WEIMARER OPTIMIERUNGS- UND STOCHASTIKTAGE 2016

# EXAMPLES OF PRODUCT ENGINEERING WITH OPTISLANG AT DIESEL SYSTEMS

DR. RAINER KECK
ROBERT BOSCH GMBH, DIESEL SYSTEMS

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# Agenda

- Diesel by Bosch
- Motivation/ Product Engineering
- Examples:
  - » Robustness of emissions by exhaust gas recirculation (EGR) against variation of pilot injection quantity
  - » Analysis of an experimental DOE concerning valve wear
  - » Impact on scatter of dosing quantity using two dosing modules for achieving the requested large dosing quantity for DENOX exhaust gas treatment system (selective catalytic reduction; SCR)
  - » Strategy of an optimal task schedule at limited resources
- Conclusion



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# Robert Bosch GmbH
# Division Diesel Systems (DS)

## Bosch facts 2015:

- Turnover:
  - 70.6 billion EURO
  - Germany: 20%
- EBIT: 6.5%
- Equity: 34.4 billion
- R&D: 9%
- Employees
  - 374.778 (end 2015)
  - Germany: 35%

## Business sectors

- Mobility Solutions
  - Diesel Systems
  - Gasoline Systems
  - Chassis Systems Ctr.
  - Electrical Drives
  - Autom. Electronics
  - Autom. Steering ...
- Consumer Goods
- Industrial Technology
- Energy and Building Technology

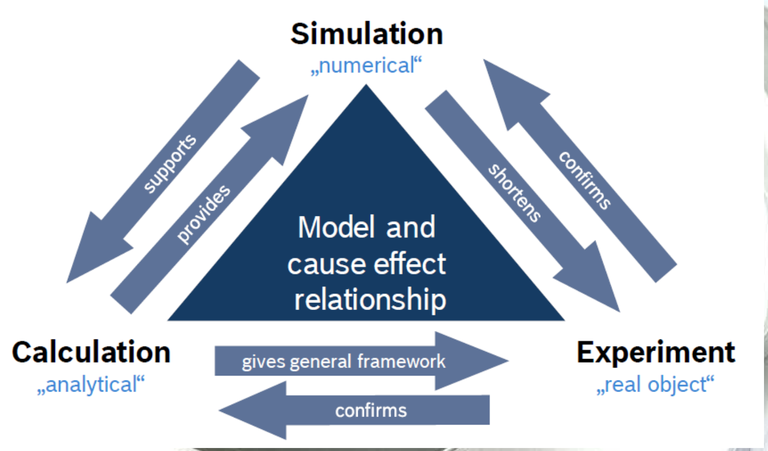
## Products at DS

- Fuel injection systems
- Exhaust gas treatment systems
- Sensors
- Starter systems
- Electronic control units

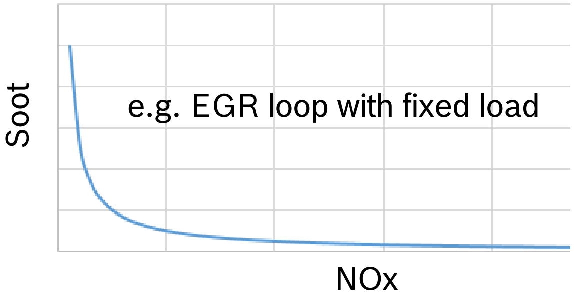
# Motivation
## Product Engineering (PE, excerpt)

- **Target:**
  Successful product engineering at Bosch
- **Task:**
  One focal point of PE is the understanding of all relevant cause effect relationships
- **Principles/ Elements:**
  - Understand products: We fully understand our product designs and production processes using suitable models describing their properties
  - Robustness
  - Reliability

1 mm



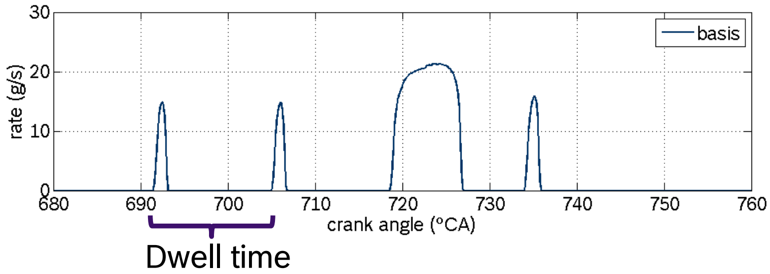
# Ex. 1: Robustness of EGR
## Task




- Engine emissions (NOx, soot, noise) are essentially influenced by
  - » Exhaust gas recirculation (EGR), i.e. mixing exhaust gas into fresh cylinder air
  - » Fuel injection pattern consisting of several pilot, main and post injections per plunger lift
- Engine application task:
  Satisfy the torque request subject to constraints like emission limits, fuel consumption, comfort, driving pleasure
- Robustness request:
  Keep the effect of tolerances within acceptable limits
- Task:
  Quantify the influence of pilot injection quantity variation on the engine emissions

# Ex. 1: Robustness of EGR
## Model

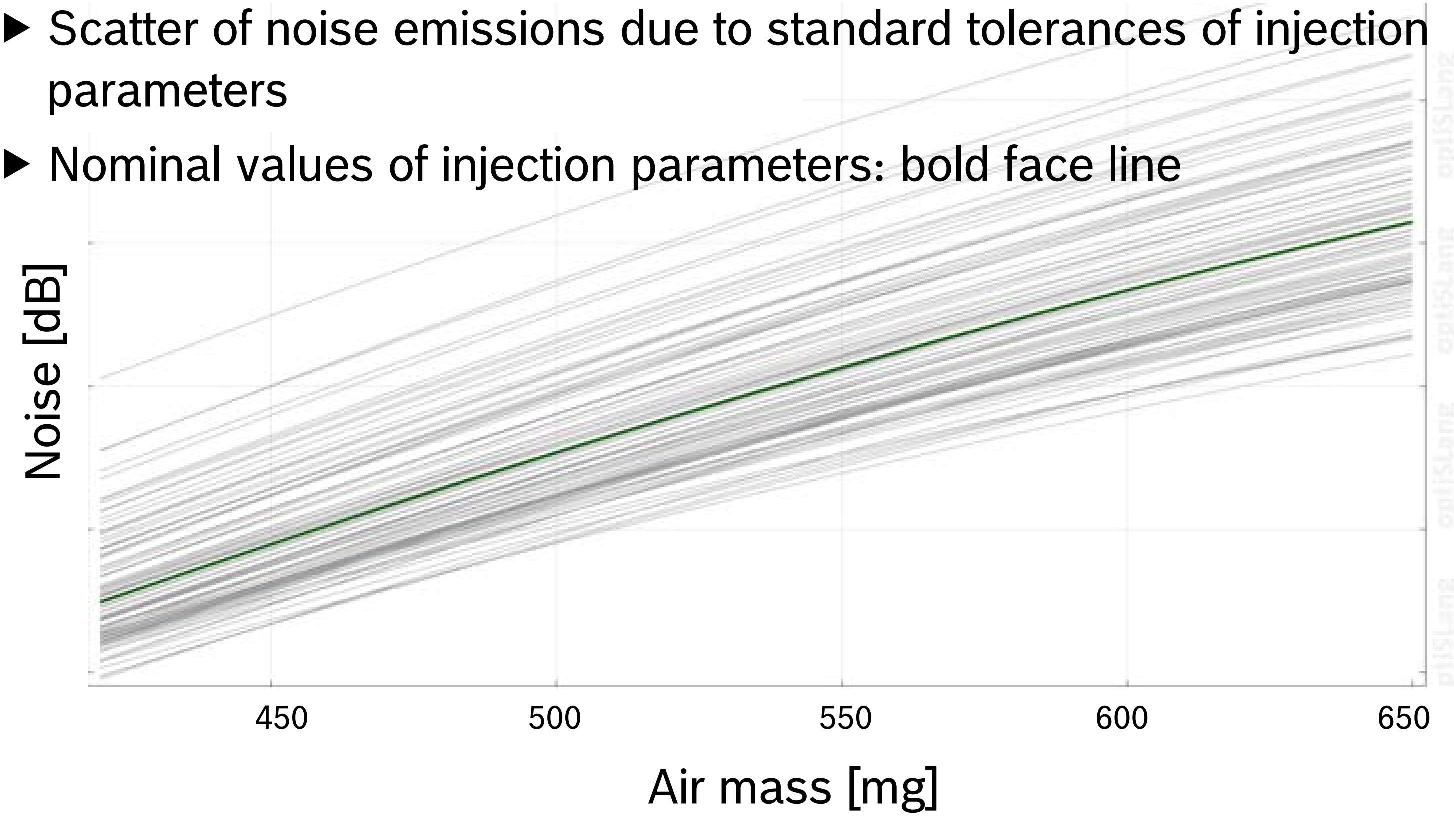
- Effect of exhaust gas recirculation is quantified by measurements
- Since the parameter space of EGR is very large a metamodel based on measurement results is used (ASCMO®)
- EGR is varying air mass between 420mg and 650mg
- Four injection parameters are considered (input parameters)
  - » Injection quantities of 1st and 2nd pilot injection (PI)
  - » Dwell time (‘Spritzabstand’) between 1st and 2nd PI as well as 2nd PI and main injection




- Output parameters:
  - » Noise
  - » NOx
  - » Soot
- Following parameters are kept constant: $CO_2$, injection pressure, air load pressure, start of injection

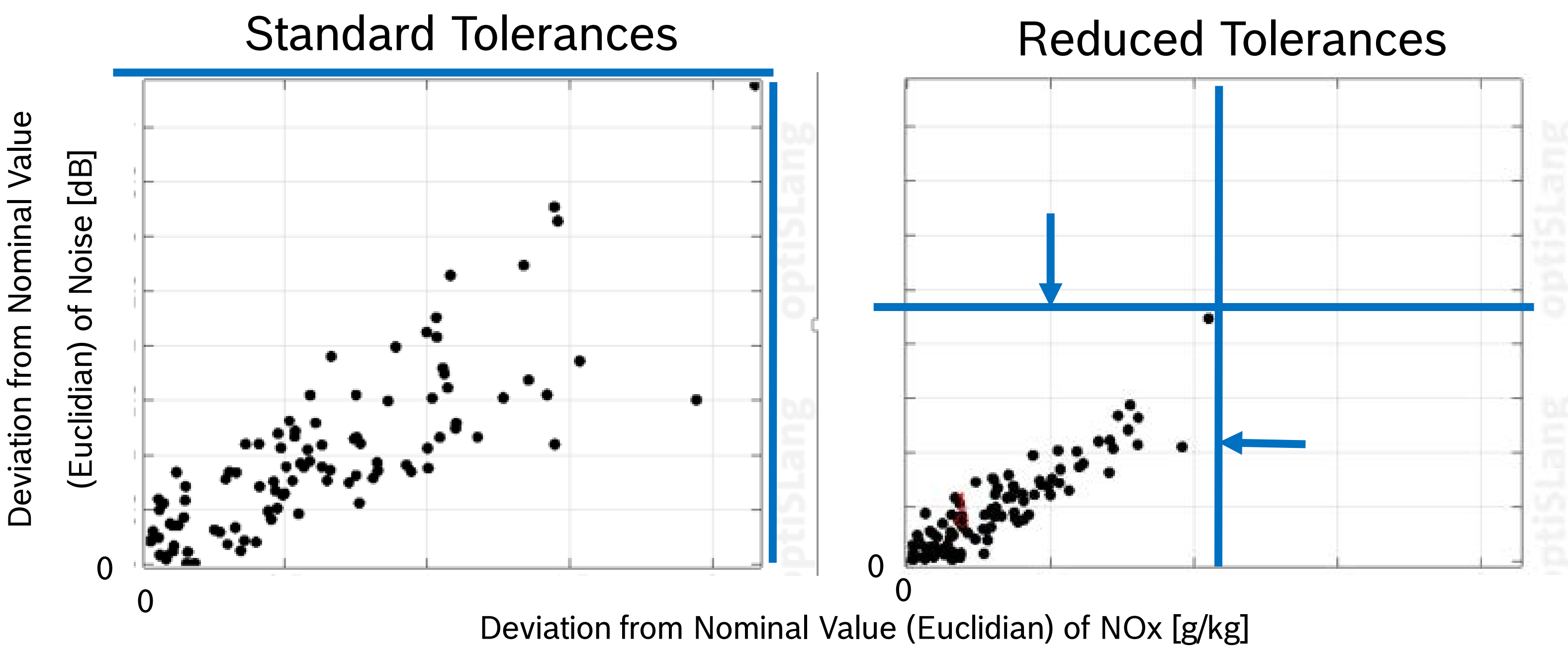
# Ex. 1: Robustness of EGR
## Quantification of Robustness

- Influence of EGR on noise emissions
- Scatter of noise emissions due to standard tolerances of injection parameters
- Nominal values of injection parameters: bold face line



# Ex. 1: Robustness of EGR
## Quantification of Robustness

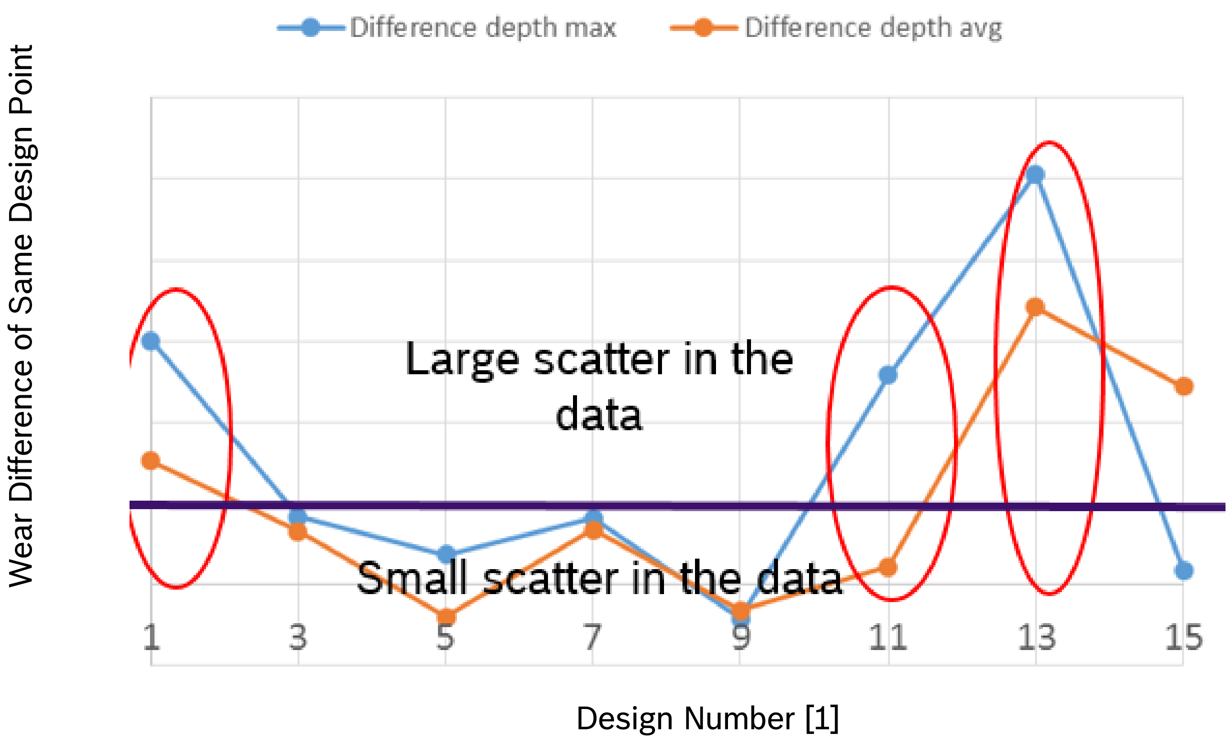
- Quantification of size of tolerances
- Same scale on both plots



# Ex. 2: Analysis of Injector Valve Wear
## Task

- At manufacturing plant the influence of three input parameters on valve wear for a common rail injector was investigated using experiments
- A 2-level full-factorial DoE (Design of Experiments) was performed using 2 samples for each design: 2 levels, 3 parameters, 2 samples per design: $2^3 x 2=16$ samples)
- Input parameters:
  - Valve body tolerance (Ventilstück; VS)
  - Armature bolt tolerance (AB)
  - Valve guidance tolerance (Kugelführung; KF)
- Output parameters: Valve wear at 8 circumferential positions reduced to average wear and maximum wear
- Tasks:
  - What are the most important input parameters?
  - How to choose the input parameters in order to minimize the wear?

# Ex. 2: Analysis of Injector Valve Wear
## Data Analysis




- There are designs that show significantly larger variation: Outliers!

# Ex. 2: Analysis of Injector Valve Wear
## Interpretation of Data Analysis

- In design number 1 and 2, 11 and 12, 13 and 14 the scatter in the wear measurement is significantly higher than in the other designs
- Possible reasons:
  - Design parameters which are not recorded may have a significant influence on the wear and may be different between the design numbers named above
  - Scatter within DoE levels
- Conclusion:
  Exclude designs with large scattering wear from the analysis, i.e. identify and exclude outliers!



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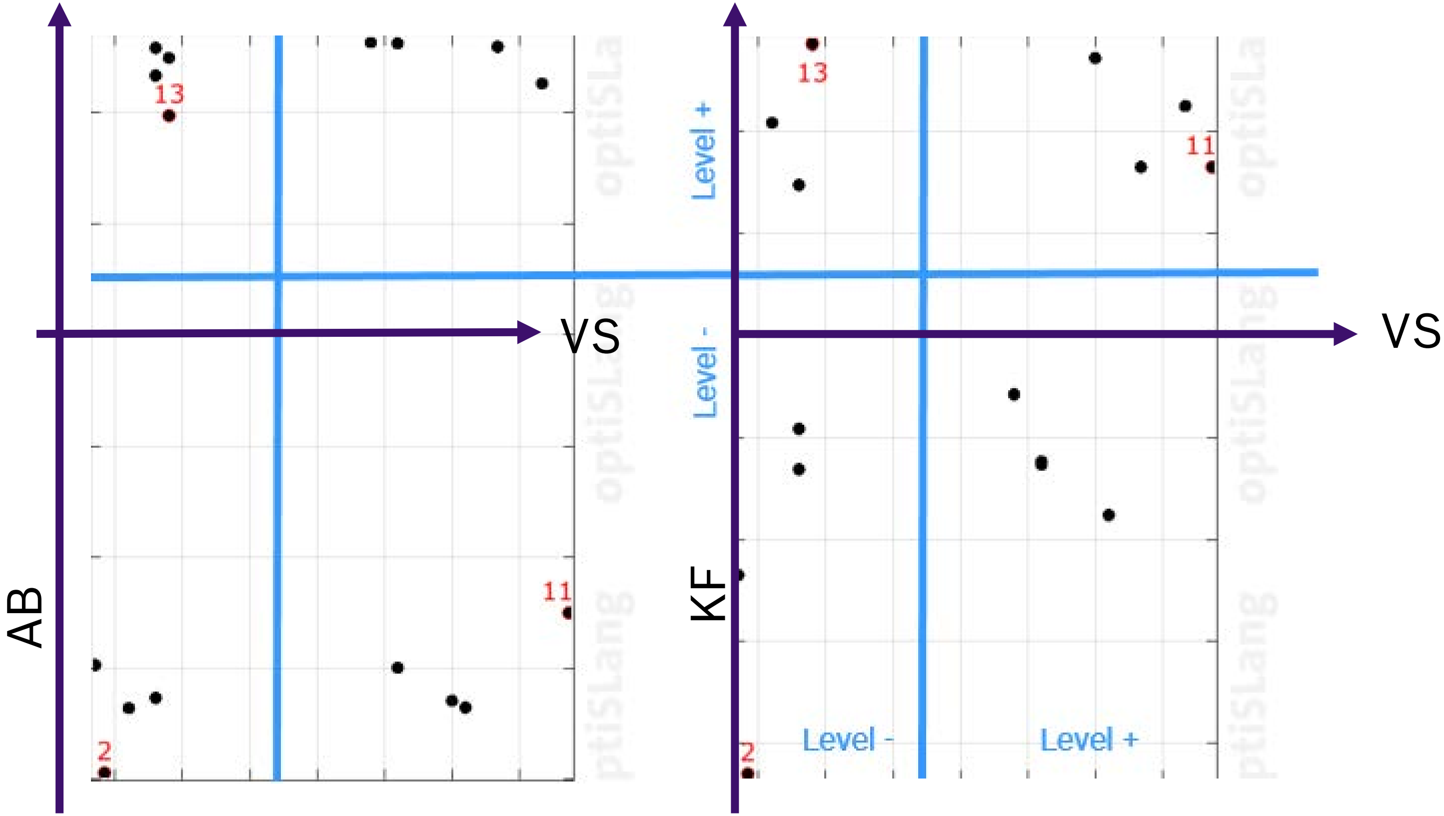
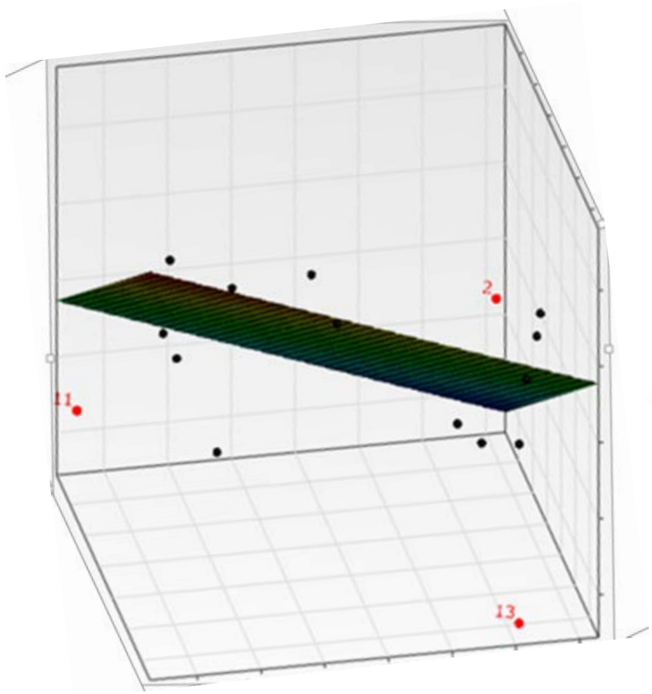
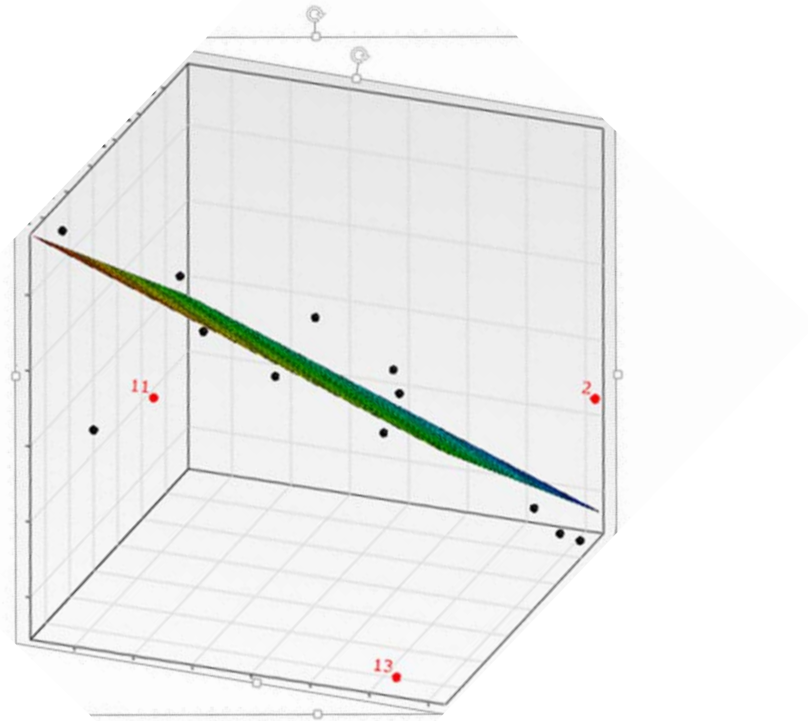
# Ex. 2: Analysis of Injector Valve Wear
## Scatter within DoE Levels




- Blue lines separate the levels
- Scatter within one level is as large as the difference between levels

# Ex. 2: Analysis of Injector Valve Wear
## Outliers Detection




- Design number 2, 11 and 13 have been identified as outliers
- Automatic procedure for outlier detection is required!



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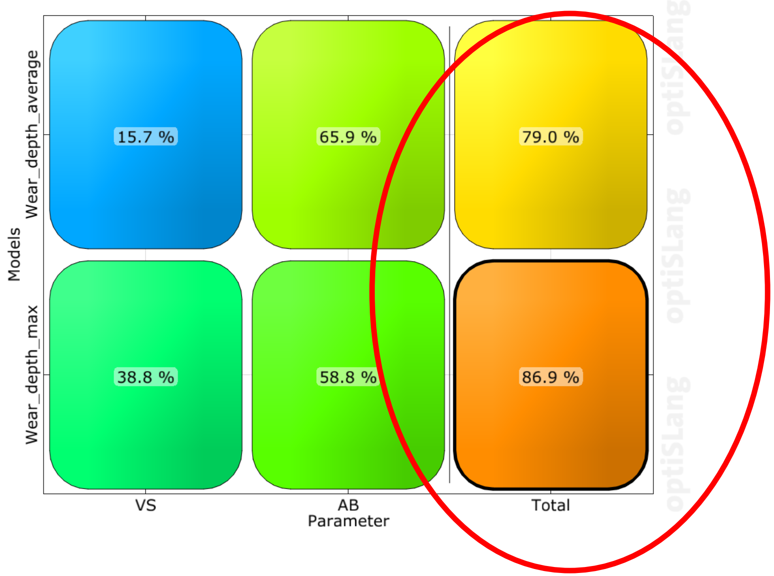
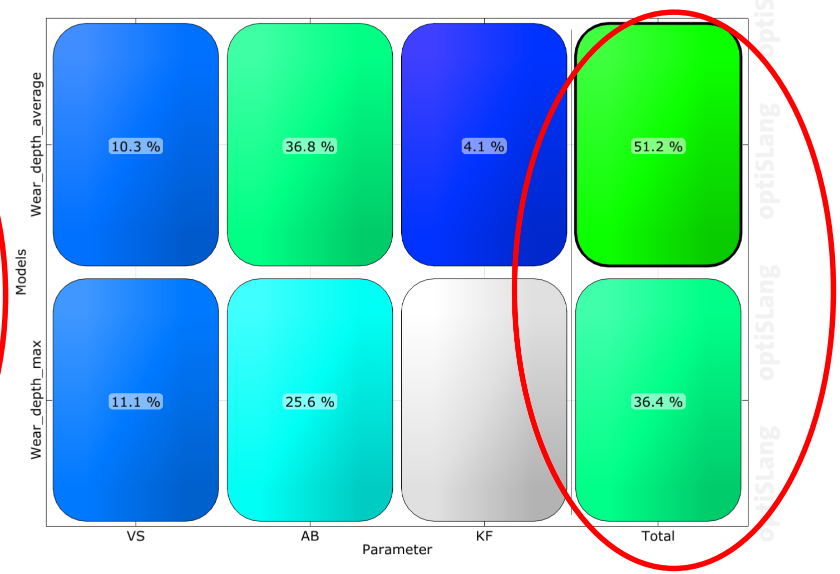
# Ex. 2: Analysis of Injector Valve Wear
## Identification of Main Influence Parameter

MOP* approx.: W/O Outliers




MOP* approx.: W/ Outliers




- W/O outliers: Large CoP**; reliable model
- W/ outliers: Small CoP; no reliable model
- Small CoP values was the trigger to search outliers

* MoP: Metamodel of Optimal Prognosis, ** CoP: Coefficient of Prognosis

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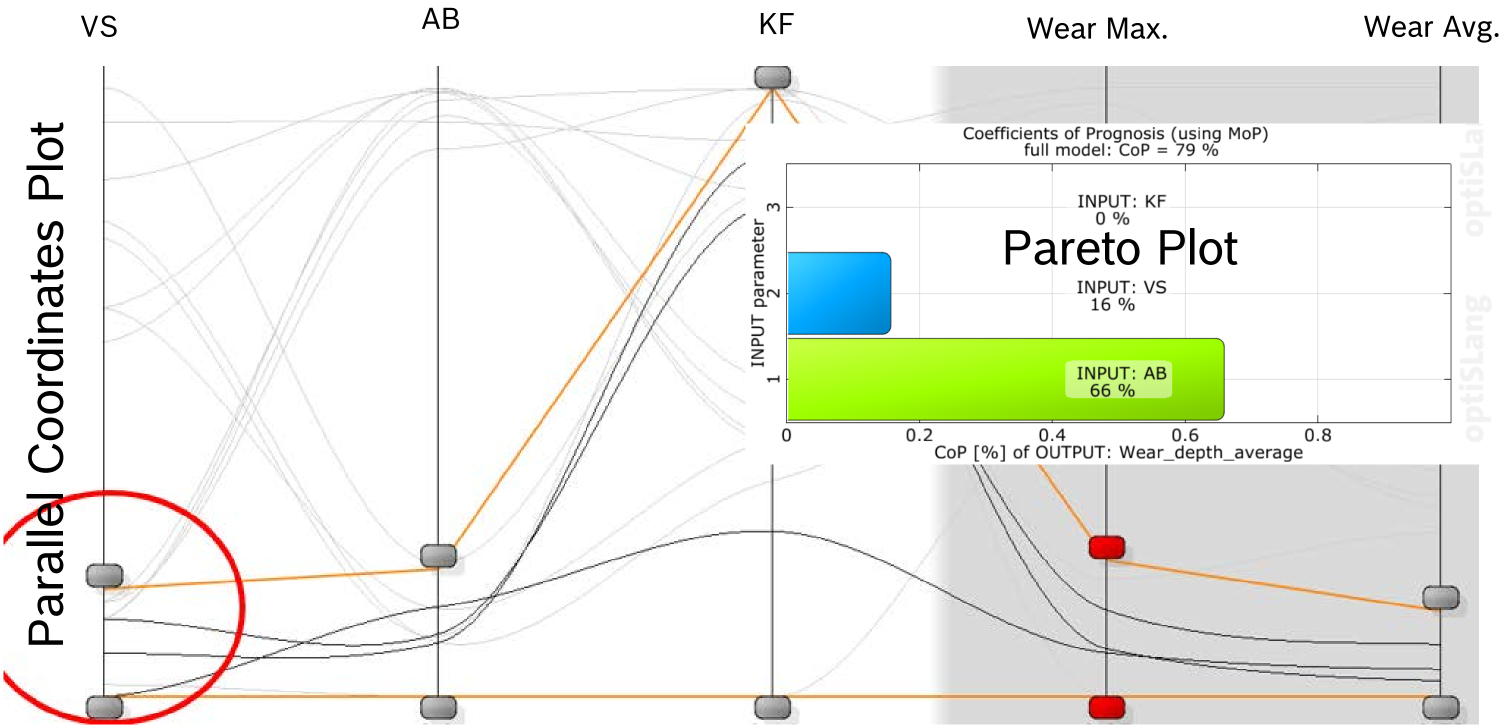
# Ex. 2: Analysis of Injector Valve Wear
## Quantification of Main Influence Parameter



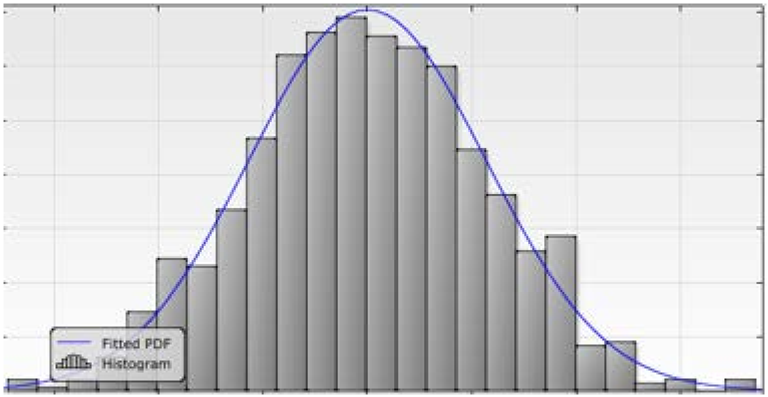

- Pareto Plot: AB and VS are significant parameters
- Parallel Coordinates Plot: Low values for VS and AB lead to low wear

# Ex. 3: Monte Carlo Simulation DENOX
## Task

- Customer request:
  An extraordinary huge dosing quantity of AdBlue® is required for a small lot size (‘Stückzahl’) application such that one dosing module is not sufficient
- Idea:
  Use two dosing modules
- Assumption:
  Let the dosing quantity of one module be normally distributed with mean $\mu$ and standard deviation $\sigma$
- Task:
  Quantify the tolerances of the sum of both dosing quantities if the tolerances for one dosing module is given

# Ex. 3: Monte Carlo Simulation DENOX
## Visualization & Verification of Results

- Monte Carlo Simulation with Optislang and sample size of 1.000




- Estimated standard deviation for sum of two dosing modules 21.53 g/h
- Theoretical consideration: If X=N(μ,σ^2) then X+X=N(μ+μ, σ^2+ σ^2)
- σ=15: $\sqrt{\sigma^2 + \sigma^2}$ = 21.51 g/h (values are falsified)
- Monte Carlo Simulation not necessary but helps to visualize the results

# Ex. 4: Optimal Task Schedule
## Task

- An internal service provider gets tasks from different divisions
- Since it has limited resources it cannot work on all tasks in parallel with maximal capacity
- Task:
  Find the optimal task schedule in order to maximize the global benefit



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# Ex. 4: Optimal Task Schedule
## Model

- N projects
- Consider for each project i:
  - Project costs $C_i$ (man power) during realization
  - Benefit rate $B_i$ after finalization
  - Amortization time $Ta_i$: Time duration which is needed for earning the project’s costs created by the project‘s benefit
- Limited man power resources for doing projects $Capa_{Total}$
- Calculate:
  - Benefit rate $B_i$: Benefit per time unit which is created due to the project; $B_i=C_i/Ta_i$
  - Project’s realization duration $Td_i$ assuming the total capacity is put on the project i; $Td_i = C_i/Capa_{Total}$



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# Ex. 4: Optimal Task Schedule
## Example

| **Project no.** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| Costs $C_i$ [TEUR] | 240 | 480 | 360 | 120 | 600 |
| Amortisation time $Ta_i$ [a] | 1 | 1,5 | 2 | 2,5 | 1,3 |
| Benefitrate $B_i$ [TEU/a] | 240 | 320 | 180 | 48 | 462 |
| Project duration $Td_i$ [a] | 0,5 | 1 | 0,75 | 0,25 | 1,25 |

- Claim:
  Optimal solution is achieved if the projects are ordered according to increasing project amortization time $Ta_i$



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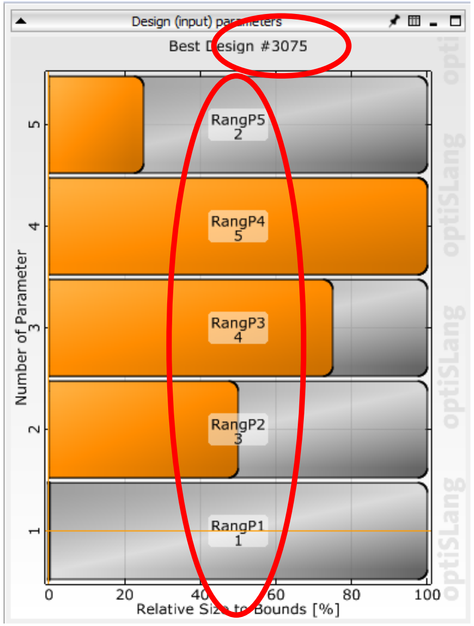
# Ex. 4: Optimal Task Schedule
## Optimal Solution

| | | | | Rang | P1 | P2 | P3 | P4 | P5 | Benefit | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 116 | 3039 | | ● | ✓ | 2 | 3 | 5 | 1 | 4 | 7883769,231 | 1 |
| 117 | 3041 | | ● | ✓ | 3 | 1 | 4 | 5 | 2 | 7866923,077 | 1 |
| 118 | 3075 | | ● | ✓ | 1 | 3 | 4 | 5 | 2 | 8077692,308 | 1 |
| 119 | 3102 | | ● | ✓ | 3 | 4 | 1 | 2 | 5 | 7621615,385 | 1 |
| 120 | 3116 | | ● | ✓ | 3 | 1 | 2 | 4 | 5 | 7669615,385 | 1 |

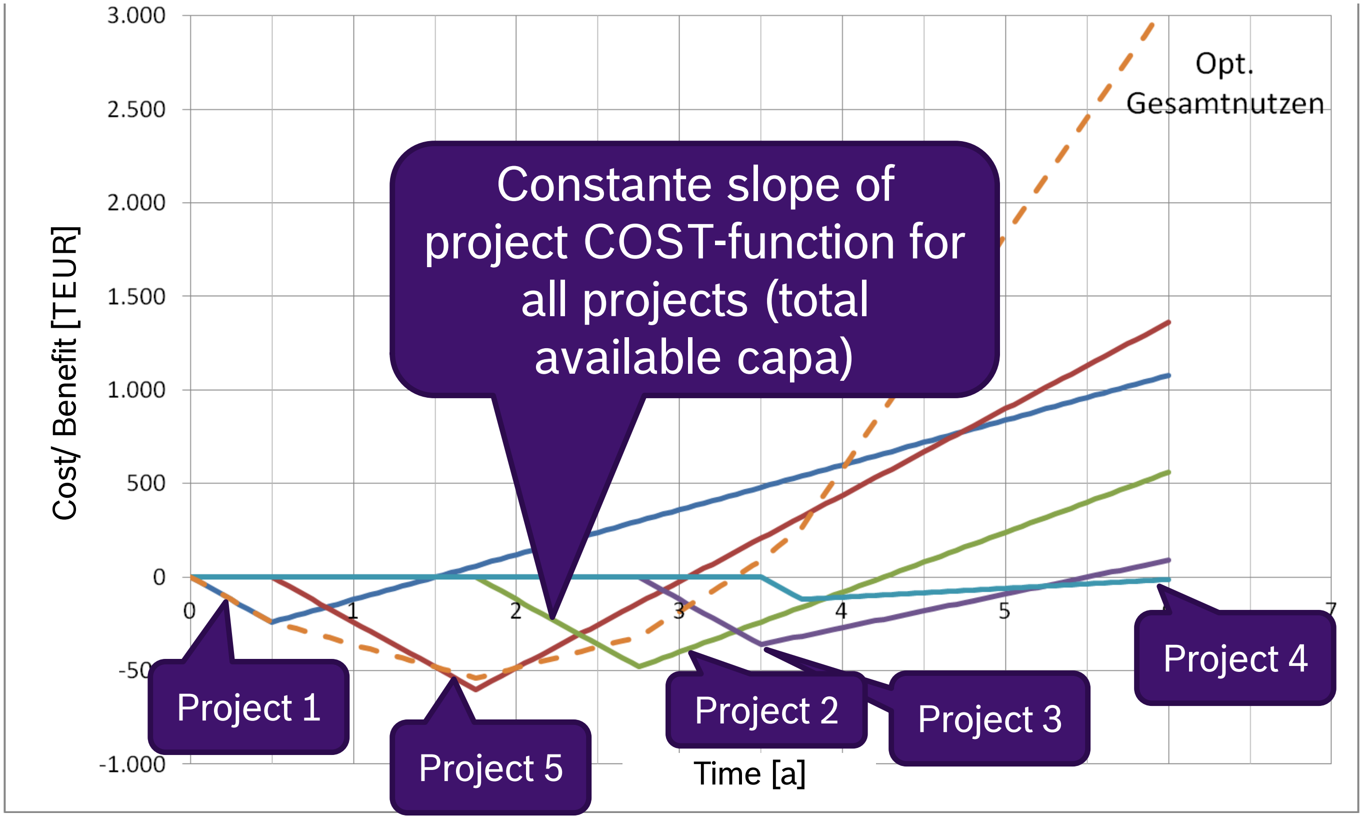



- Compute all 120 permutations (5*4*3*2*1=120)
- Max. benefit for variant 3075 (after 10 years)
- Optimal ranking:

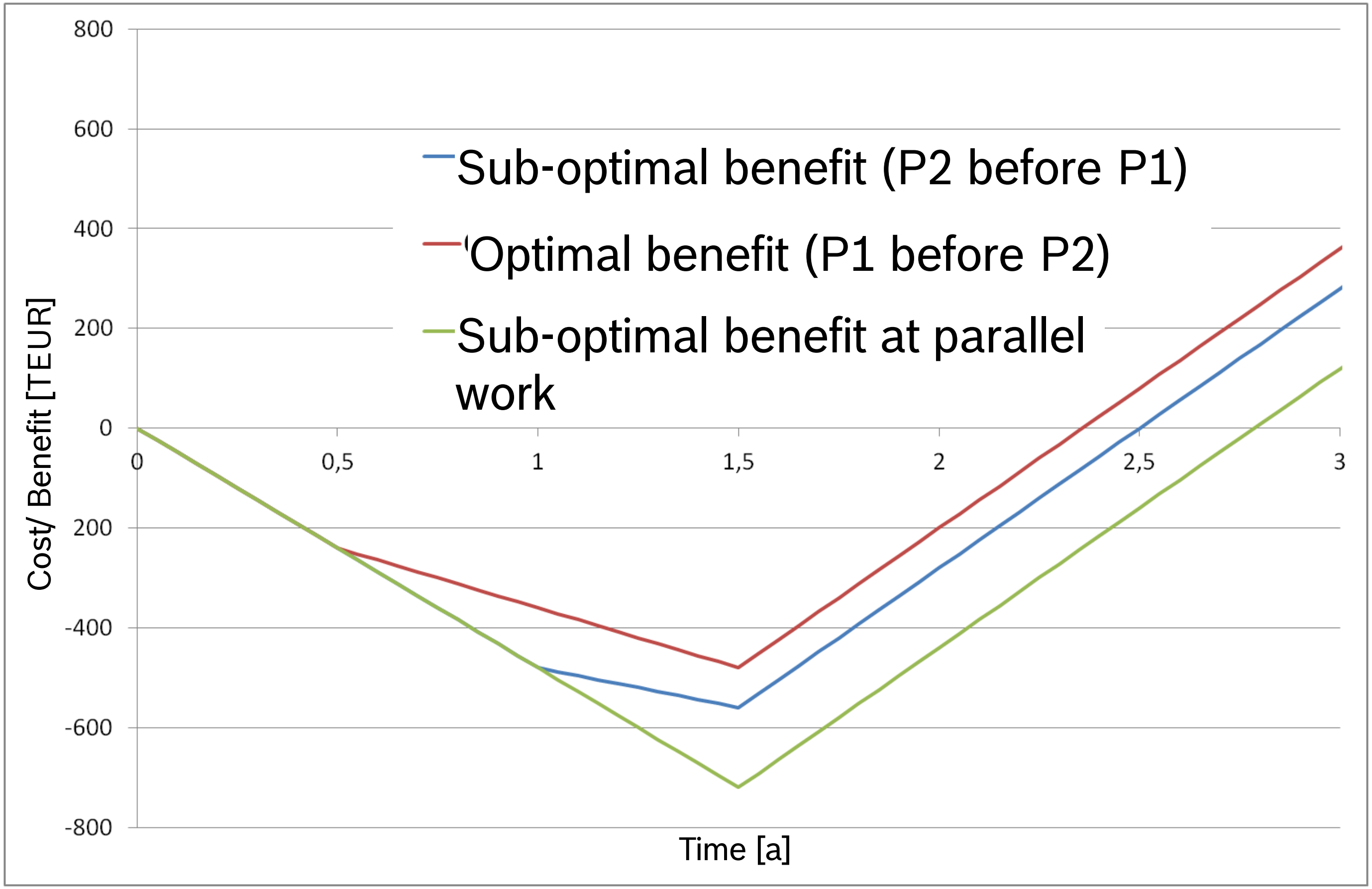
  P1 (Ta=1), P5 (Ta=1.3), P2 (Ta=1.5), P3 (Ta=2), P4 (Ta=2.5)

  Rk(P1)=1, Rk(P5)=2, ...

# Ex. 4: Optimal Task Schedule
## Example



# Ex. 4: Optimal Task Schedule
## Sub-Optimality of Parallel Work







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# Conclusion
## Optislang Supports PE at DS

- EGR loop
  - » Convert expensive experiments into a fast metamodel
  - » Quantification of robustness of EGR
- Valve wear
  - » Analysis of experimental results
  - » Outlier detection
  - » Identification/ quantification of main influence parameters
- DENOX dosing modules
  - » Visualization/ verification of theoretical results
- Task schedule
  - » Classical optimization problem
  - » Verification of ‘stomach’ feeling