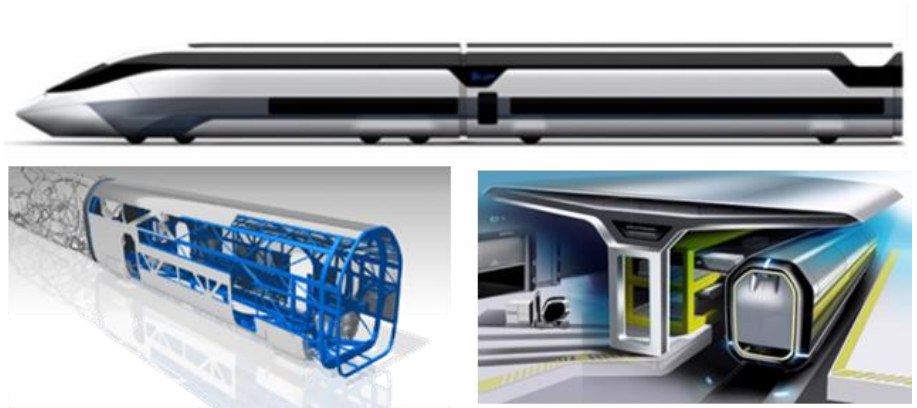
Inefficient design: Sensitivity analysis and numerical investigation of load cases from EN 12663-1 on railway car bodies

Nicolai Schmauder[1], Gregor Malzacher[1] and Sönke Kraft[1]

[1]German Aerospace Center
Institute of Vehicle Concepts
Pfaffenwaldring 38-40
70569 Stuttgart, Germany

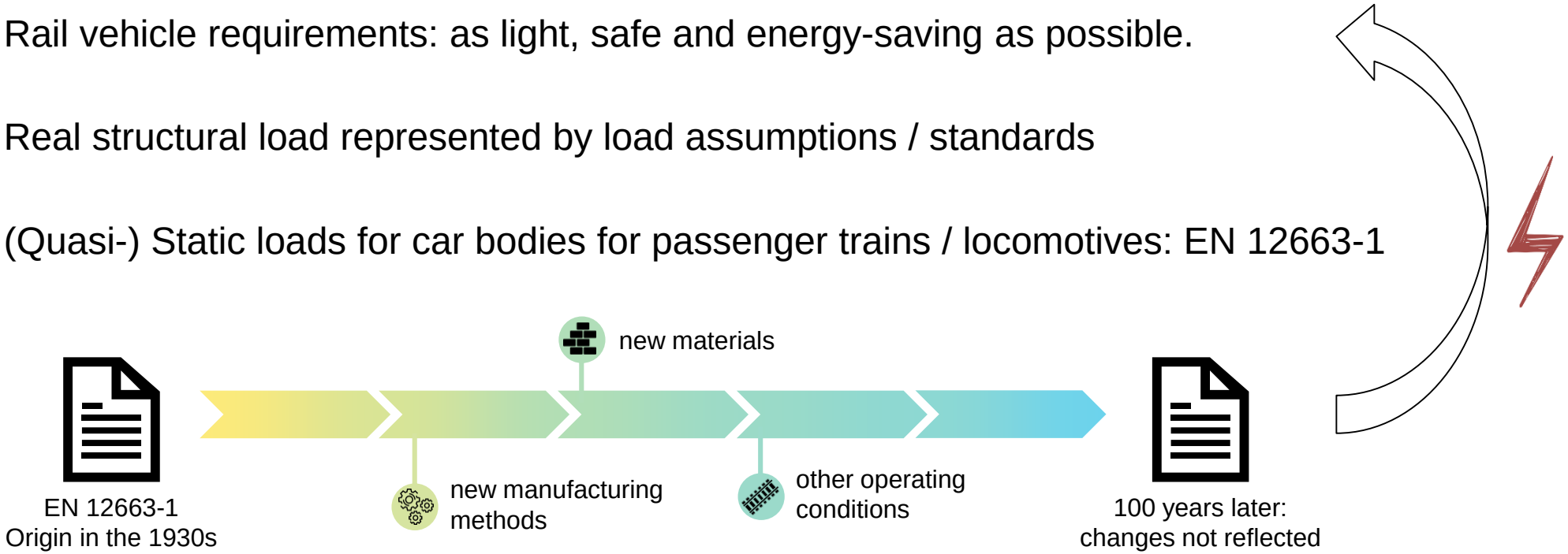
German Aerospace Center (DLR)
Overview

- Germany's research center for aerospace
- 10 000 employees / 55 institutes / 30 locations
- Research Areas
  - Aeronautics
  - Space Research and Technology
  - Defence and Security
  - Space Administration
  - Project Management Agency
  - **Energy and Transport → NGT Metaproject**
    - Innovative rail vehicle concepts
    - Lightweight design and structures
    - System dynamics, Aerodynamics, LCC
    - Traffic management



Motivation

- Rail vehicle requirements: as light, safe and energy-saving as possible.
- Real structural load represented by load assumptions / standards
- (Quasi-) Static loads for car bodies for passenger trains / locomotives: EN 12663-1

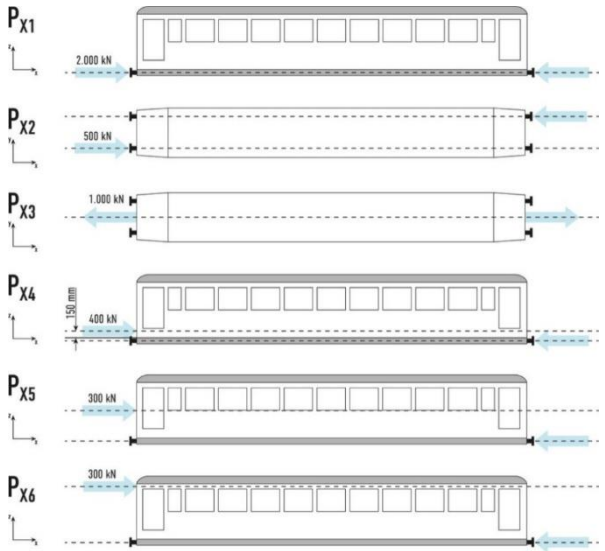


- Aim: Optimize the design process of rail vehicles
  - Identification of design-relevant load cases

Investigated load cases

EN 12663-1

- Different categories: P-1 (most conservative)
- Static longitudinal loads
  - Superimpose with different weight forces

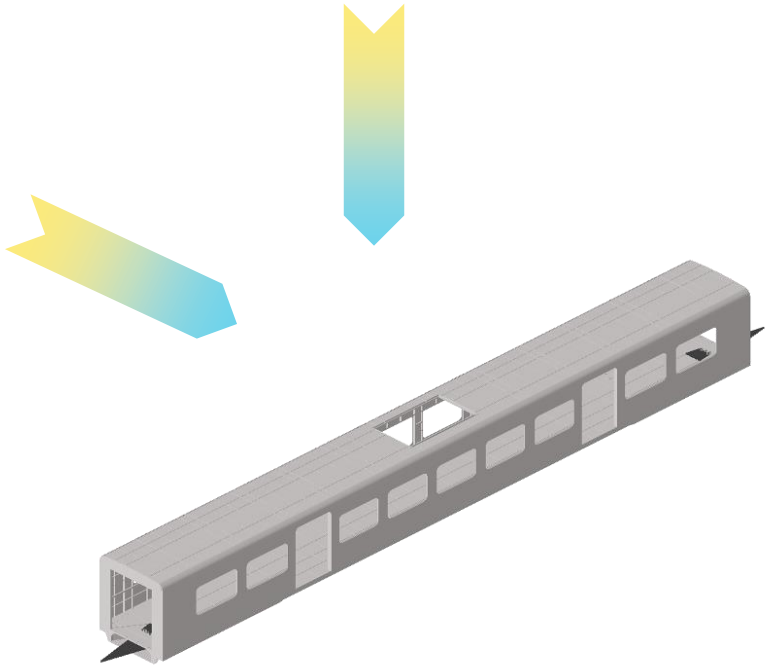


Inspired by: IHME, Joachim. *Schienenfahrzeugtechnik*. Wiesbaden: Springer Vieweg, 2016.

- Static vertical loads
  - Normal / exceptional payload
  - Lifting and jacking
  - Superimpose with lateral force
- Acceleration of equipment and bogies
- Quasistatic loads
  - Excitations in different directions depending on mass of the car body
  - Superimpose with each other

Further load cases

- Real operating situations
- Further superimpositions



DLR

Sensitivity analysis

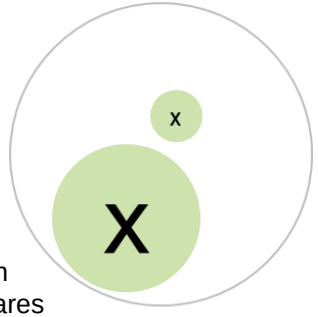
- Methodology:

Changing the input parameters X_i *(load amount)*

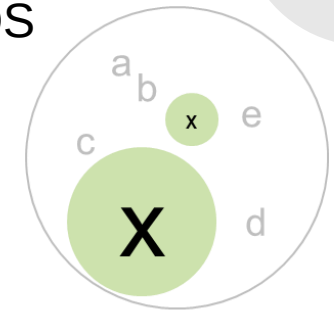
Analyze the system response Y_i *(stress distribution)*
- In general
- Maximum stress
- Specific at selected fixed points

Variation of Y_i: Sensitivity of the Parameter

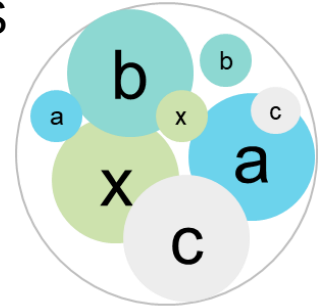
Factor screening:
- Qualitative analysis of each parameter for itself
- Aim: detect similarities, reduce number of parameters



Local sensitivity analysis:
- Quantitative analysis of one parameter in its OS
- Aim: detect correlations in different OS

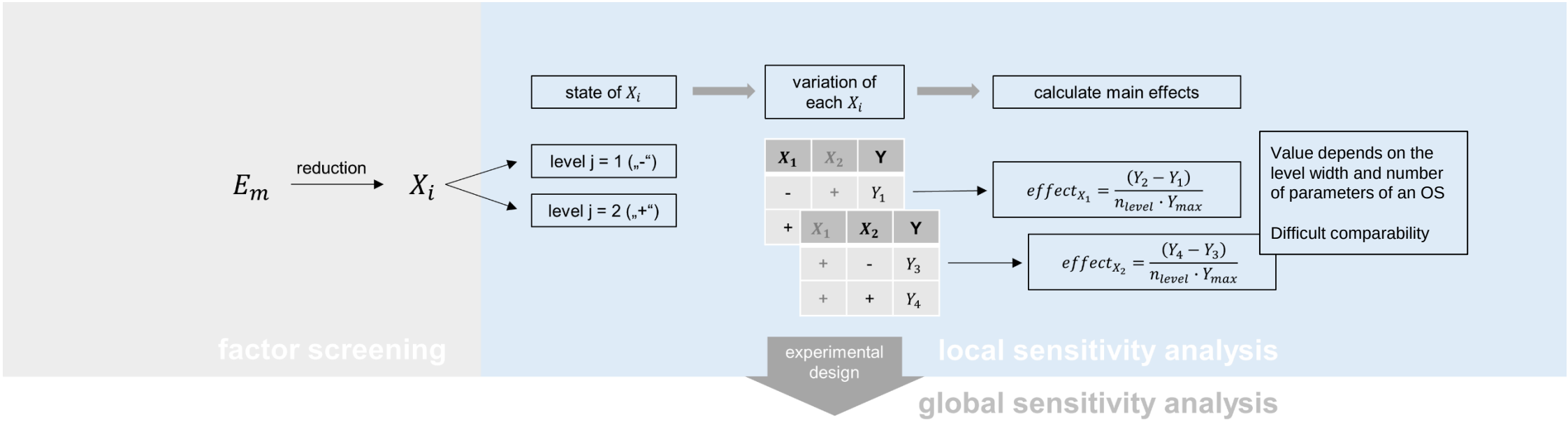


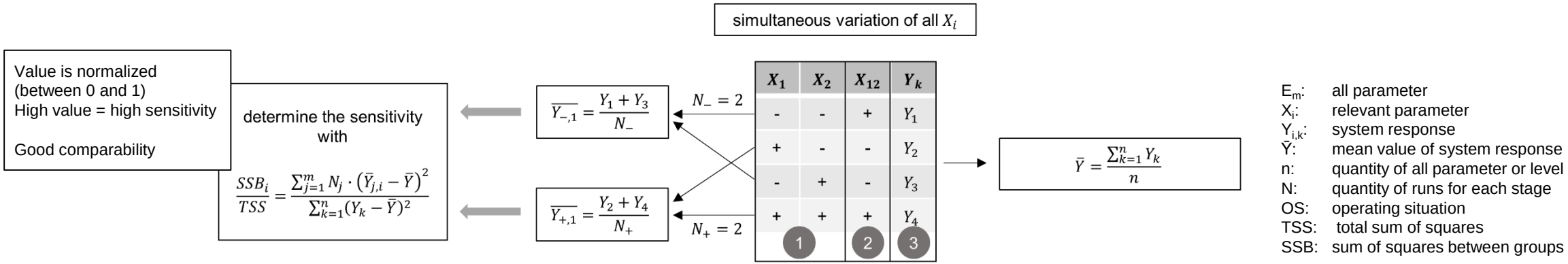
Global sensitivity analysis:
- Varying all parameters of an OS simultaneously
- Aim: detect interrelationship of loads within a OS



OS: operating situation
TSS: total sum of squares
SSB: sum of squares between groups

Sensitivity analysis – Mathematical Methodology

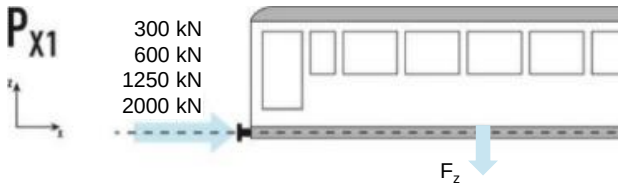




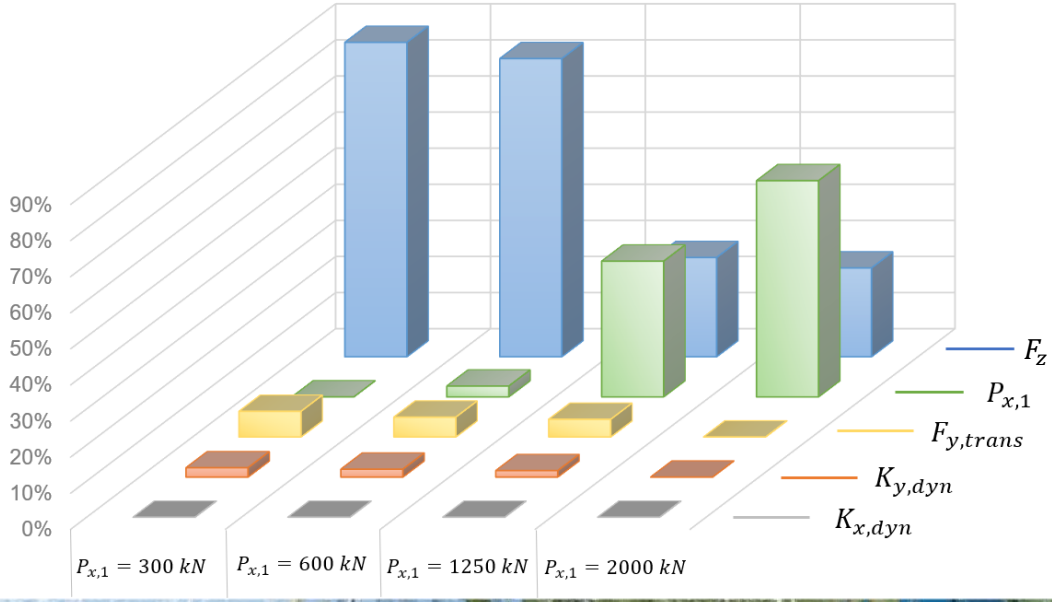
E_m: all parameter
X_i: relevant parameter
$Y_{i,k}$: system response
$\bar{Y}$: mean value of system response
n: quantity of all parameter or level
N: quantity of runs for each stage
OS: operating situation
TSS: total sum of squares
SSB: sum of squares between groups

Results

- Sensitivity to the maximum stress correlates with the sensitivity at fixed points
- Most critical load case: buffer force (2000 kN) x weight with exceptional payload
  - Sensitivity on Y_i of buffer force: 60 %
- Detailed considerations: Influence of buffer force starting at 1000 kN
- Operating situations:
  - 300 kN: maximum traction / braking force ICE 3[1]
  - 600 kN: light buffer impact
  - 1250 kN: sufficient for design[2]
    - Shinkansen trains: 980 kN sufficient for longitudinal compressive force at buffer level[3]



		$P_{x,1} = 300\ kN$	$P_{x,1} = 600\ kN$	$P_{x,1} = 1250\ kN$	$P_{x,1} = 2000\ kN$
Weight force	F_z	87.1%	82.6%	27.5%	24.6%
Buffer force (compression)	$P_{x,1}$	0.0%	0.0%	0.0%	59.9%
Transversal shock	$F_{y,trans}$	2.6%	2.2%	1.8%	0.0%
Dynamic excitation in y	$K_{y,dyn}$	7.1%	5.5%	4.9%	0.0%
Dynamic excitation in x	$K_{x,dyn}$	0.0%	3.0%	37.6%	0.0%

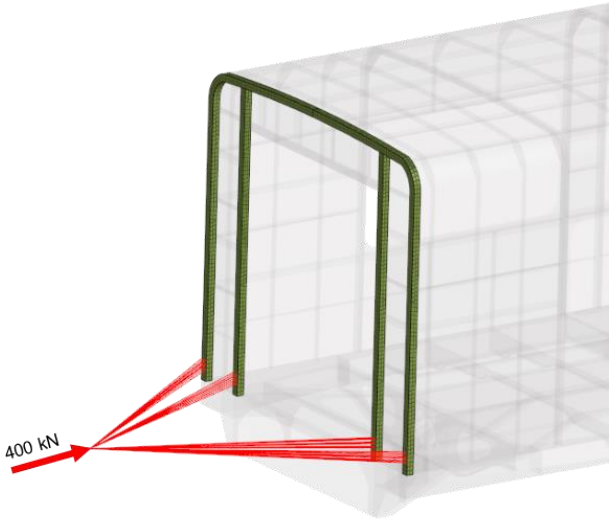


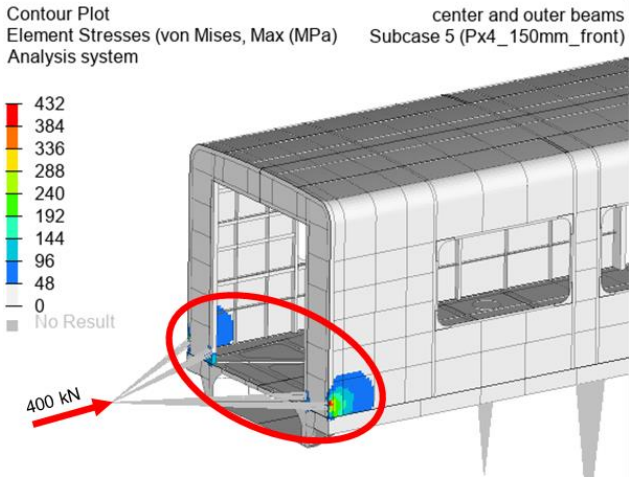
[1]HECHT M, KRAUSE G and POLACH O. Fahrzeugtechnik - Schienenfahrzeuge. 1st ed. Berlin: Springer-Verlag, 2005.
[2]MALZACHER G and MOHR M. Lastannahmen der DIN EN 12663-1: Stand der Technik? In VDEI (eds) Eisenbahn Ingenieur Kompendium: p. 66-86, 2020
[3]JIS E7106 Rolling stock - Car body structure for passenger cars - General rules for design

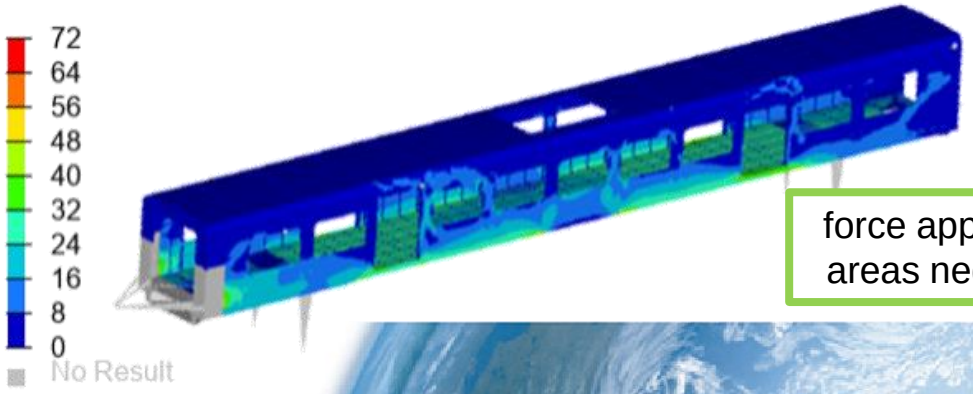
Results

- Weight force:
  - High global sensitivity / dominant force
  - Linear system
    - higher weight force = higher sensitivity
    - 8 Redundant load cases in EN 12663-1
  - Superimposition with lateral / longitudinal loads: high local sensitivity

- Dynamic excitations / Quasistatic load cases
  - Sensitivity of weight force always > 80 %
  - Lateral excitations > longitudinal excitations
    - Maximum sensitvity: 8.6 %







force application areas neglected

high local stress areas

Conclusion

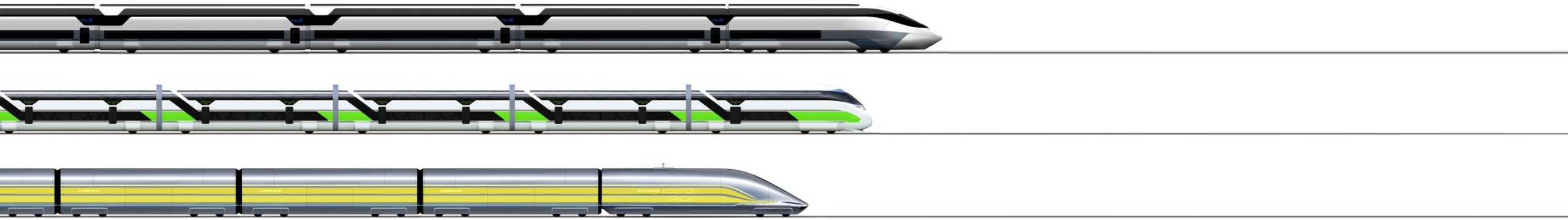
- Weight force is the major parameter for critical points

- Longitudinal buffer-force
  - High sensitivity, dominant
  - Reduced to a realistic magnitude: low sensitivity on the system

- Inefficient design process through:
  - Redundant load cases / superimpositions
  - Obsolete loads with no current scientific basis

Overdimensioning, not economical, not resource efficient

- For a future competitive design process: thorough revision necessary
  - Closer examination of the actually acting loads is necessary



Thank you for your attention!

Nicolai Schmauder
German Aerospace Center
Institute of Vehicle Concepts
Pfaffenwaldring 38-40, 70569 Stuttgart, Germany
☏ +49 711 6862 8547
✉ nicolai.schmauder@dlr.de