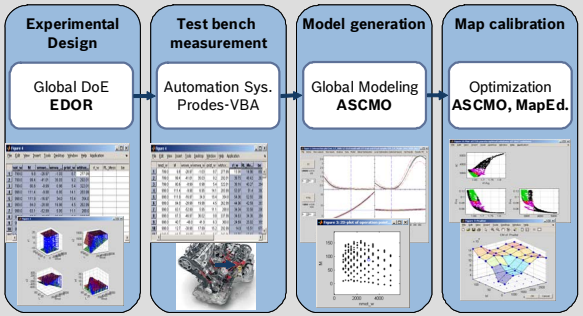
Usage of Design of Experiments

Current Examples of Modern ECU Calibration



Thorsten Huber, Bosch Engineering GmbH

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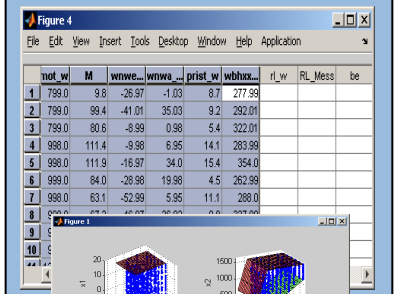
Overview

- **Design of Experiments (DoE) at Bosch Engineering GmbH (BEG)**
- Current example – Diesel
- Current example – Gasoline
- Further examples and Conclusion

Bosch group-wide available DoE-Toolchain

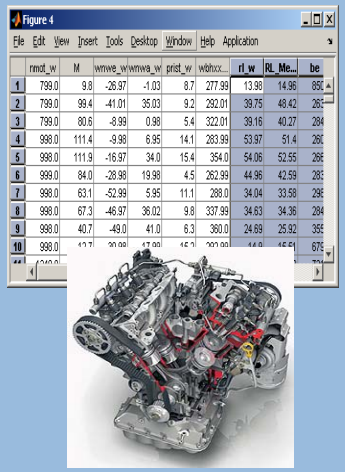
Experimental Design

Global DoE
EDOR



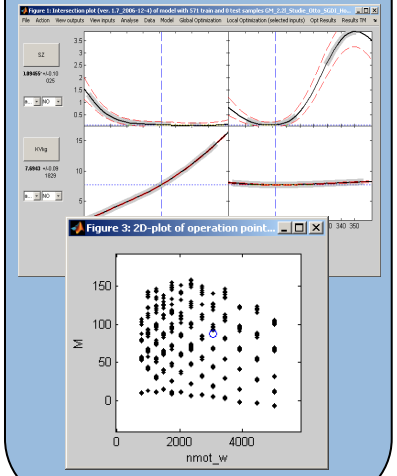
Test bench measurement

Automation Sys.
Prodes-VBA



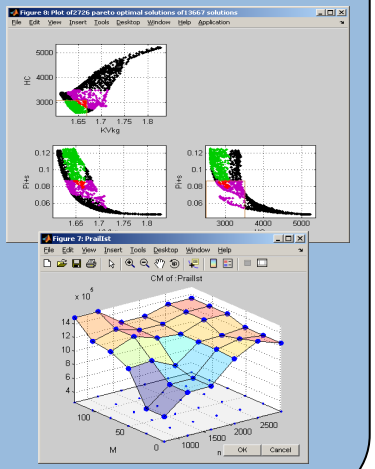
Model generation

Global Modeling
ASCMO



Map calibration

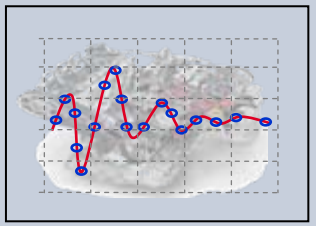
Optimization
ASCMO, MapEd.



Design of Experiments (DoE) at BEG

- Bosch Engineering GmbH has access to tools and methods of the Bosch Group
- As a development partner BEG participates in advancements and adaptations of the tool chain
- On the basis of the available tools/methods BEG-specific solutions are constantly being developed
- Besides the classic DoE tasks the algorithms could also be used for other areas of application

Next, two examples of the implementation of DoE will be shown for diesel as well as spark-ignition engines



Overview

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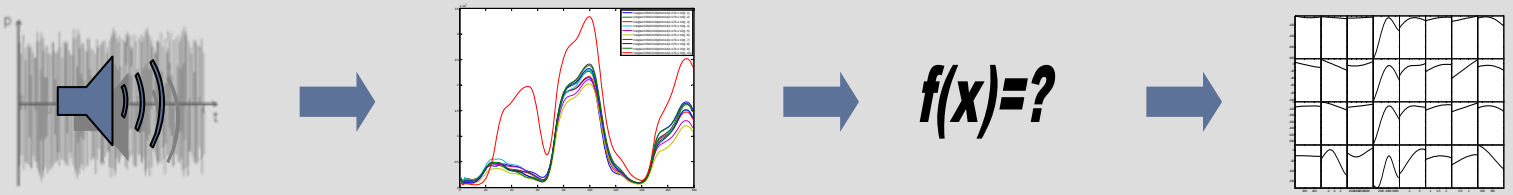
Rating/Optimization of engine noise (Diesel)

Objectives

- Definition of a measurable value based on physical dimensions (quality criterion) which meets the human sound feeling
- Make the character of the engine noise (during low-idle) available as another emission value during engine optimization

Challenges

- Subjective rating of the engine acoustics
- Strong interactions of the influencing parameters
- Compromise between acoustics and emission-optimization necessary



Approach for the sound rating

- Modeling of the causes (engine compartment design, arrangement of the components, etc) is replaced by a numeric model of the perceivable dimensions (engine noise)
- A profound understanding of the sound causes is not necessary at the time of the calibration
- Present and influence the correlation of the resulting sound with the available calibration parameters

- Clear simplification of the model complexity
- Clear increase in benefit/effort relation

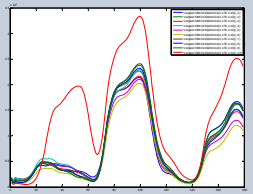
Optimization process

- DoE-Parameter
  - Air mass
  - Rail pressure
  - Start of main injection
  - Start of injection / quantity of both pilot injections
- Create a DoE experimental design
- Take measurements and record the engine noise
- Analyze and evaluate the engine noise with the help of a function specially developed for this case
- Modeling of the dependencies and optimization

Need of modern modeling approaches

- The demands of the task exceed by far the possibilities of the classic polynomial approach
- The algorithms developed by Bosch can be used effectively for two different phases of the development
  - Definition of the evaluation criteria for the sound rating (verify the functional correlations)
  - Modeling of the dependencies and optimization

The availability of modern modeling approaches allows a sufficiently precise representation of the engine acoustics in a regression model



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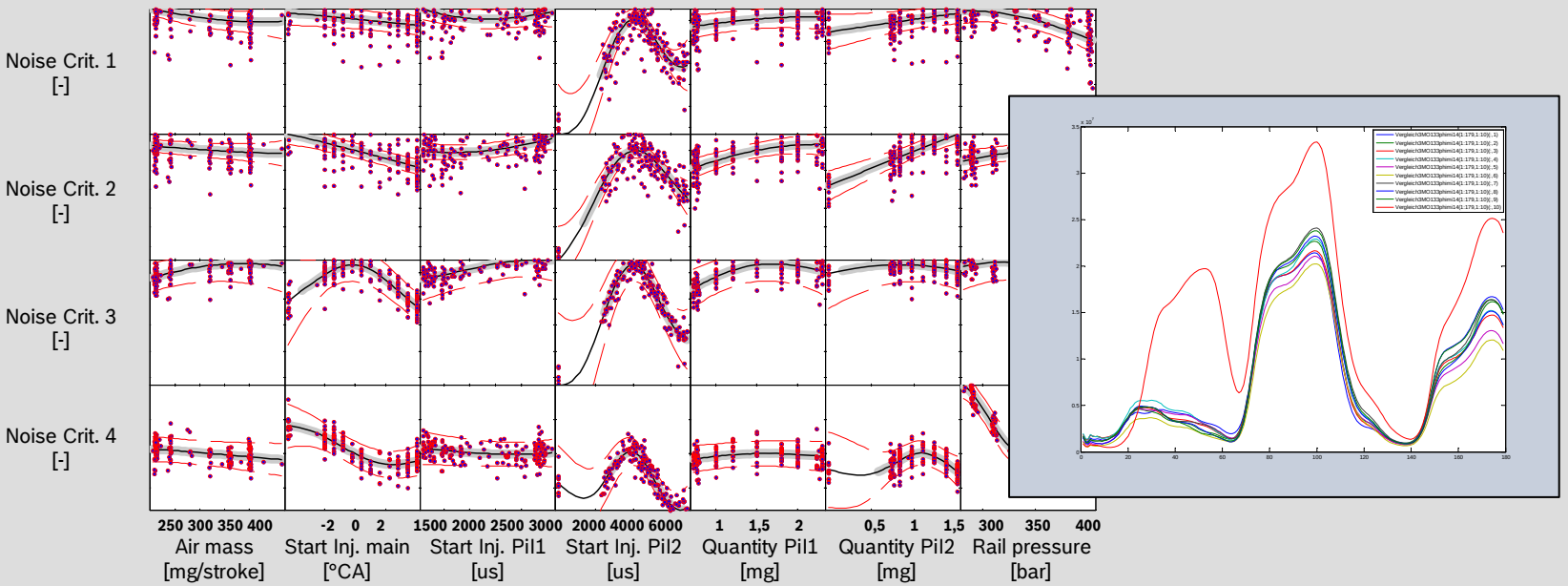
Visualization/Conclusion



- Use of the algorithm for modeling and functional development
- Realization of subjective sound impressions into a measurable dimension
- Intensified use of statistic learning process for a finer structuring of individual criteria → automated optimization

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Idle optimization with DoE (Gasoline)

Objective

- Optimization of engine run during idle speed with respect to standard deviation of engine speed and LVZ*

Boundary conditions

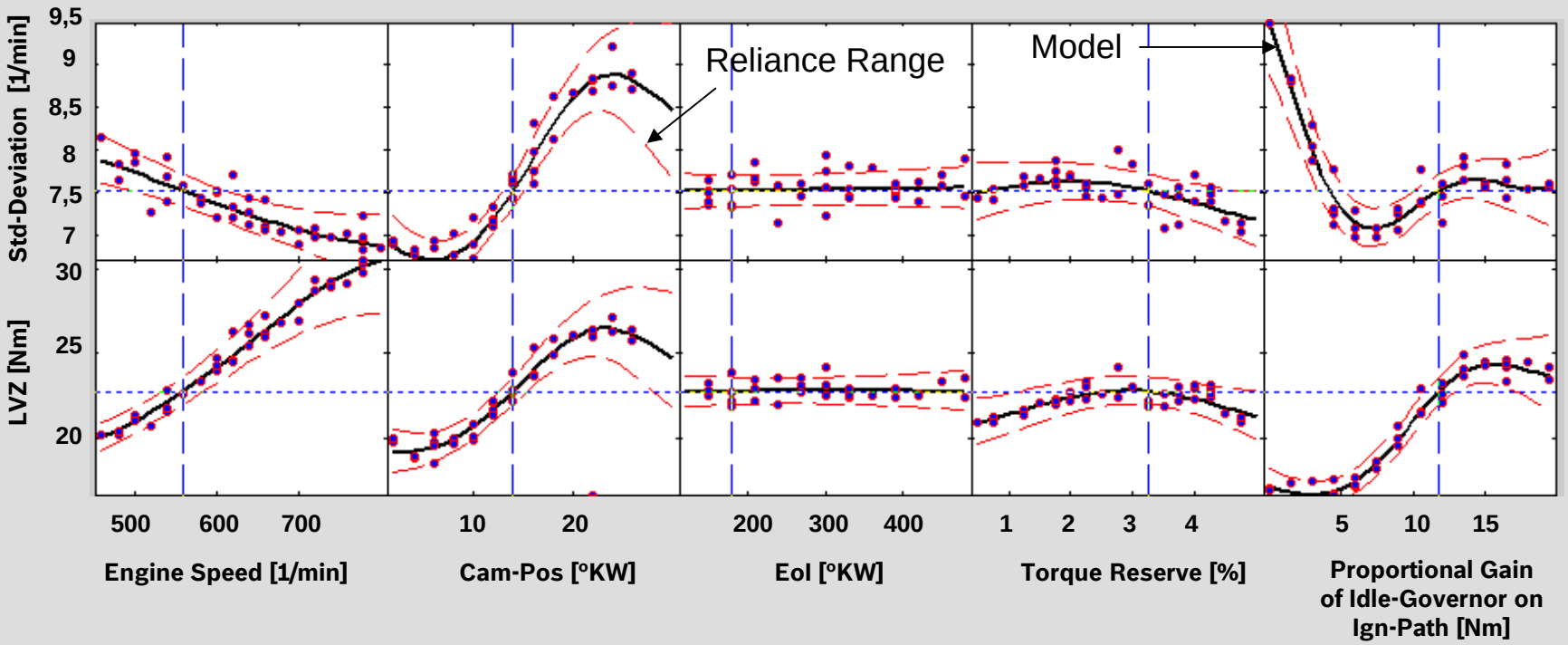
- Warm engine
- No additional load
- Engine fan off

*LVZ (idle-vibration-number) is the frequency weighted engine speed gradient according to Norm VDI2057 Wk, multiplied with the engine flywheel mass. In this case, the influence of the flywheel mass can be considered as a constant, as it is not varying within the measurements.

Optimization process

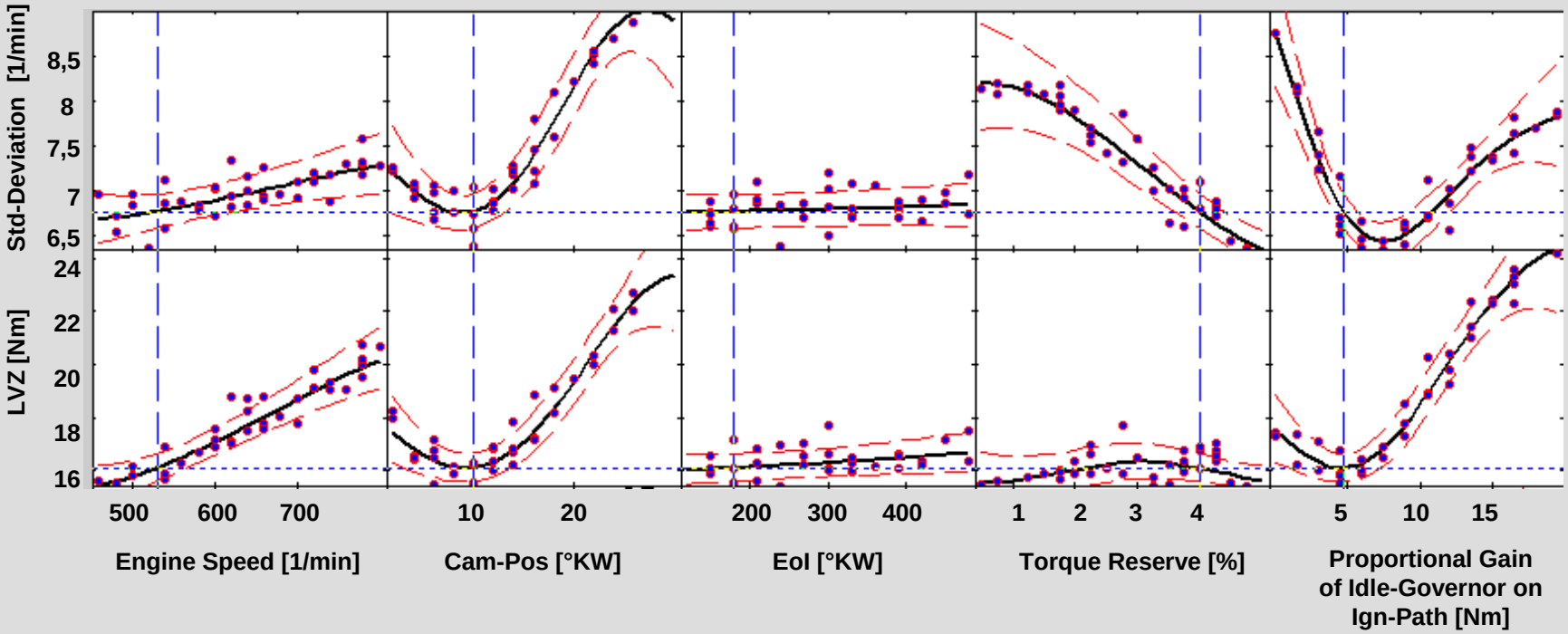
- DoE-Parameter
  - Engine speed
  - Camshaft position
  - Injection timing
  - Torque-Reserve
  - P-Gain of idle-governor on ignition-path
- Create a DoE experimental design
- Take measurements and record the idle speed behavior
- Analyze and evaluate the idle speed with the help of a tool specially developed for this case
- Modeling of the dependencies and optimization

Before model-based optimization



- Standard Deviation: 7,5 1/min
- LVZ: 22,8 Nm
- Engine Speed: 560 1/min
- Torque-Reserve: 3.25 %

After model-based optimization



- Standard Deviation: 6,8 1/min
- LVZ: 16,1 Nm
- Engine Speed: 530 1/min
- Torque-Reserve: 4 %

Summary

- Quality improvement due to objective quality factors
- Reliable and efficient detection of the optimum
- Basis for discussions with the customer

Forecast

- Considering resonance frequency of the peripheries
- Fully automated

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Further examples of DoE practices

- Base calibration (emissions, fuel consumption, etc.)
- Catalyst heating
- Diesel Particulate Filter (DPF) Regeneration
- Parallel optimization oil dilution/soot
- Calibration of governors
  - Temperature
  - Boost-Pressure
- Multiple injection strategies
- Robustness

Conclusion

- Bosch Engineering GmbH uses the available modular tools and methods of the Bosch Group
- A wide range of cases are processed with the DoE-method
- On the basis of the available tools/methods BEG-specific solutions are constantly being developed
- The experiences won thereby flow back into the tool development
- Besides the classic DoE tasks, the algorithms are also used for other areas of application

The use of DoE methodology is an inherent part of the calibration and development activities in many different areas of application at Bosch Engineering GmbH.

Thank you for your attention!