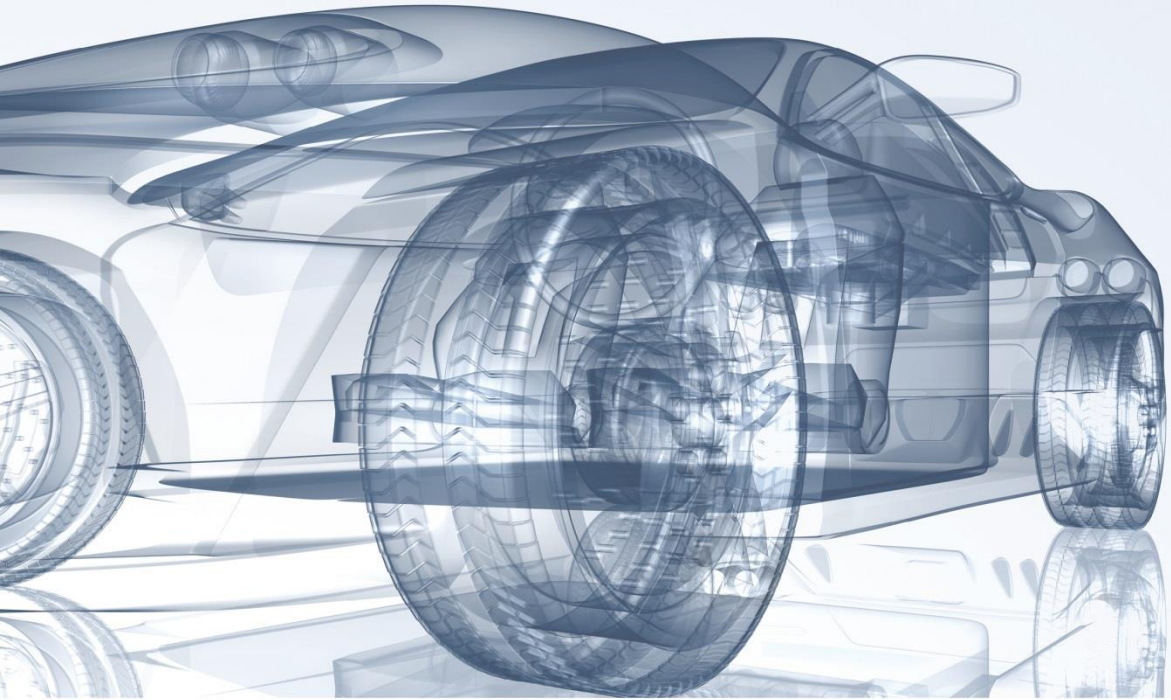
evs 30



The 30th International
Electric Vehicle
Symposium & Exhibition

October 9–11, 2017

Messe Stuttgart, Germany

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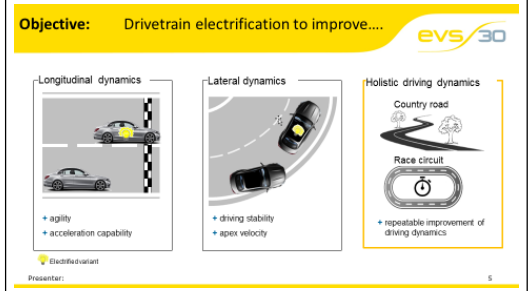
A Method for Quantification of Powertrain Electrification Impacts on Driving Dynamics

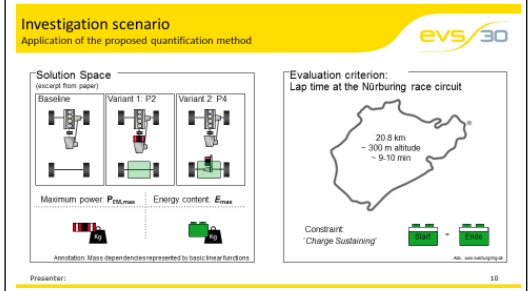
A Method for Quantification of Powertrain Electrification Impacts on Driving Dynamics

Agenda:

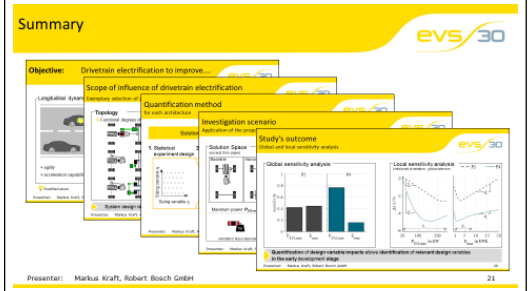
Motivation & Method



Method Application

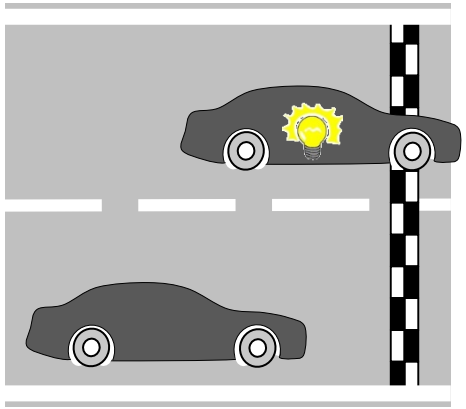


Summary



Motivation:
Drivetrain electrification to improve….

Longitudinal dynamics



+ agility
+ acceleration capability

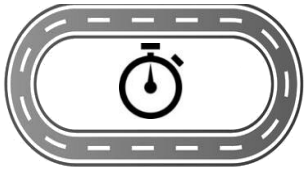
Lateral dynamics

+ driving stability
+ apex velocity

Driving dynamics

Country road

Race circuit



+ repeatable improvement of driving dynamics

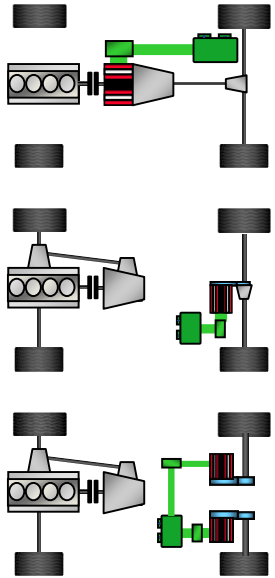
Electrified variant

Scope of influence

Exemplary selection of topology and components

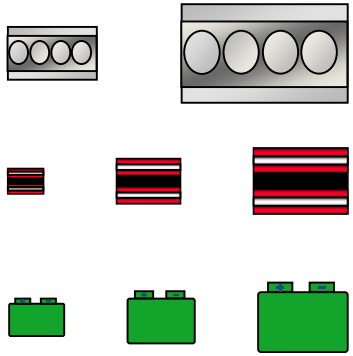
Topology

→ Functional extensions



Sizing

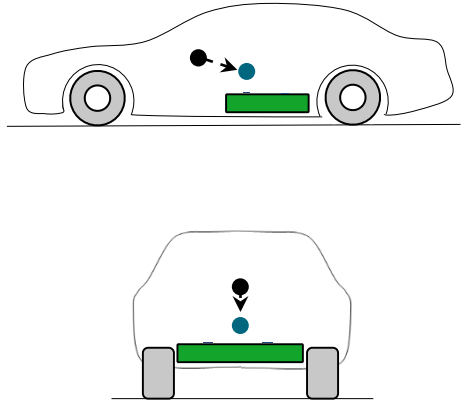
→ performance capability



→ Dependency to component masses

Integration

→ Modification of vehicle characteristics



● Centre of gravity ● modified centre of gravity

System design results in a **wide & complex solution space**.

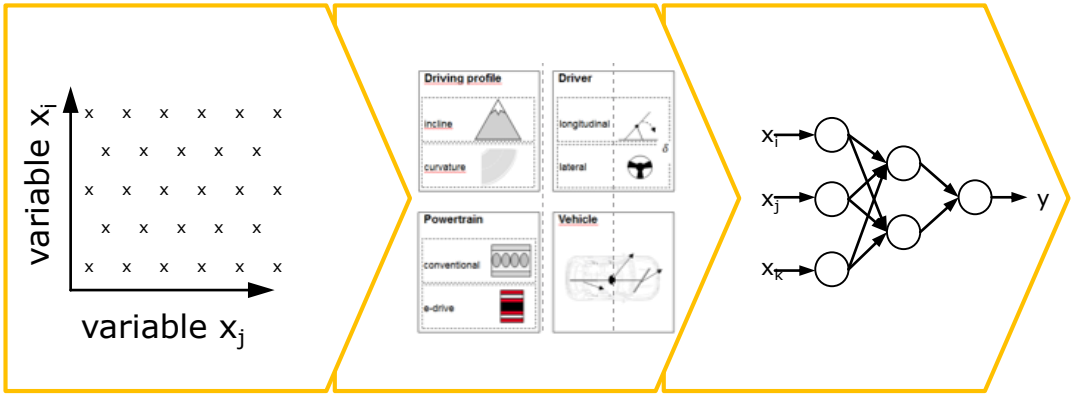
Quantification method
for each topology

Solution space approximation

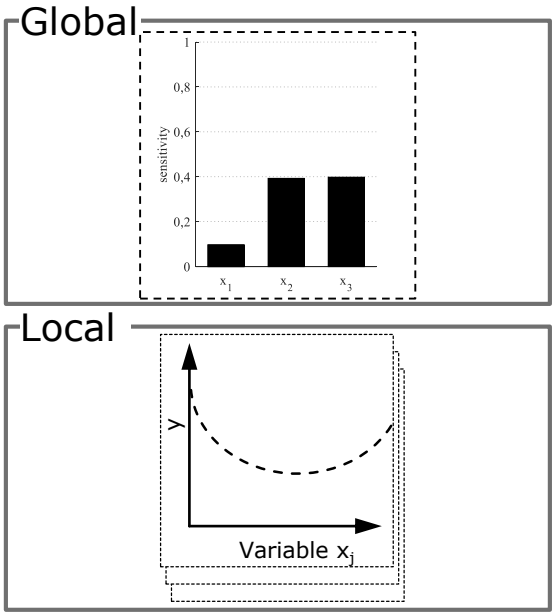
1. Statistical experiment design

2. Simulation-based evaluation

3. Mathematical data model

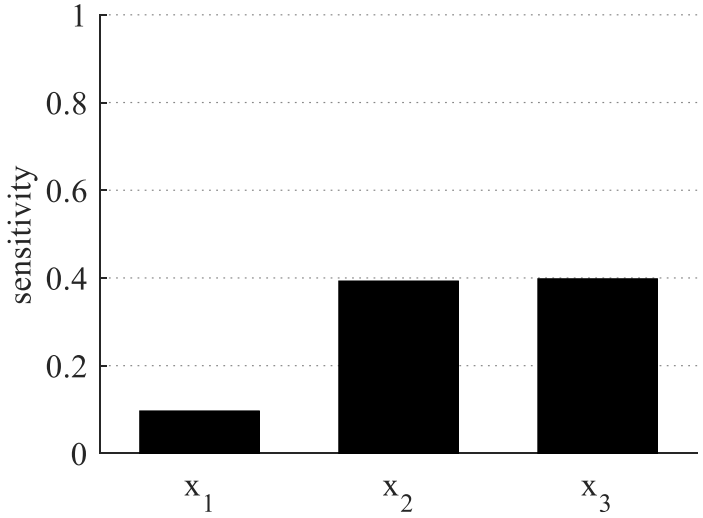


Sensitivity analysis



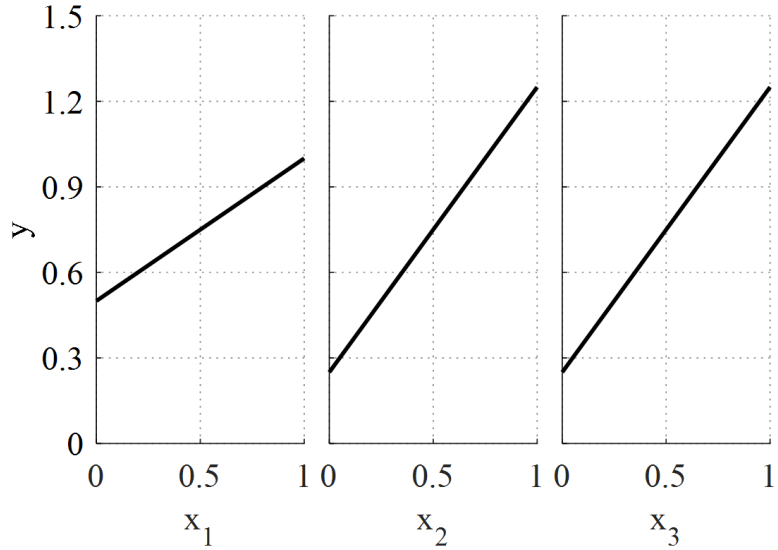
Exemplary function: $y = \frac{1}{2}x_1 + 2 \cdot x_2 \cdot x_3, \qquad x_j \in \{0,1\}$

Global sensitivity analysis



Local sensitivity analysis

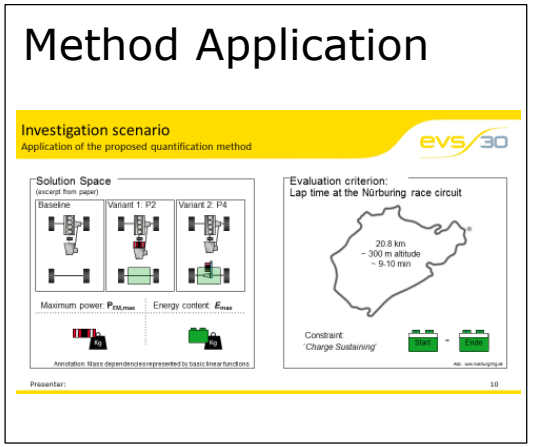
Initial point of variation: $x_j = 0.5$

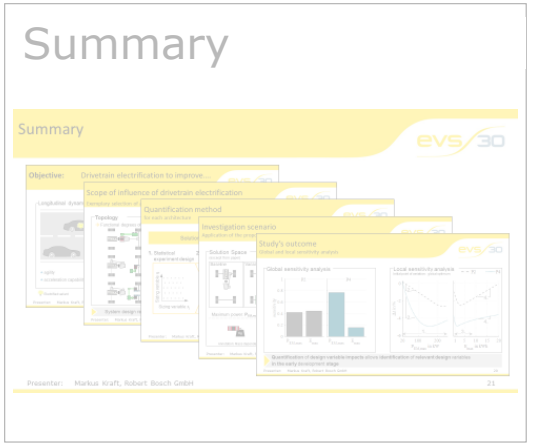


Sensitivity represents the **correlation strength** of design variables & an evaluation criterion.

A Method for Quantification of Powertrain Electrification Impacts on Driving Dynamics

Agenda:



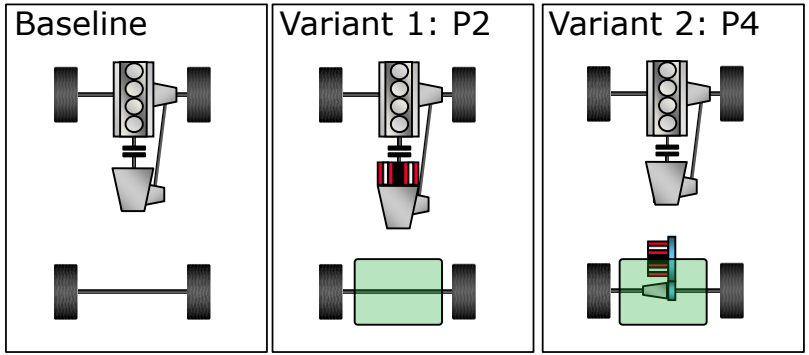


Investigation scenario

Application of the proposed quantification method

Solution Space

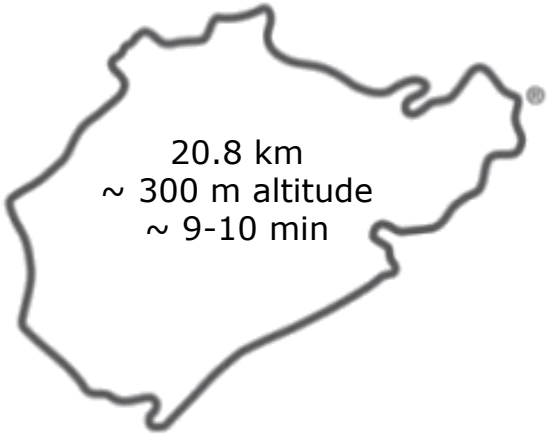
(excerpt from paper)



Annotation: Mass dependencies represented by basic linear functions

Evaluation criterion:

Lap time at the Nürburgring race circuit



Constraint:
'*Charge Sustaining*'

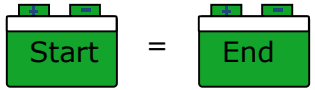
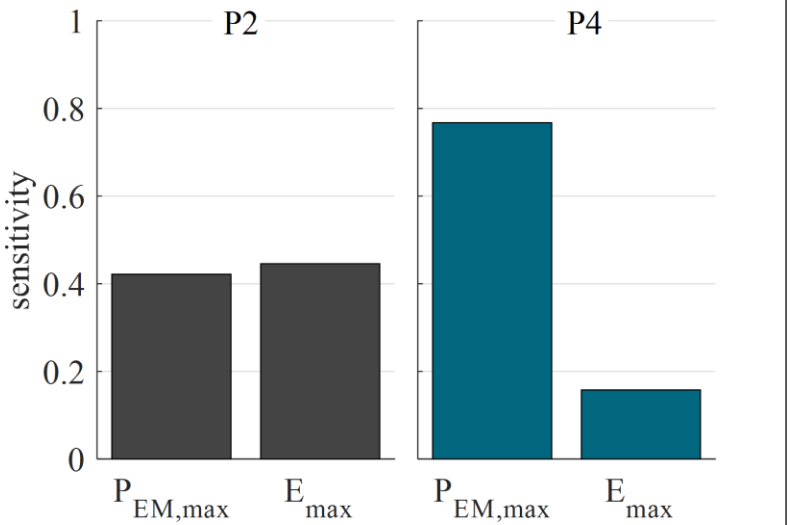


Abb.: www.nuerburgring.de

Study‘s outcome
Global and local sensitivity analysis

Global sensitivity analysis



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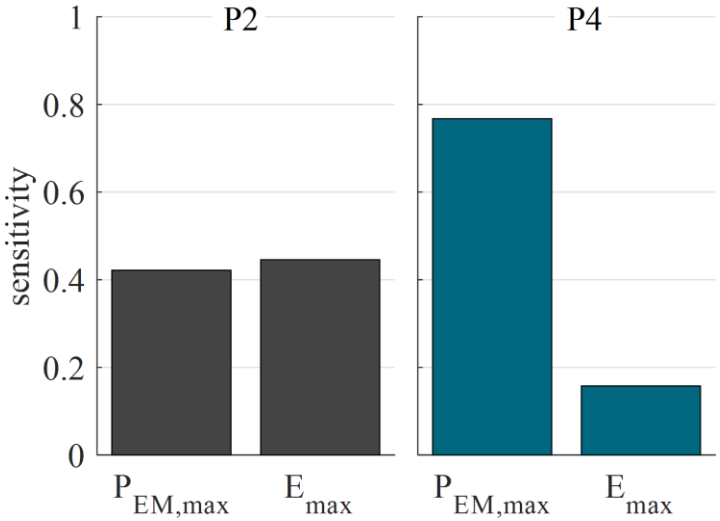
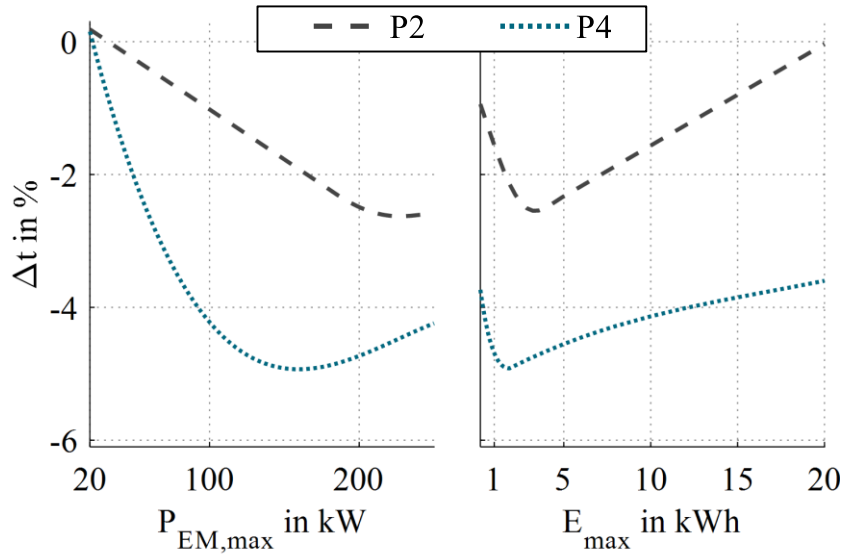


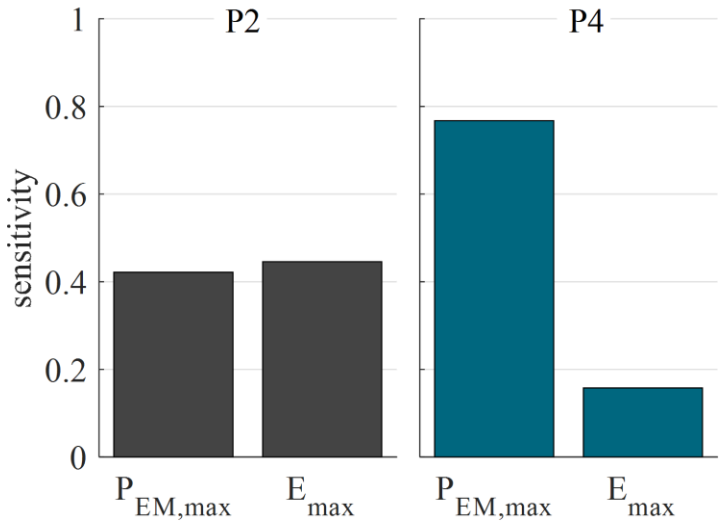
Local sensitivity analysis

Initial point of variation: global optimum



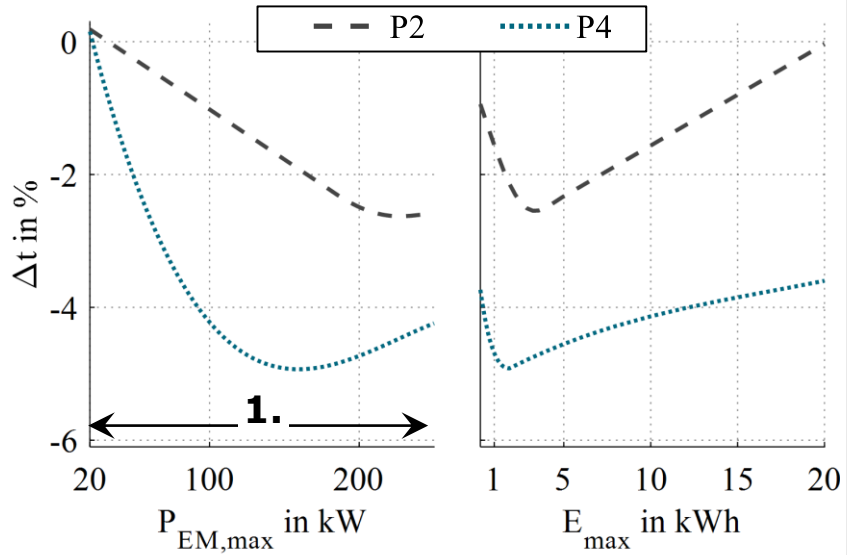
Study‘s outcome
Global and local sensitivity analysis

Global sensitivity analysis



Local sensitivity analysis

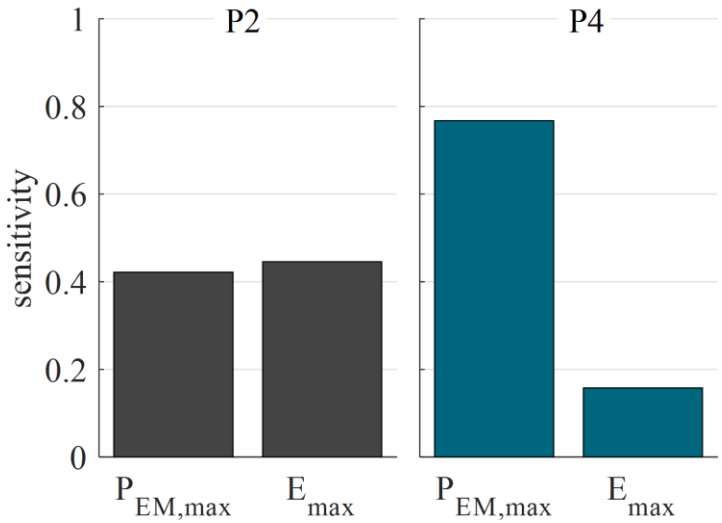
Initial point of variation: global optimum



1. $P_{EM,max}$ Sizing:
   - Lap time increase up to a point of saturation
   - With saturation: Additional mass increase results in lap time reduction

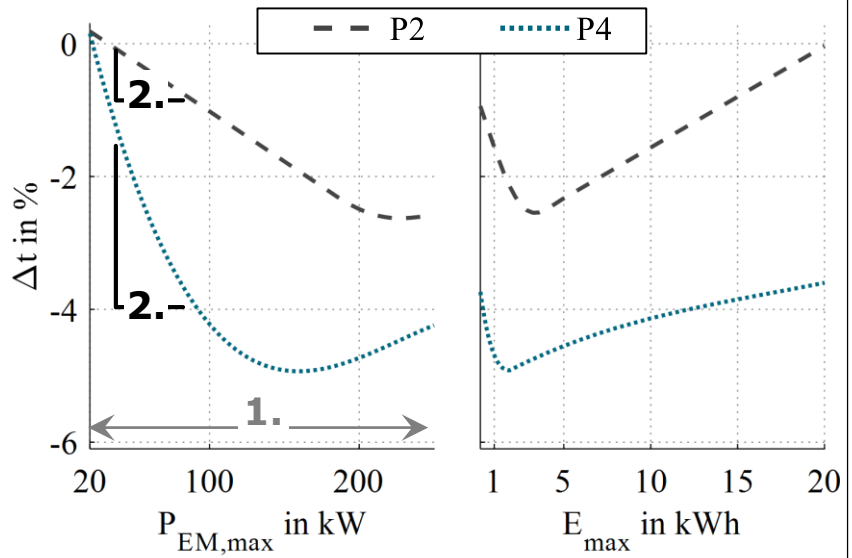
Study‘s outcome
Global and local sensitivity analysis

Global sensitivity analysis



Local sensitivity analysis

Initial point of variation: global optimum

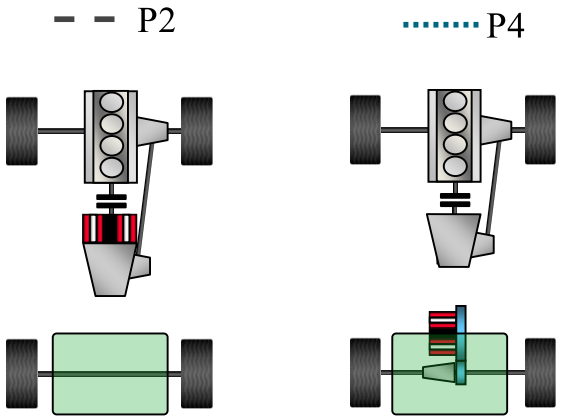


2. $P_{EM,max}$ Sizing:
- Lap time gradients in the area of 20-100 kW are dependent on topology
- Cause: Topology specific traction capability regarding electric machine

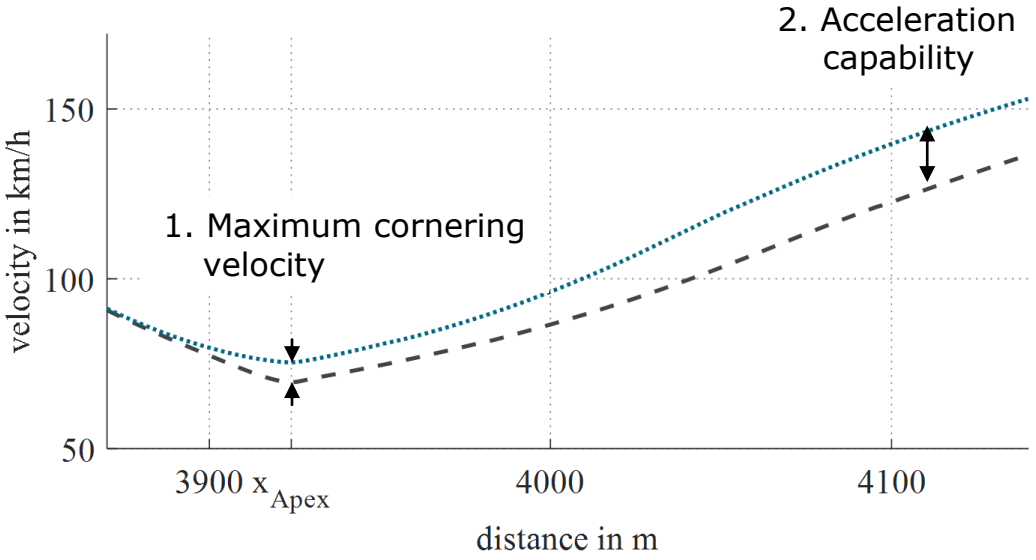
Impact of power sizing & topology

Topology specific capabilites

Topology



Example: Cornering maneuver for same sizing

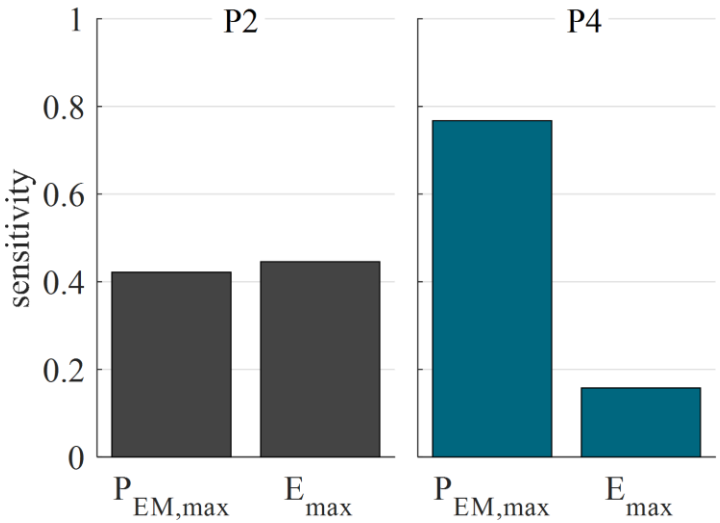


P2: Electric Machine can just utilize traction at the front wheels, which is not used by the engine

P4: Electric Machine can utilize the whole rear axle traction

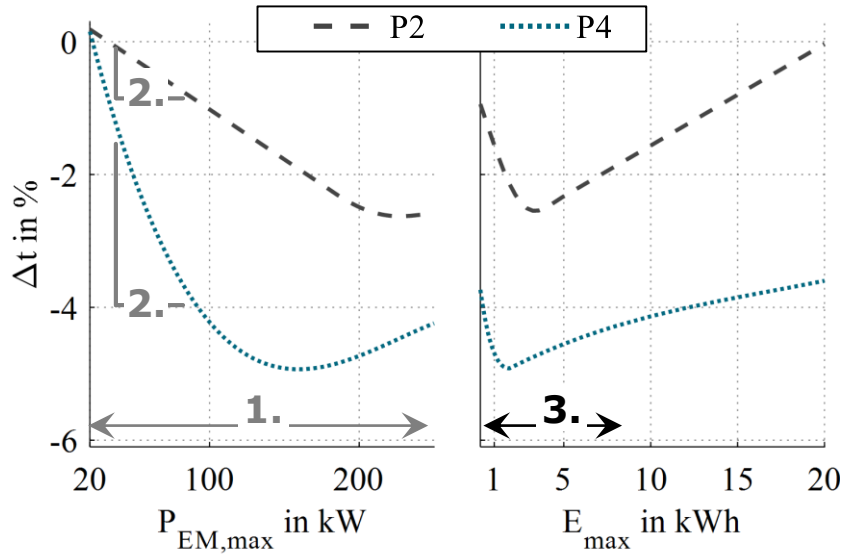
Study‘s outcome
Global and local sensitivity analysis

Global sensitivity analysis



Local sensitivity analysis

Initial point of variation: global optimum

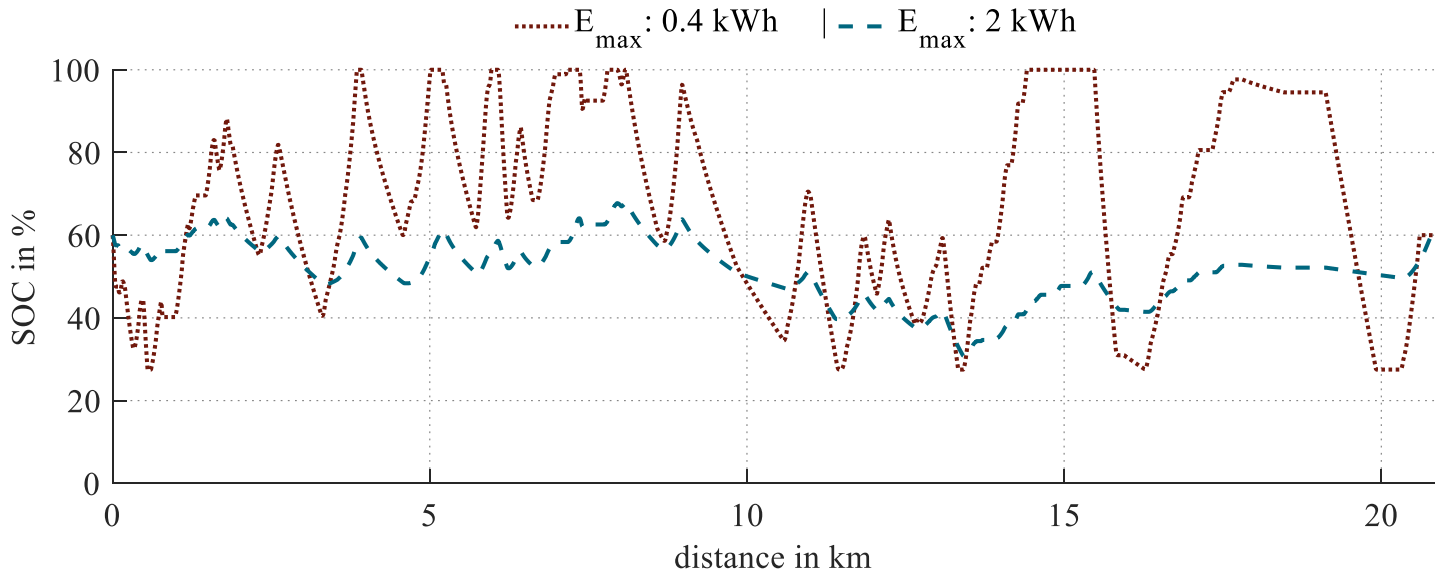


3. E_{max} Sizing: - Small sizings cause functional restrictions
- Bigger sizings results in overdimensioning (additional masses without functional benefit)

Impact of energy content sizing

Functional restriction due to small energy content sizing

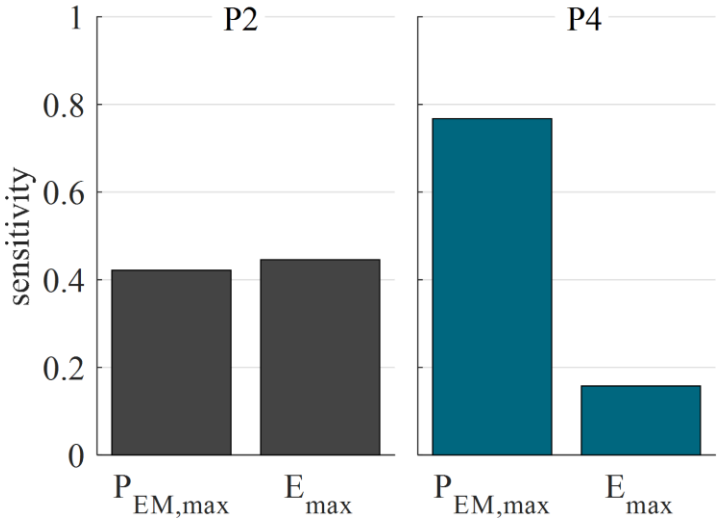
Battery's State-of-Charge over the distance



Functional restriction: Limitations of the recoverable electrical energy results in a limitation of the applicable electrical energy

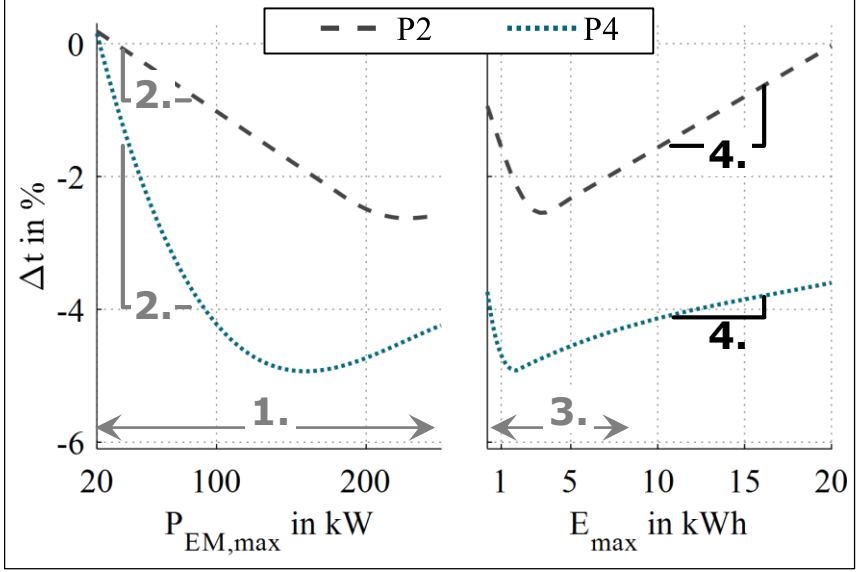
Study‘s outcome
Global and local sensitivity analysis

Global sensitivity analysis



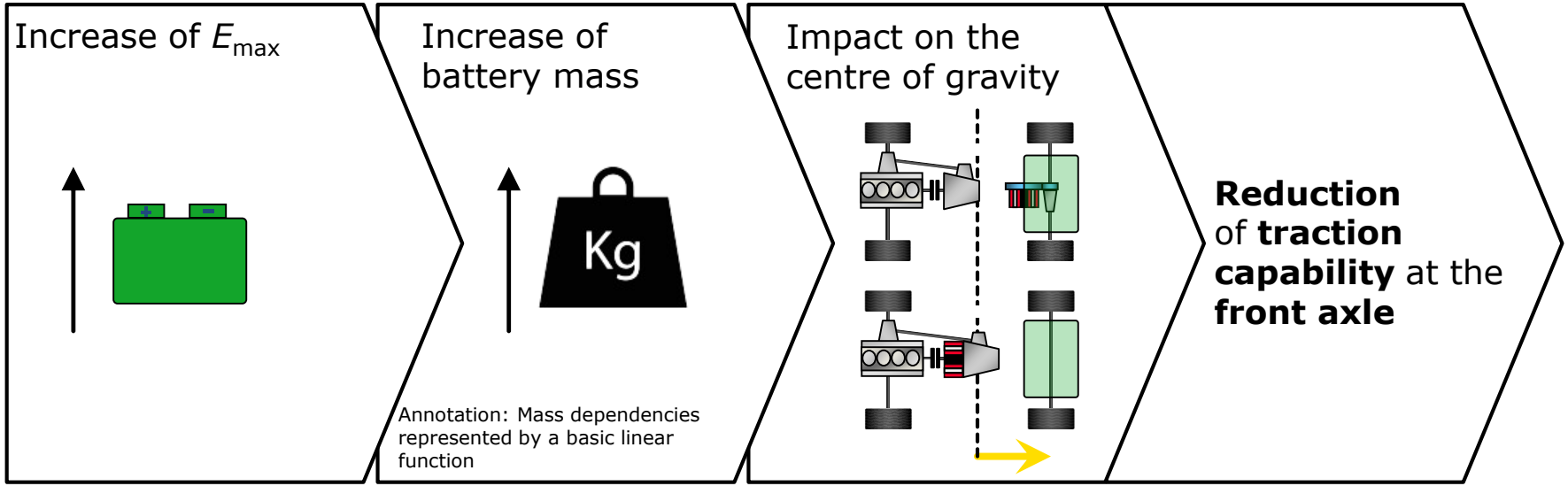
Local sensitivity analysis

Initial point of variation: global optimum



4. E_{max} Sizing:
- Topology specific gradients in the area of overdimensioning
- Cause: Battery integration impacts on the traction capability

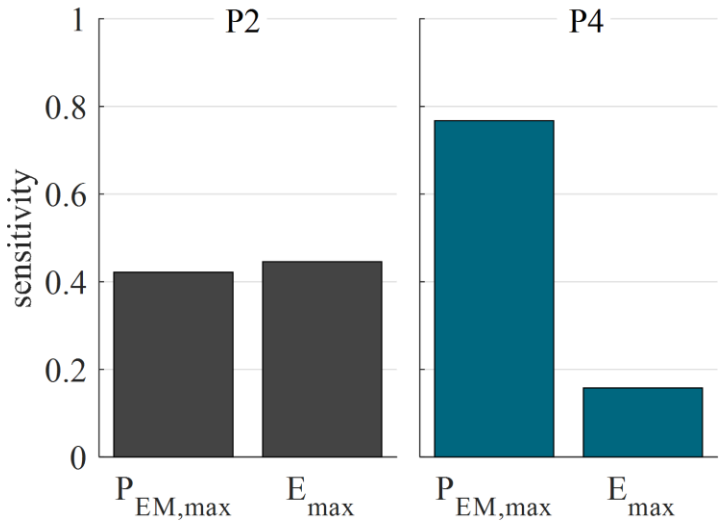
Impact of energy content sizing
due to battery integration at the rear axle



Reduction of traction capability at the front axle can not be compensated in the P2 topology

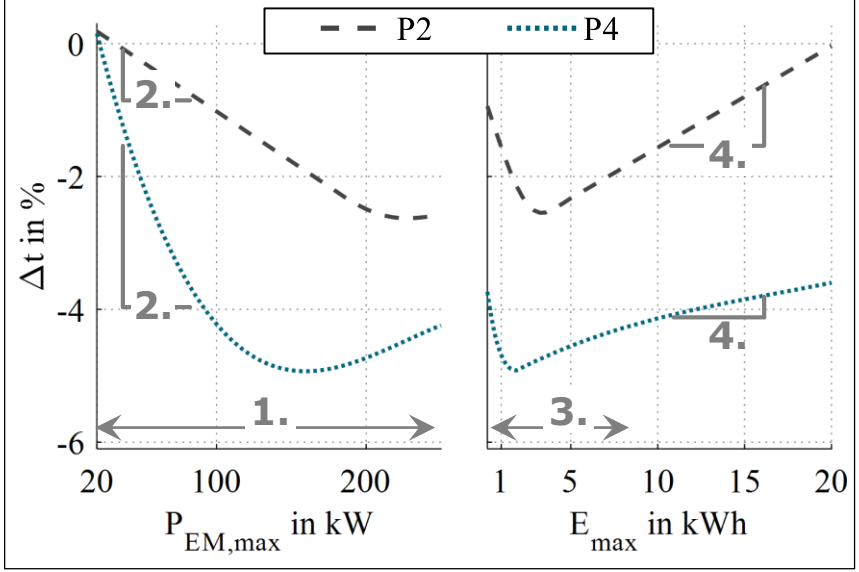
Study‘s outcome
Global and local sensitivity analysis

Global sensitivity analysis



Local sensitivity analysis

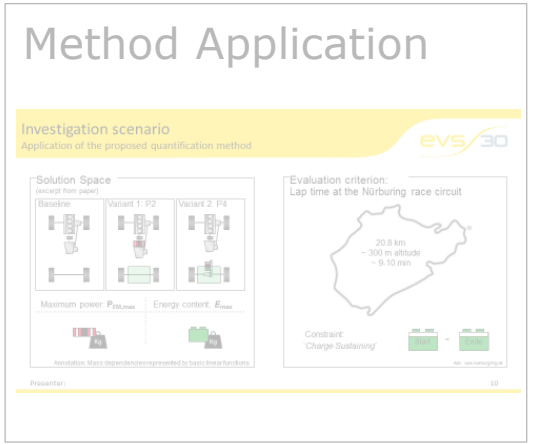
Initial point of variation: global optimum

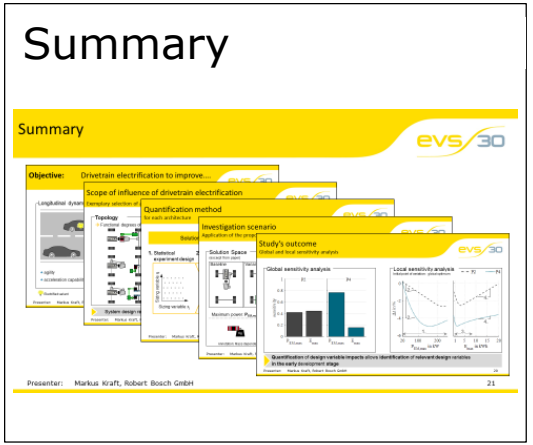


Quantification of **design variable impacts** allows **identification** of **relevant design variables in the early** development **stage**

A Method for Quantification of Powertrain Electrification Impacts on Driving Dynamics

Agenda:

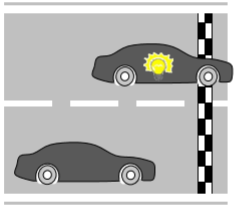




Summary

Objective:
Drivetrain electrification to improve….

Longitudinal dynamics



+ agility
+ acceleration capability

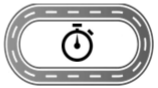
Lateral dynamics

+ driving stability
+ apex velocity

Driving dynamics

Country road

Race circuit



+ repeatable improvement of driving dynamics

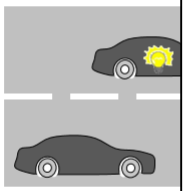
Electrified variant

Presenter: Markus Kraft, Robert Bosch GmbH 3

Summary

Objective:
Drivetrain electrification to improve

Longitudinal dyna



+ agility
+ acceleration capabil

Electrified variant

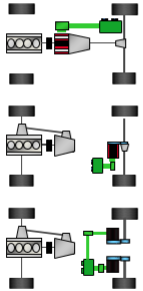
Presenter: Markus Kraft, Ro

Scope of influence: design variables

Exemplary selection of architecture and components

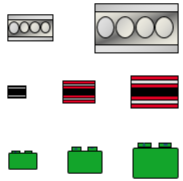
Topology

→ Functional extensions



Sizing

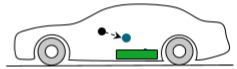
→ performance capability



→ Dependency to component masses

Integration

→ Modification of vehicle characteristics



Centre of gravity modified centre of gravity

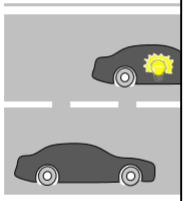
System design results in a wide solution space.

Presenter: Markus Kraft, Robert Bosch GmbH 4

Summary

Objective:
Drivetrain electrification to improve

Longitudinal dyna



+ agility
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Electrified variant

Presenter: Markus Kraft, Ro

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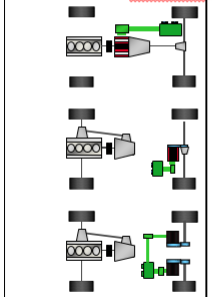
→ Functional extension



System design r

Presenter: Markus Kraft, Ro

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1. Statistical experiment design
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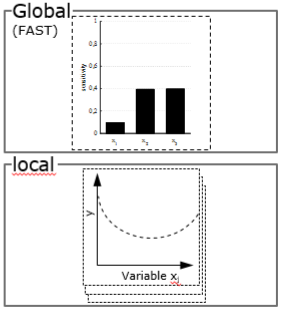
3. Mathematical data model

Sensitivity analysis



Presenter: Markus Kraft, Robert Bosch GmbH 6

Summary

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Drivetrain electrification to improve

Longitudinal dyna

+ agility
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Presenter: Markus Kraft, Ro

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System design r

Presenter: Markus Kraft, Ro

Quantification method
for each architecture

Solution s

1. Statistical experiment design
2. Si ev

Sizing variable x_i
Sizing variable x_j

Presenter: Markus Kraft, Ro

Investigation scenario
Application of the proposed quantification method

Solution Space
(excerpt from paper)

Baseline	Variant 1: P2	Variant 2: P4

Maximum power: $P_{EM,max}$ Energy content: E_{max}

Kg Kg

Annotation: Mass dependencies represented by basic linear functions

Evaluation criterion:
Lap time at the Nürburing race circuit

20.8 km
~ 300 m altitude
~ 9-10 min

Constraint:
'Charge Sustaining'

Start = Ende

Abb.: www.nuerburgring.de

Presenter: Markus Kraft, Robert Bosch GmbH 9

Summary

Objective:
Drivetrain electrification to improve

Longitudinal dyna

+ agility
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Presenter: Markus Kraft, Ro

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Sizing variable x_j

Presenter: Markus Kraft, Ro

Investigation scenario
Application of the proposed quantification method

Solution Space
(excerpt from paper)

Baseline
Variant

Maximum power: $P_{EM,m}$

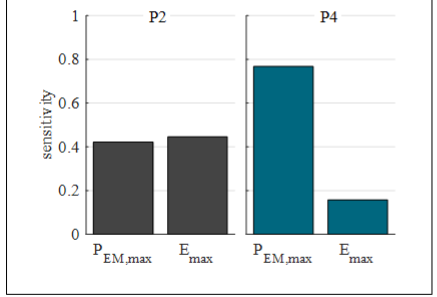
Kg

Annotation: Mass dependencies r

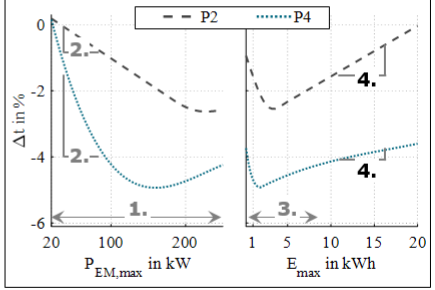
Presenter: Markus Kraft, Ro

Study's outcome
Global and local sensitivity analysis

Global sensitivity analysis



Local sensitivity analysis
Initial point of variation: global optimum



Quantification of **design variable impacts** allows **identification** of **relevant design variables in the early** development **stage**

Presenter: Markus Kraft, Robert Bosch GmbH 19

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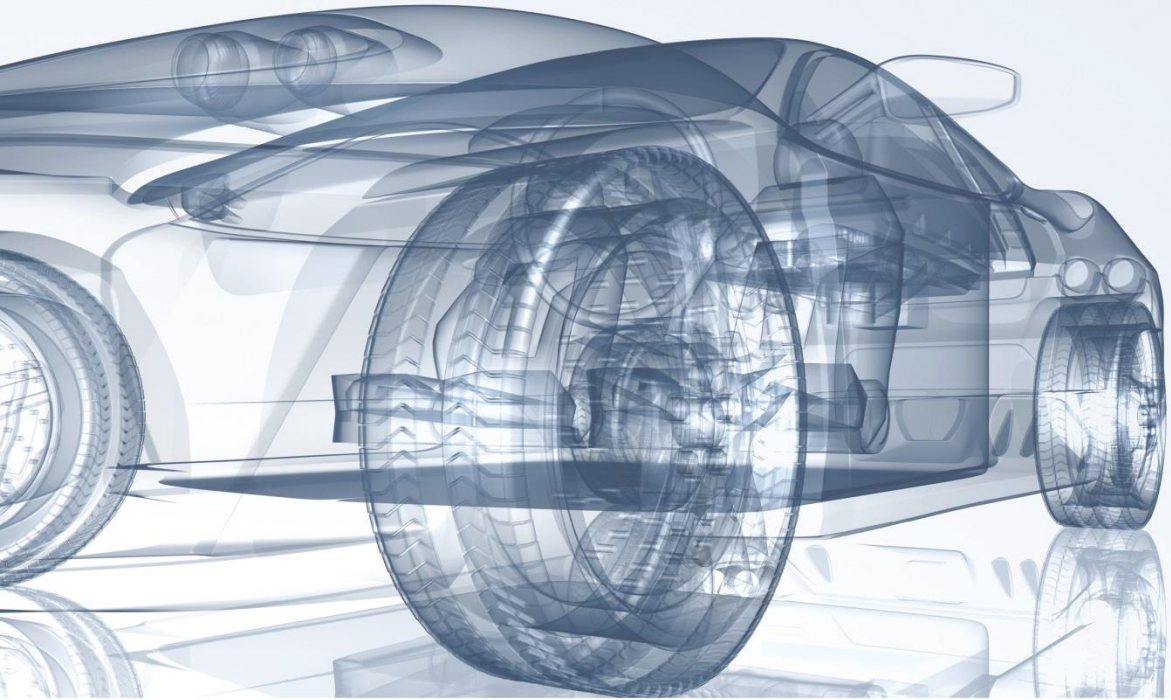

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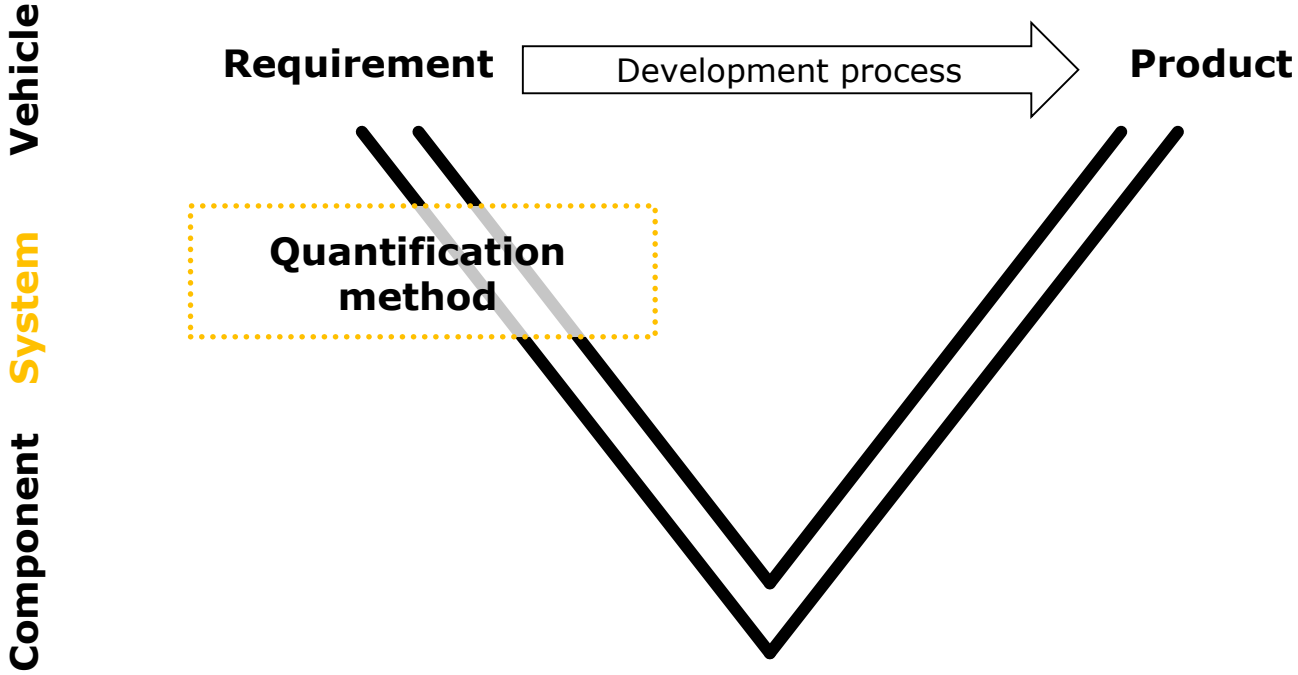
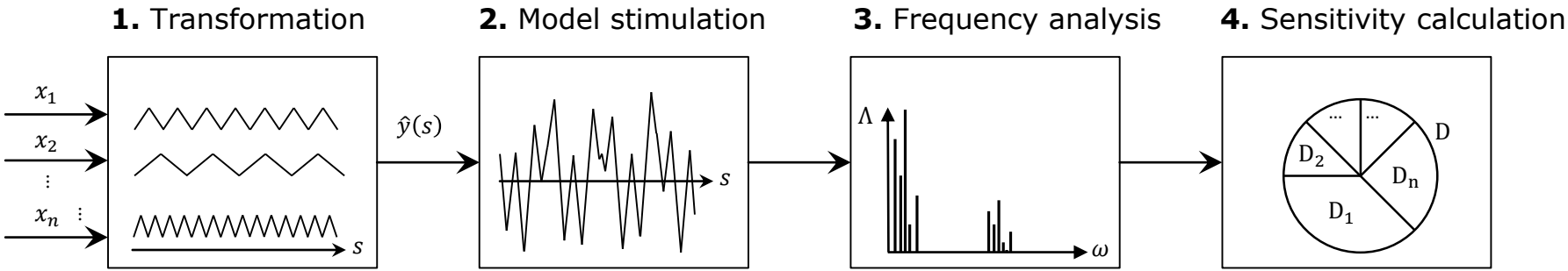
Objective:
Understanding of design variables impacts



Global sensitivity analysis using *‚Fourier Amplitude Sensitivity Test‘*



$$\hat{x}_j = G_j[\sin(\omega_j \cdot s)]$$

$$\hat{y}(s) = f\left(\hat{x}_j(s)\right)$$

$$\hat{S}_j = \frac{\hat{D}_j}{\hat{D}} = \frac{\sum_{k=1}^{+\infty} \Lambda_{k\omega_j}}{\sum_{k=1}^{+\infty} \Lambda_k}$$

ω_i - frequency

G_i - transformation function

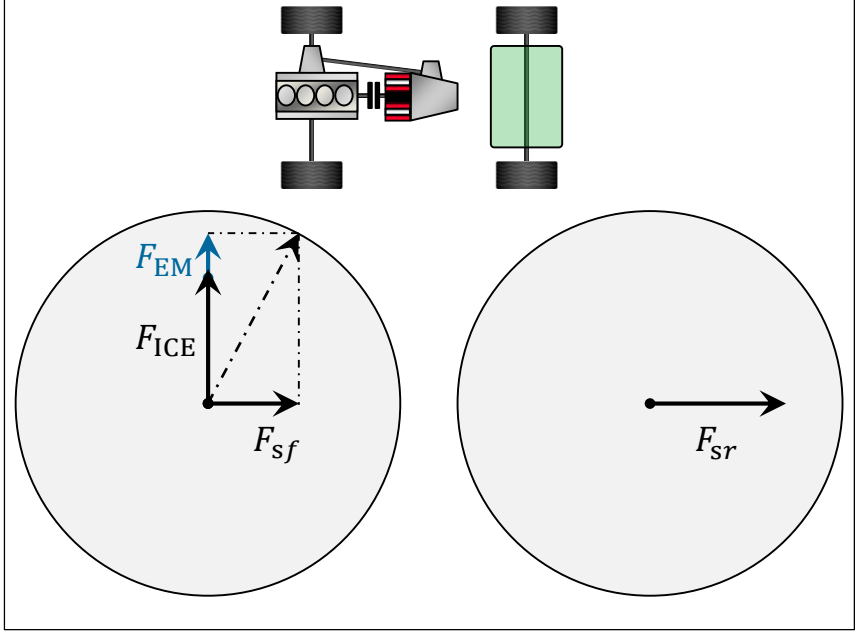
s – compensatory variable

Λ - amplitude

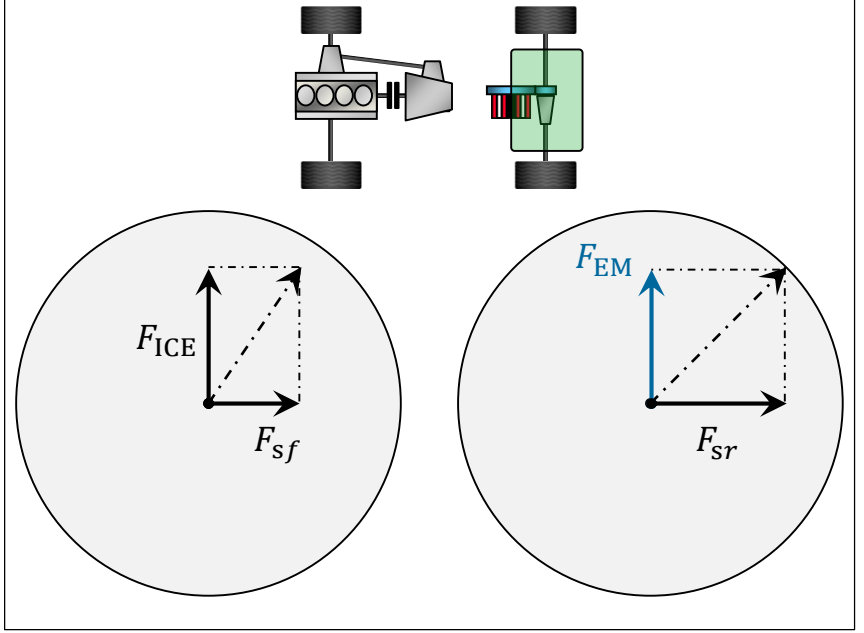
$\hat{S}_j$ - sensitivity

Impact of maximum power sizing: Wheel forces while cornering (Kamm'scher circle)

Traction capability: P2



Traction capability: P4



F_{ICE} – Traction force of the internal combustion engine

F_{EM} – Traction force of the electrical motor

$F_{sf/r}$ – Lateral force at the front or rear axle