ **relevant linear correlations (ρ >0.5) to output parameters**

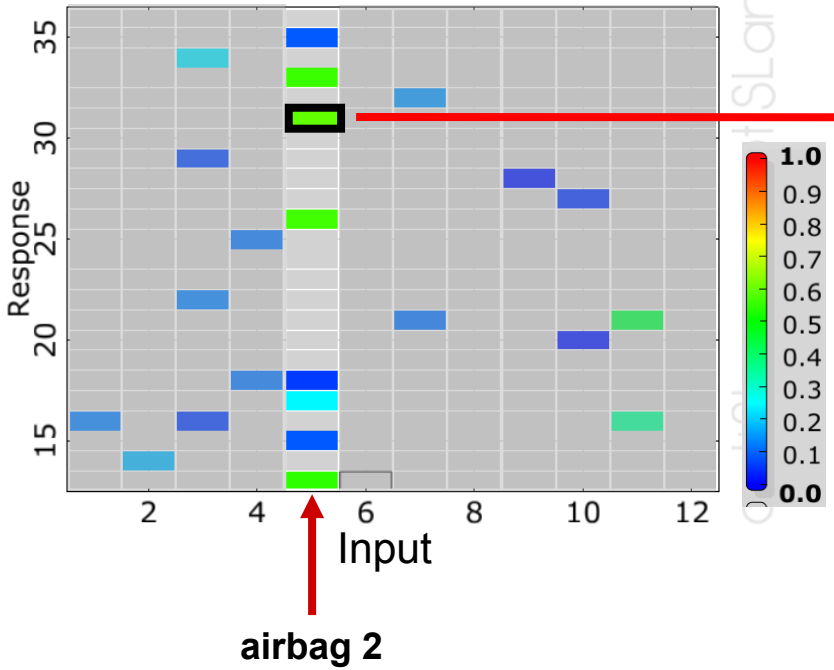
Identifying relevant input parameters

Quadratic correlations

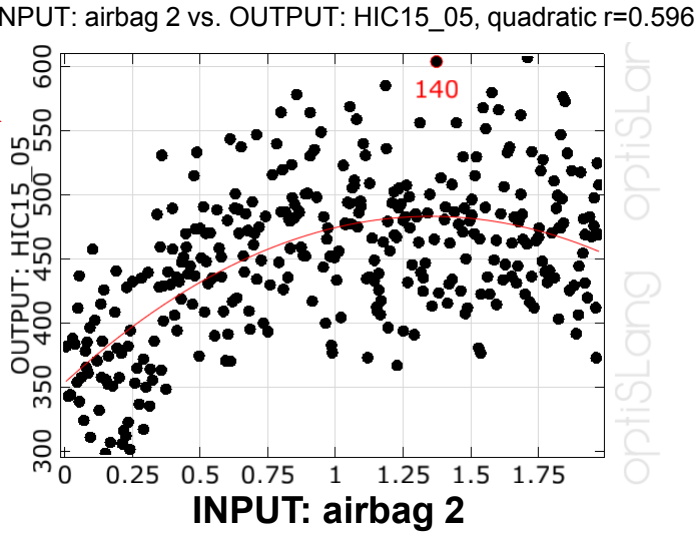
Quadratic correlation matrix C_{XX}

Anthill plot – linear correlation

Quadratic – linear correlation coefficients



airbag 2



quadratic correlation

0.5 < ρ ≤ 0.7 low
0.7 < ρ ≤ 0.9 medium
0.9 < ρ ≤ 1.0 high

Quadratic regression y = a*x² + b*x + c

coefficients:

a = -70.8635

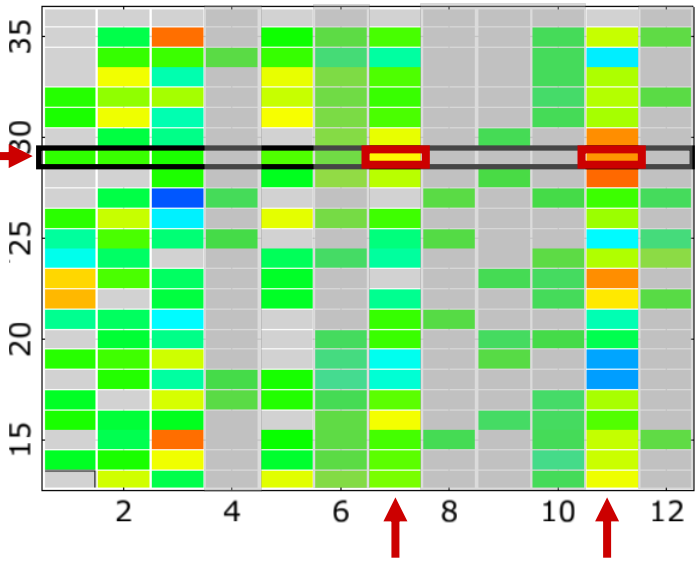
b = 191.588

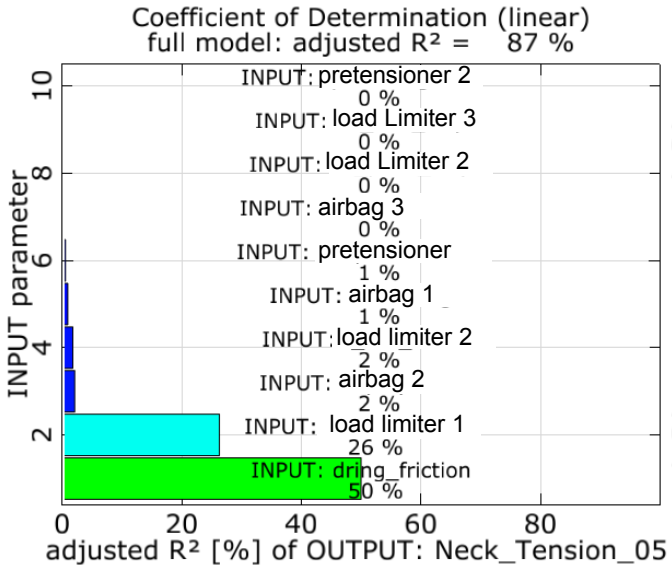
c = 353.606

relevant quadratic correlations (ρ >0.5) only for airbag 2

Important Input – Output correlations

Neck tension





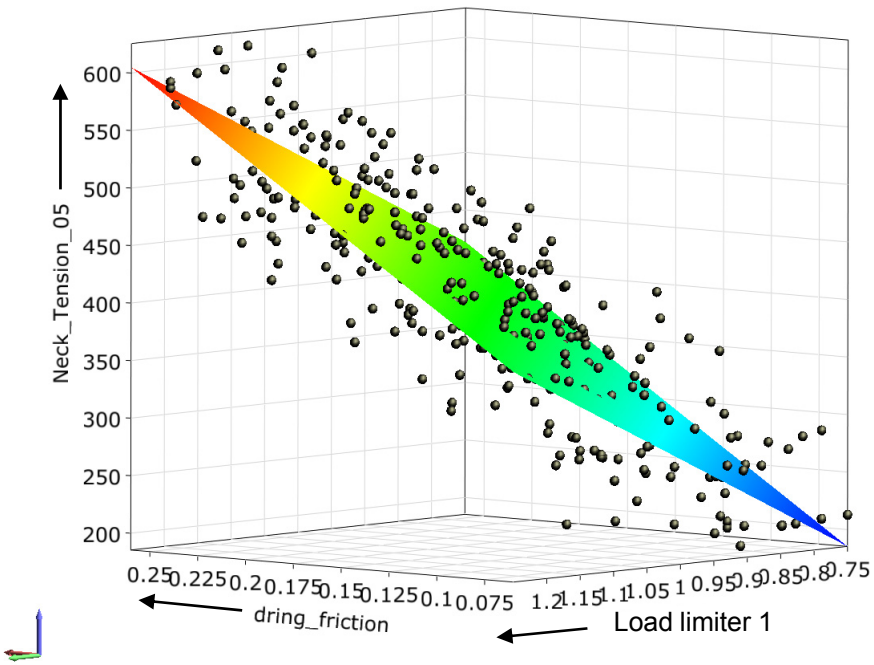
	Load limiter 1	D-ring friction
Neck tens.	ρ R²	0.52 26% (87%)	0.71 50% (87%)

lin. corr.: low / 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

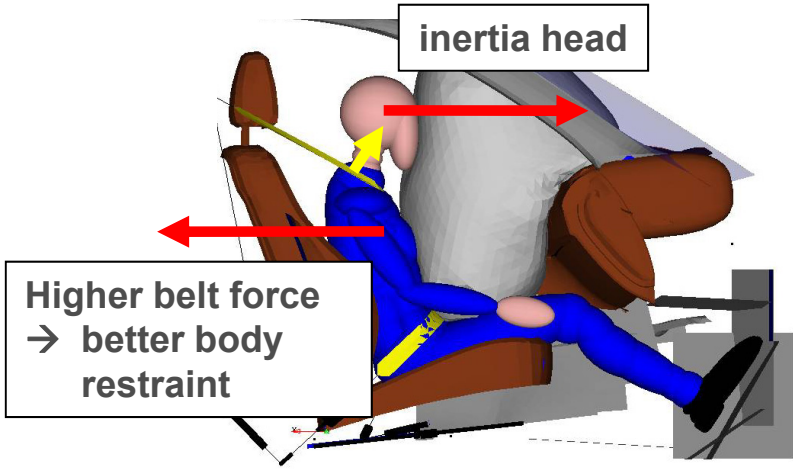


Simultaneous increase in

- 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	ρ 0.48 R^2 23% (28%)	
NTF	ρ R^2	
NCE	ρ R^2	-0.69 48% (85%)
NCF	ρ -0.47 R^2 22% (90%)	-0.68 46% (90%)
Neck tens.	ρ 0.52 R^2 26% (87%)	0.71 50% (87%)
Neck compr.	ρ 0.46 R^2 20% (87%)	0.72 52% (87%)
IRF Neck	ρ R^2	-0.53 28% (45%)

lin. corr.

low
med
high

Neck criteria correlate linear with belt parameters

- D-Ring friction*
- Load limiter 1*

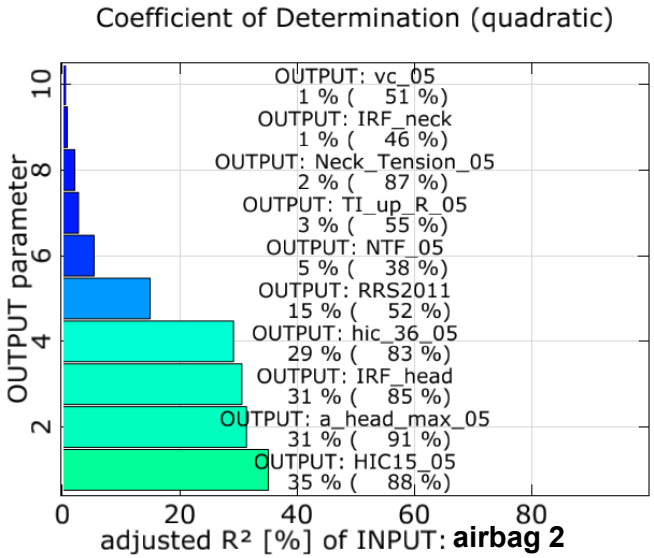
* Basis: interval approach for input parameters

Results for Head injury values

		airbag 2	D-Ring friction	airbag 1	generator
HIC36	ρ R^2	0.54 29% (83%)	0.47 22% (73%)		
HIC15	ρ R^2	0.60 35% (88%)		0.47 22% (76%)	
IRF_{head}	ρ R^2	0.56 31% (85%)		0.47 22% (75%)	
$a_{head,max}$	ρ R^2	0.56 31% (91%)			-0.53 28% (80%)
$t\_a_{head,max}$	ρ R^2				-0.83 69% (71%)

lin. corr.: low, med, high

quad. corr.: low, med, high

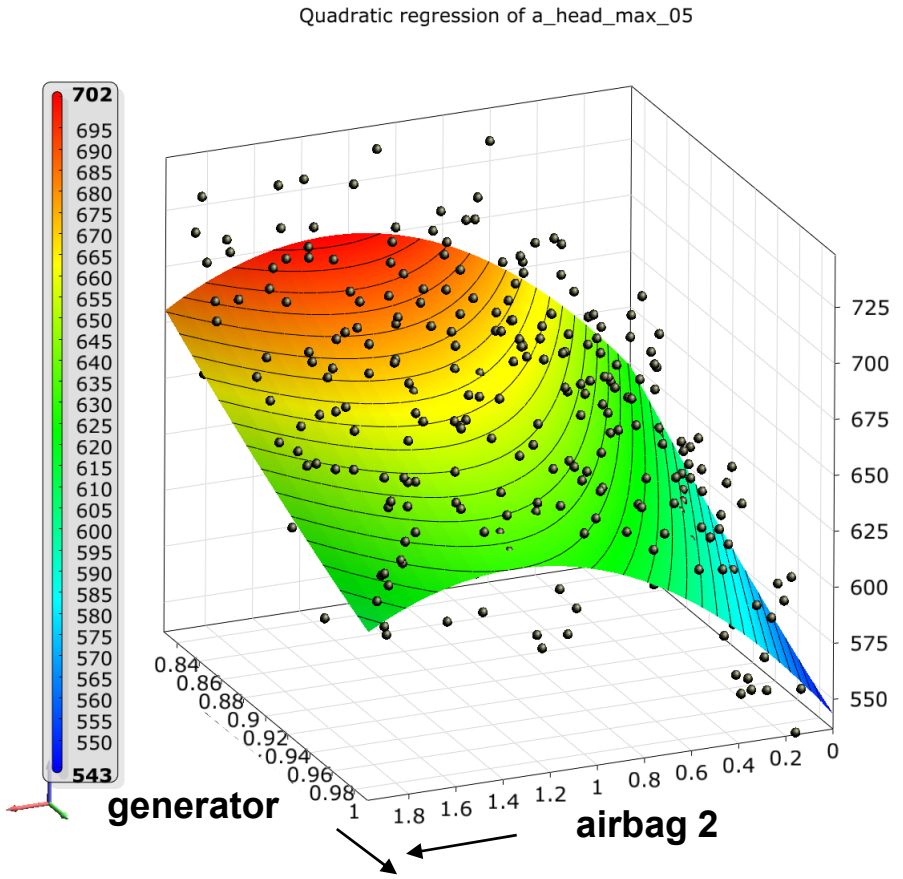


important correlations (quadr.) of **airbag 2** with head injury values

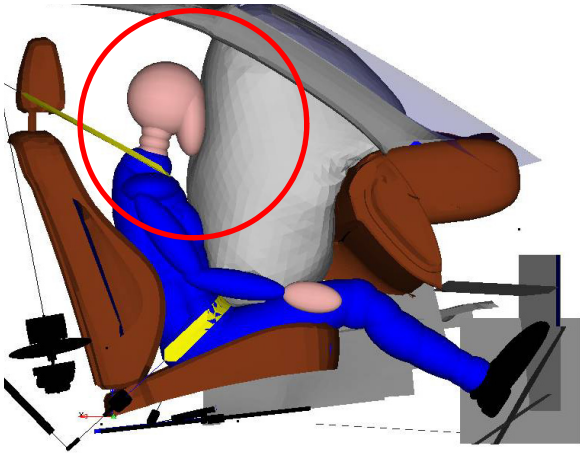
➡ **Head criteria influenced by airbag parameters**

Response surface

Quadratic regression for head deceleration $a_{head,max}$



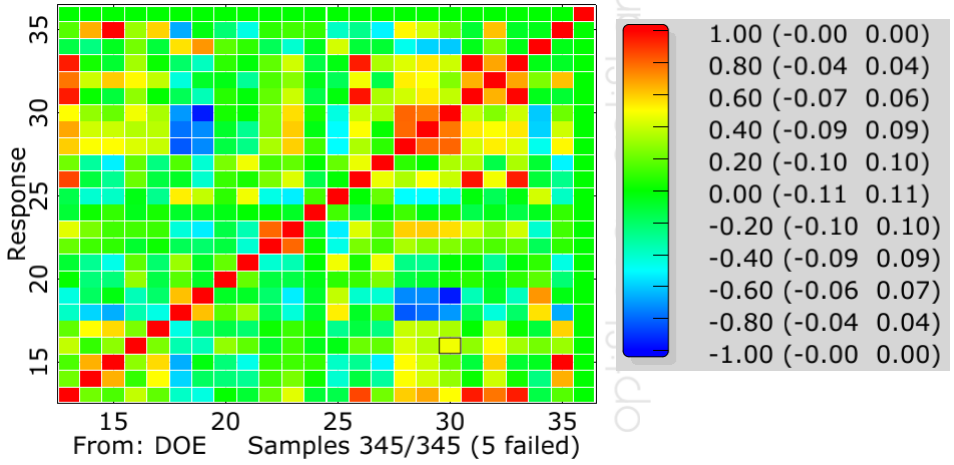
Contact head - airbag



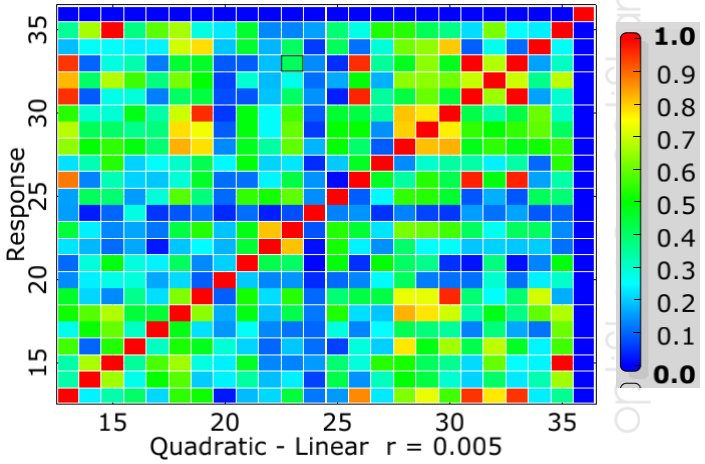
➡ **early coupling head - airbag → low head deceleration**

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

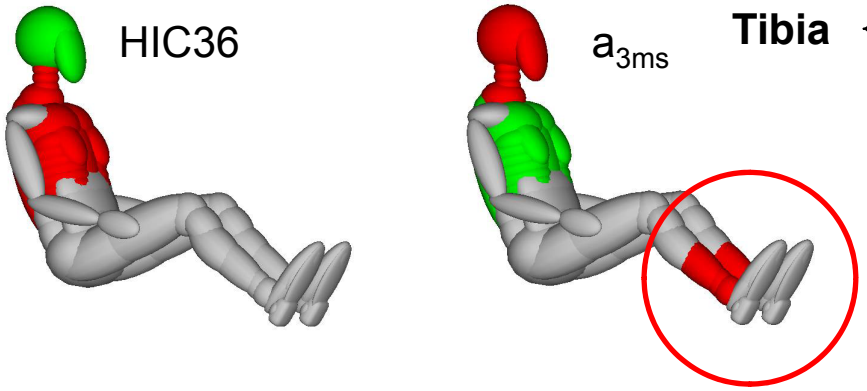
HIC36

		ρ_{lin}	ρ_{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

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

Body regions with correlating dummy criteria



Correlation Tibia – Thorax?

Causal relationship?

Summary

- Identification of relevant input parameters → reduction of input parameters (e.g. for optimizations)
- Correlations reveal tendences (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