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A joint company of Daimler and Bosch

Engineering up to the physical limits
-
Enabled by Multi-Target-Multi-Domain-Optimization

Marc Brück
Weimar, June 2nd, 2017

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EM-motive GmbH – A joint company of Daimler & Bosch

- More than 300 000 e-motors manufactured since 2012
- Full-range portfolio for EVs, plugin-hybrids and hybrids
- Customer vehicles with EM-motive e-motor

Mercedes-Benz C350e, C300h

Porsche 918 Spyder

Peugeot 3008 Diesel Hybrid

Citroen DS5 Diesel Hybrid

Streetscooter Work

Volkswagen Touareg E-Hybrid

Volvo V60 Diesel Plug-in Hybrid

Fiat 500e

Smart fortwo electric drive

Mercedes-Benz GLC350e

Porsche Panamera S E-Hybrid

Peugeot 508 Diesel Hybrid

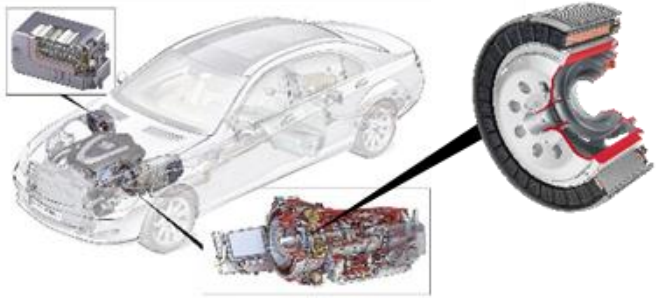
Mercedes-Benz E300e, E350e

Porsche Cayenne S E-Hybrid

Mercedes-Benz GLE500e

Mercedes-Benz S500e, S300h, S400h

Mercedes-Benz SLS electric drive



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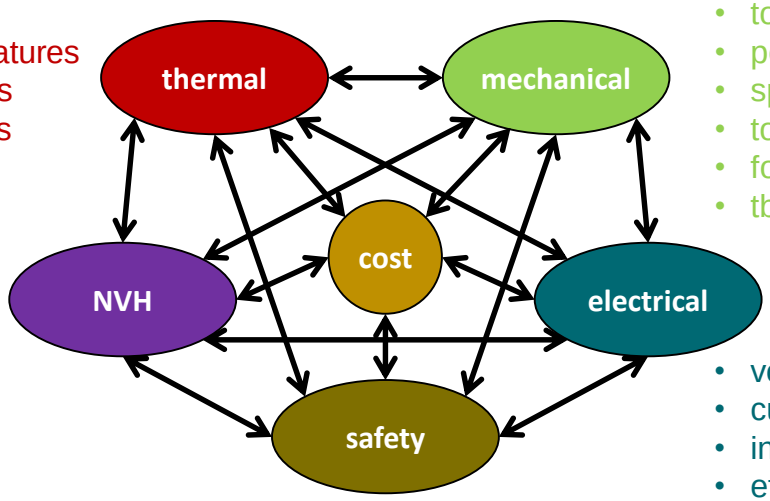
Customer requirements / engineering constraints

- Customer requirements touch different physical domains



- coolant flow-rate
- coolant temperature
- environment temperatures
- winding temperatures
- magnet temperatures
- tbc

- mounting space
- torque
- power
- speed
- tolerances to other parts
- forces on bearings
- tbc

- airborne noise
- structure-born noise
- tbc

- voltage
- current
- inverter-specific properties
- efficiency
- tbc

- back-emf
- short-circuit current
- inverter-specific properties
- tbc

- Main engineering constraints
  - Cost
  - Mounting space
  - Cooling
  - Inverter

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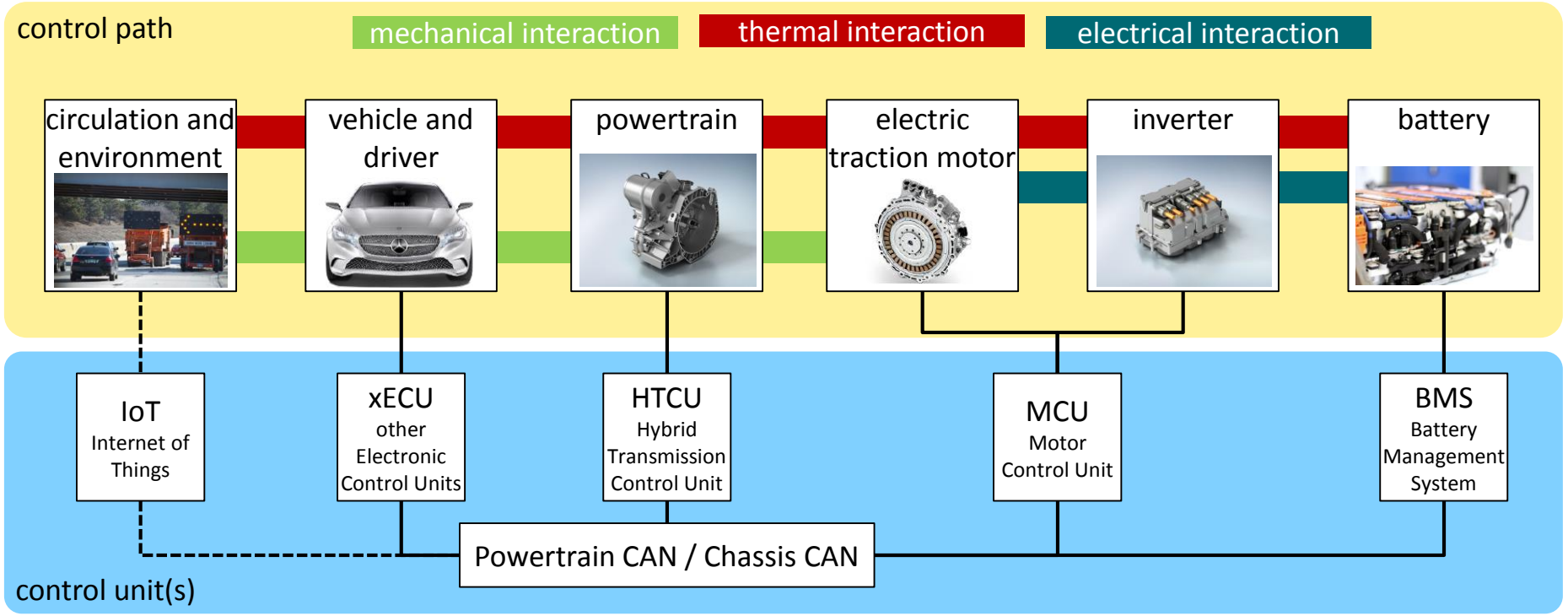
Component vs. (or better and?) systems engineering



- Components strongly interact
- Static boundary conditions not suitable for dynamic interactions
- Systems engineering necessary to handle the complexity

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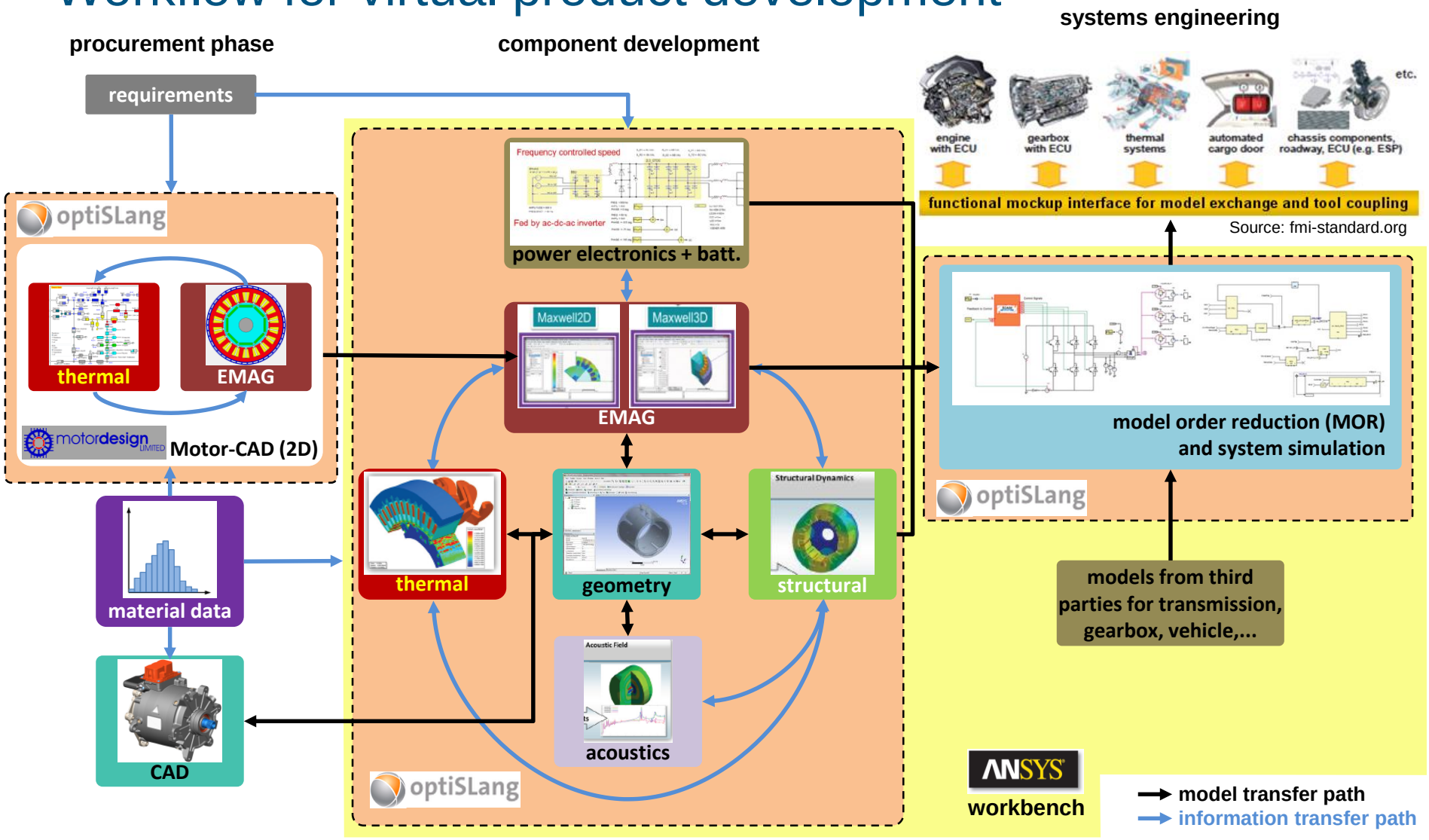
Workflow for virtual product development



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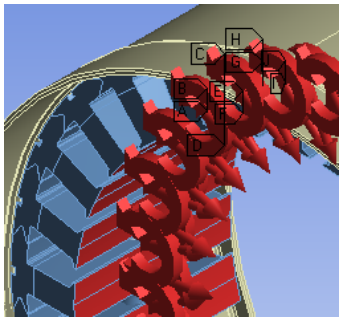
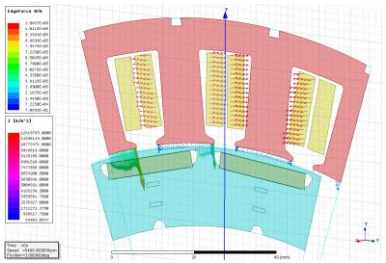
Example 1: Noise due to electromagnetic forces

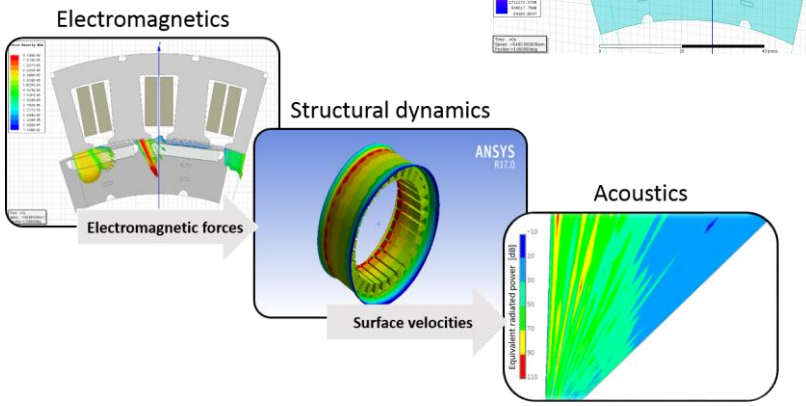
- Background
  - Forces and bending moments act on stator teeth
  - Dynamic deformation of stator and housing surface
  - Generation of pressure waves

  → Emission of noise



- Workflow for simulation
  - ANSYS Maxwell: Electromagnetic forces and moments
  - ANSYS Mechanical:
    - Modal analysis
    - Harmonic response analysis
    - Acoustic analysis via ERP-level (Equivalent Radiated Power)
    - Postprocessing via Waterfall diagram





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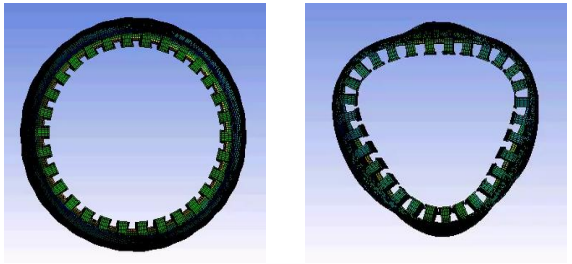
Example 1: Noise due to electromagnetic forces

- Results
  - Eigenmodes 0 and 3

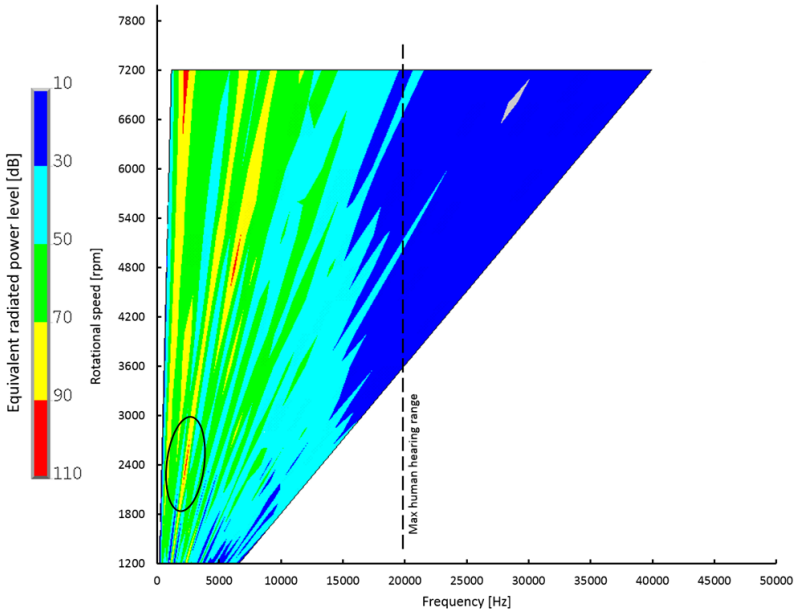


  - Equivalent radiated power level L_{ERP} [dB]
    - ρ air density
    - c speed of sound
    - S surface area
    - v_n surface normal velocity
    - P_0 reference sound power

$$L_{ERP} = 10 \lg \frac{ERP}{P_0}$$

$$ERP = \frac{1}{2} \rho c S \overline{|v_n^2|}$$

  - Postprocessing with waterfall diagram
    - L_{ERP} for various speed and frequencies
    - Idendification of operating points with high noise emissions for specific motor orders



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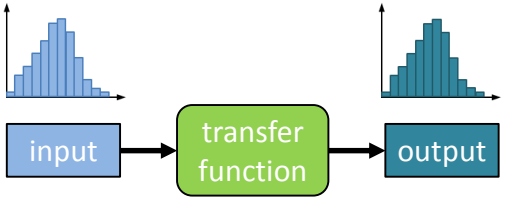
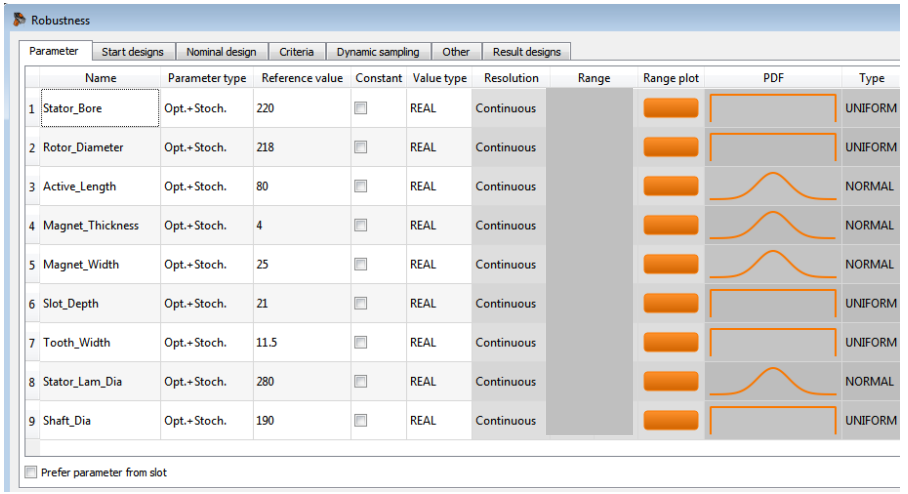
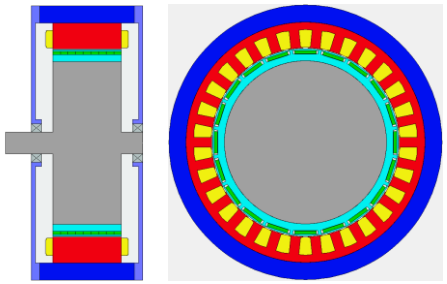
Example 2: Impact of scattering input parameters

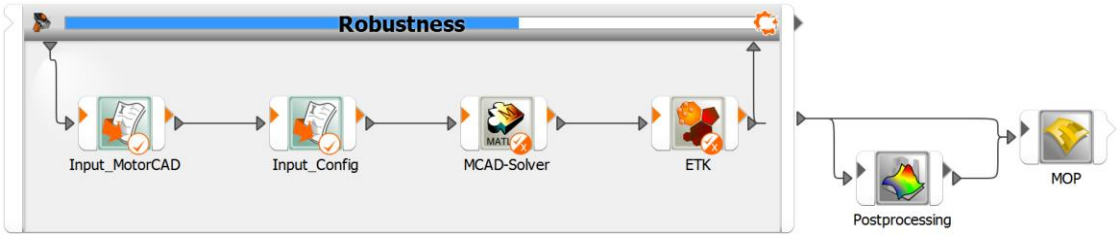
- Background
  - Scattering of input parameters affects output responses
  - Probability density functions (pdf) often unkonwn
  - Low scattering in output responses required



- Workflow for simulation
  - optiSLang:
    - definition of input parameters and scattering
    - management of overall simulation procedure
  - motorDesign LIMITED Motor-CAD:
    - 2D-FEA of electromagnetics
    - characteristic curves







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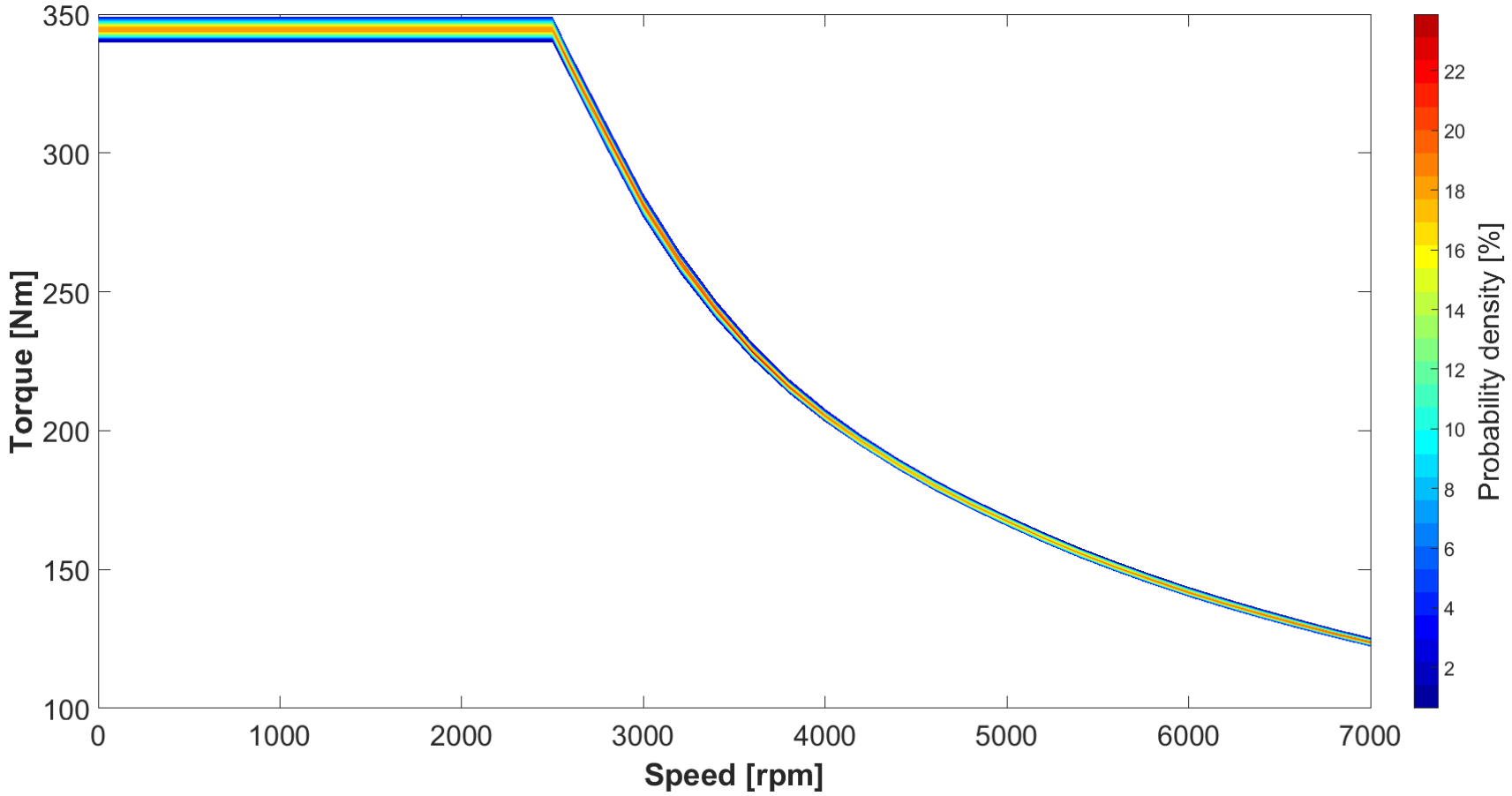
Example 2: Impact of scattering input parameters

- Results
  - Probability density function of characteristic curves due to scattering of input parameters



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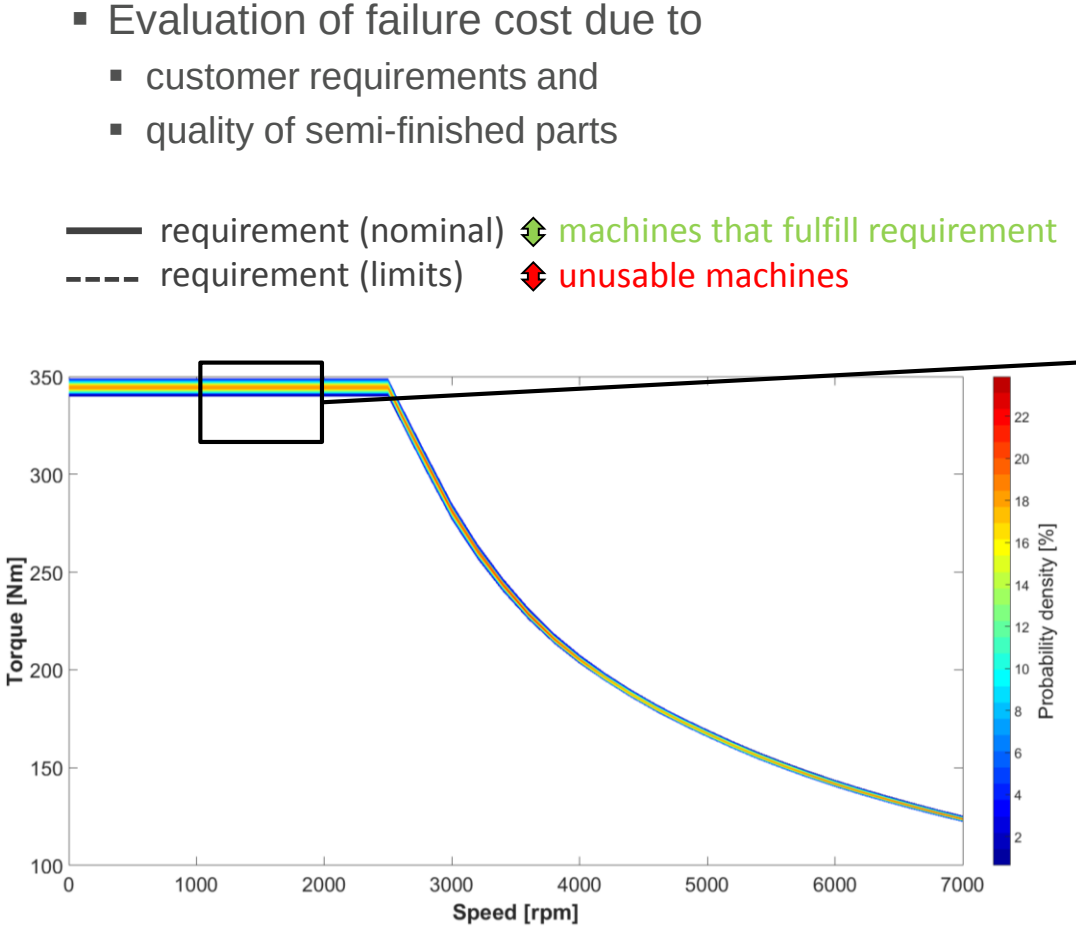
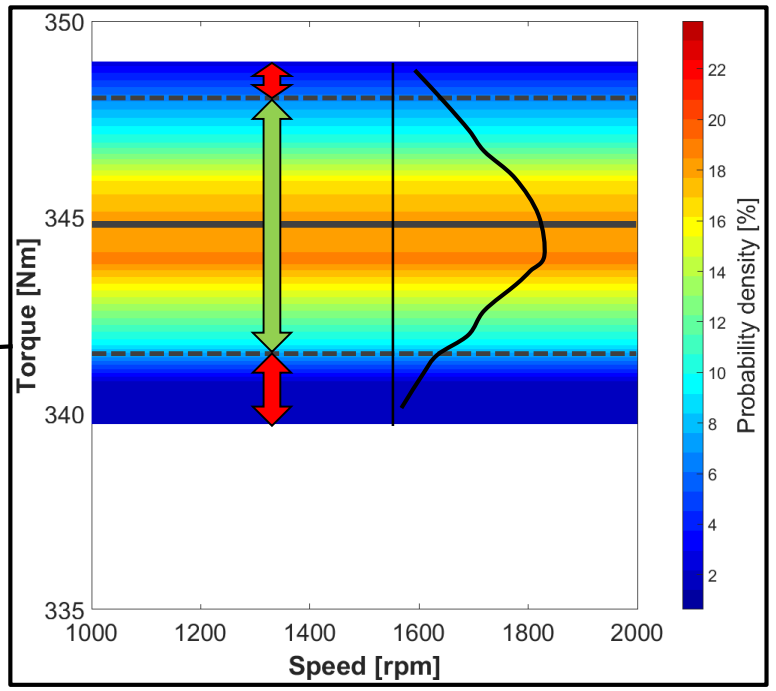
Example 2: Impact of scattering input parameters

- Results
  - Probability density function of characteristic curves due to scattering of input parameters
  - Evaluation of failure cost due to
    - customer requirements and
    - quality of semi-finished parts

requirement (nominal) machines that fulfill requirement
requirement (limits) unusable machines





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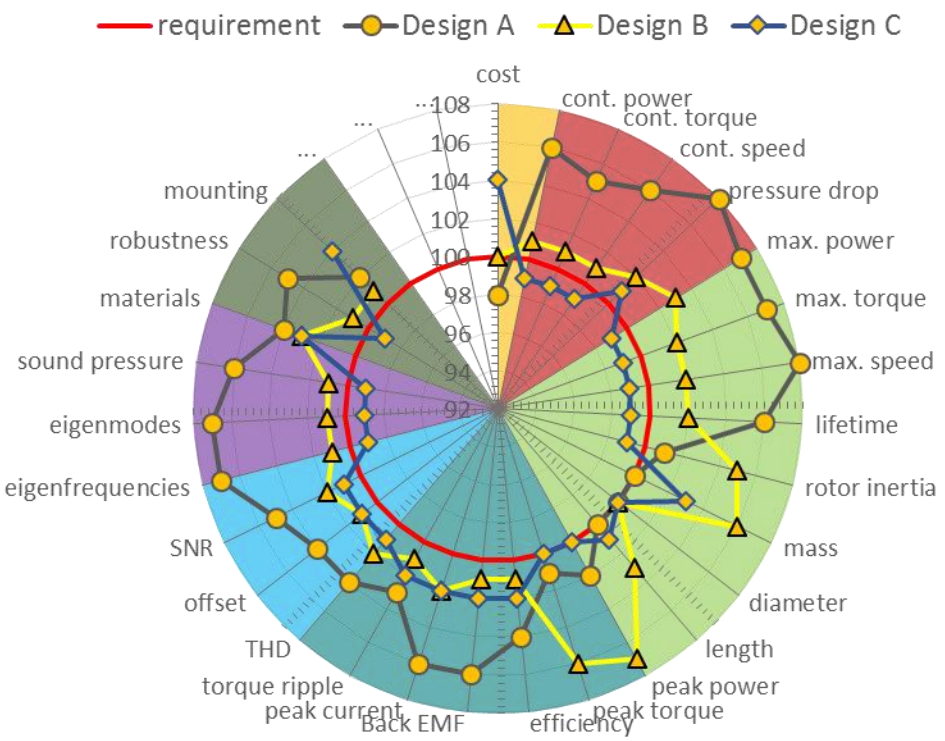
Workflow for virtual product development

- Postprocessing with evaluation of performance „at a glance“

- Requirements and performance indicators in different domains
  - Cost
  - Thermal
  - Mechanical
  - EMAG
  - Control
  - NVH
  - Environment
  - tbc



- Radar chart
  - Dimensionless representation
  - Requirements as 100 % reference (outside red circle = requirement fulfilled)
  - All information in one single chart
  - Easy comparison of several designs

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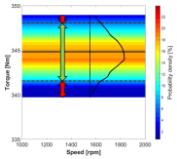
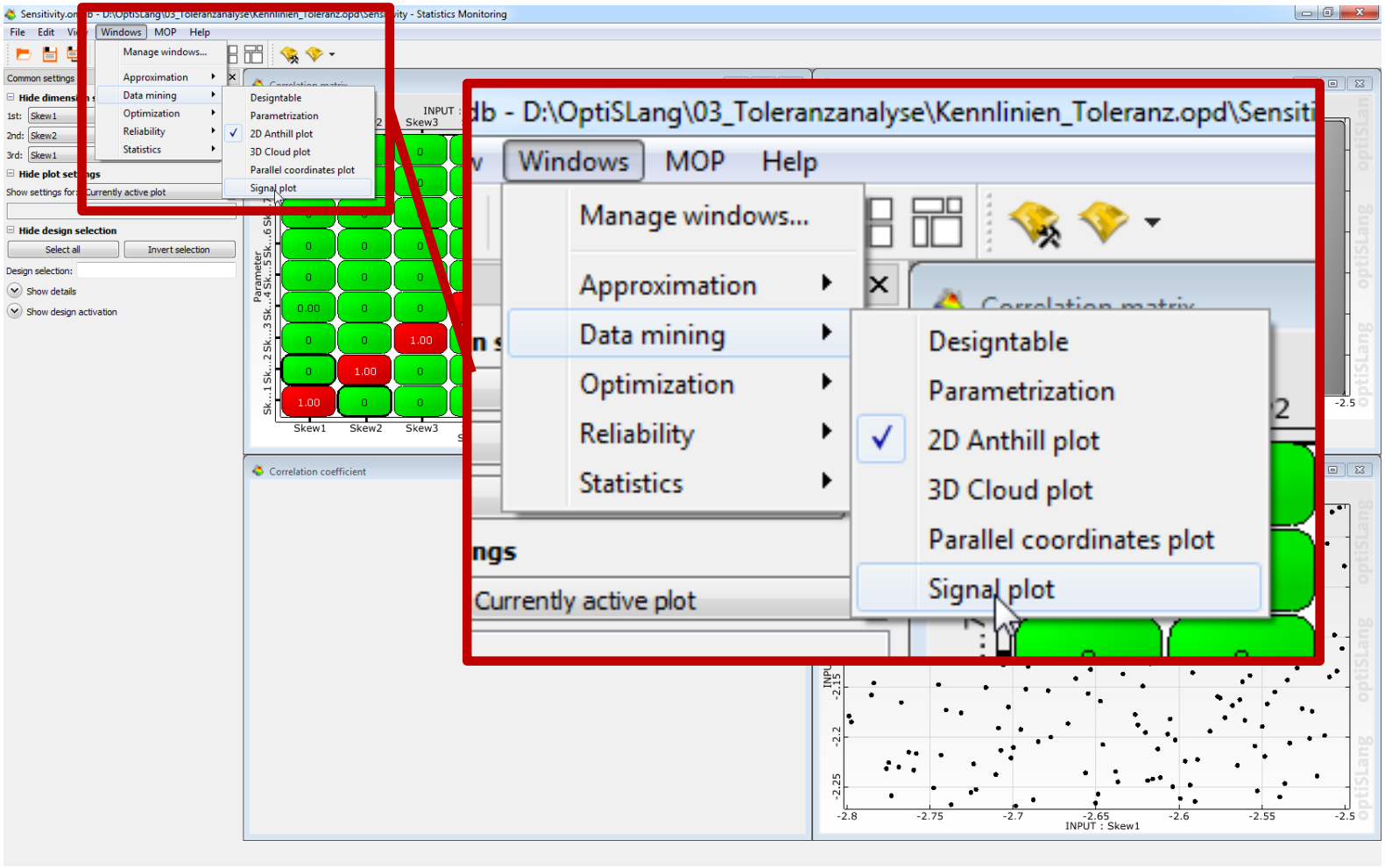
New postprocessing features in optiSLang



- Signal plot with scattering (already available in optiSLang 6.1)



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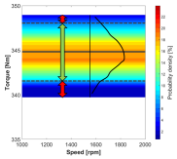

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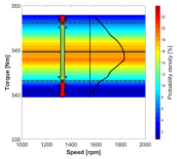

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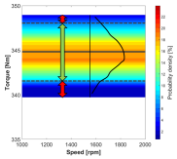

- Signal plot with scattering (already available in optiSLang 6.1)

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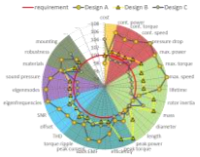
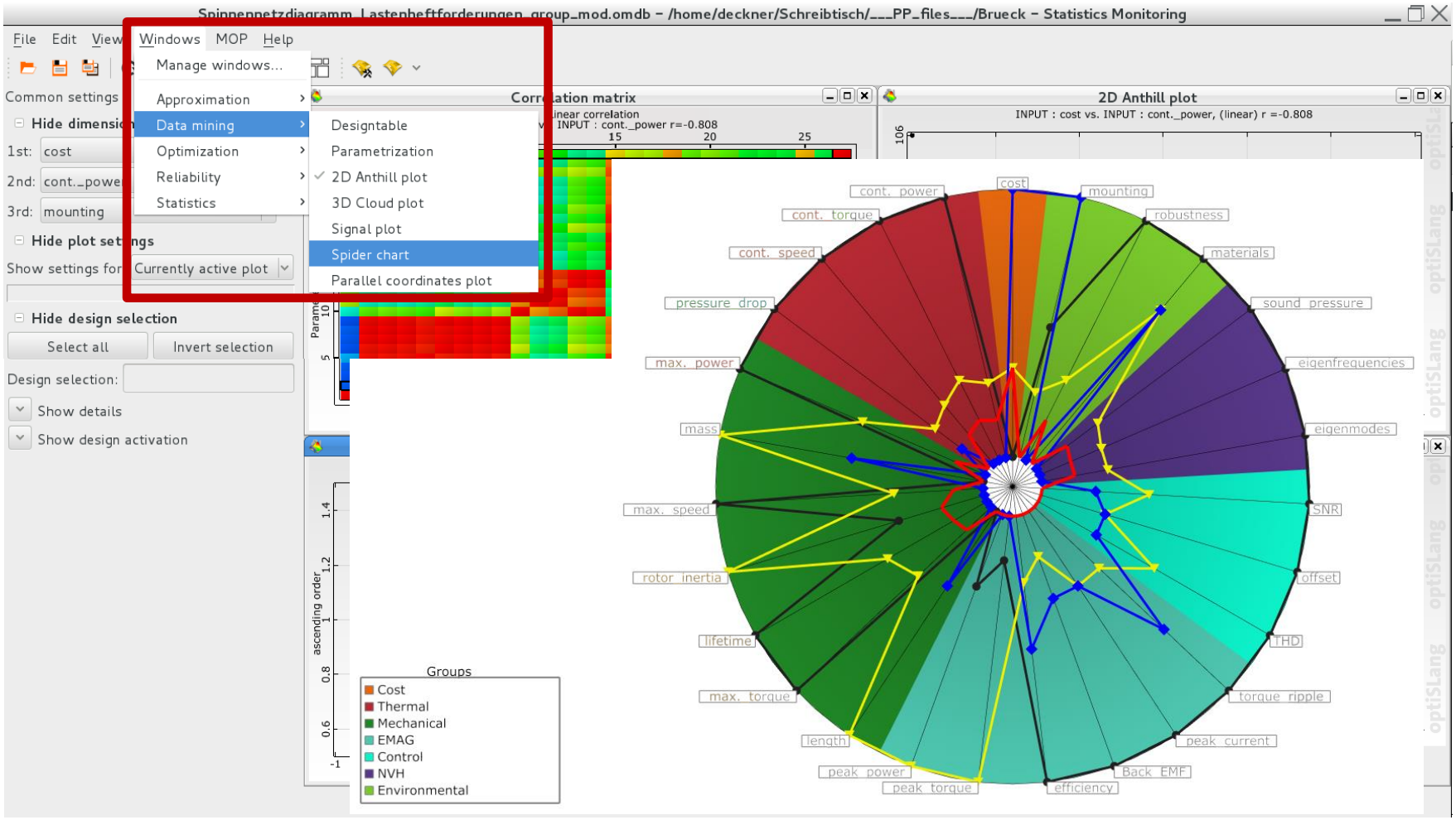
New postprocessing features in optiSLang

- Radar chart (will be available in optiSLang 6.2)





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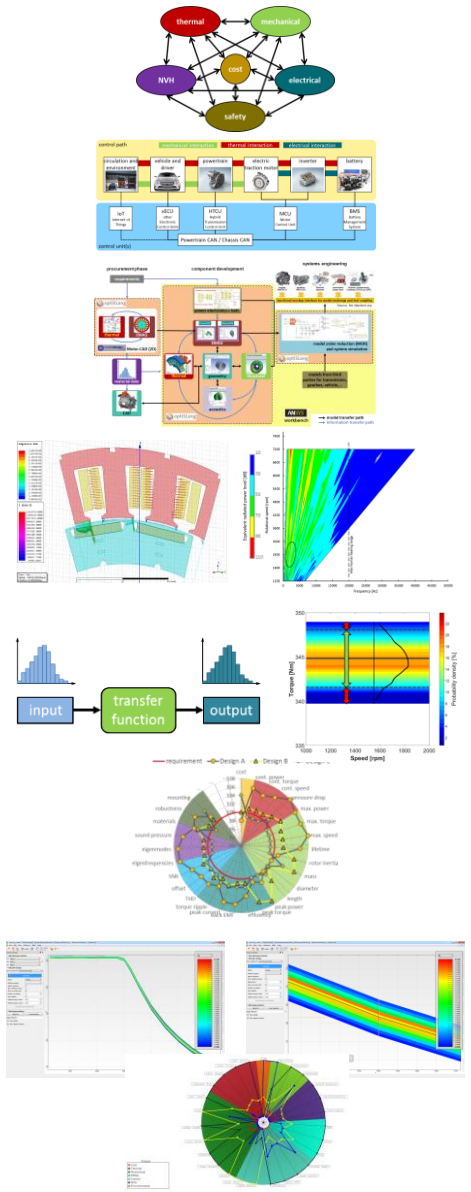
Summary

- Requirements cover different physical domains and interact
- Systems engineering necessary to handle the complexity
- Workflow using Motor-CAD, ANSYS and optiSLang software presented
  - Example 1: Noise due to electromagnetic forces
    - Coupling of electromagnetics and structural mechanics
    - Harmonic response analysis with electromagnetic forces and bending moments as loads
    - Evaluation of noise via ERP-level and waterfall diagram
  - Example 2: Impact of scattering input parameters
    - Robustness analysis with optiSLang and Motor-CAD
    - Probability density functions for all input parameters
    - Characteristic curves with probability density distribution as output
    - Evaluation of failure cost
  - Postprocessing via Radar chart
- New postprocessing features implemented in optiSLang (signal plot with scattering & radar chart)



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Dr.-Ing. Marc Brück

Senior Expert Simulation Technology

EM-motive GmbH / Postfach 30 02 40 / 70442 Stuttgart

Marc.Brueck@em-motive.com
Phone: +49 711 811 40227