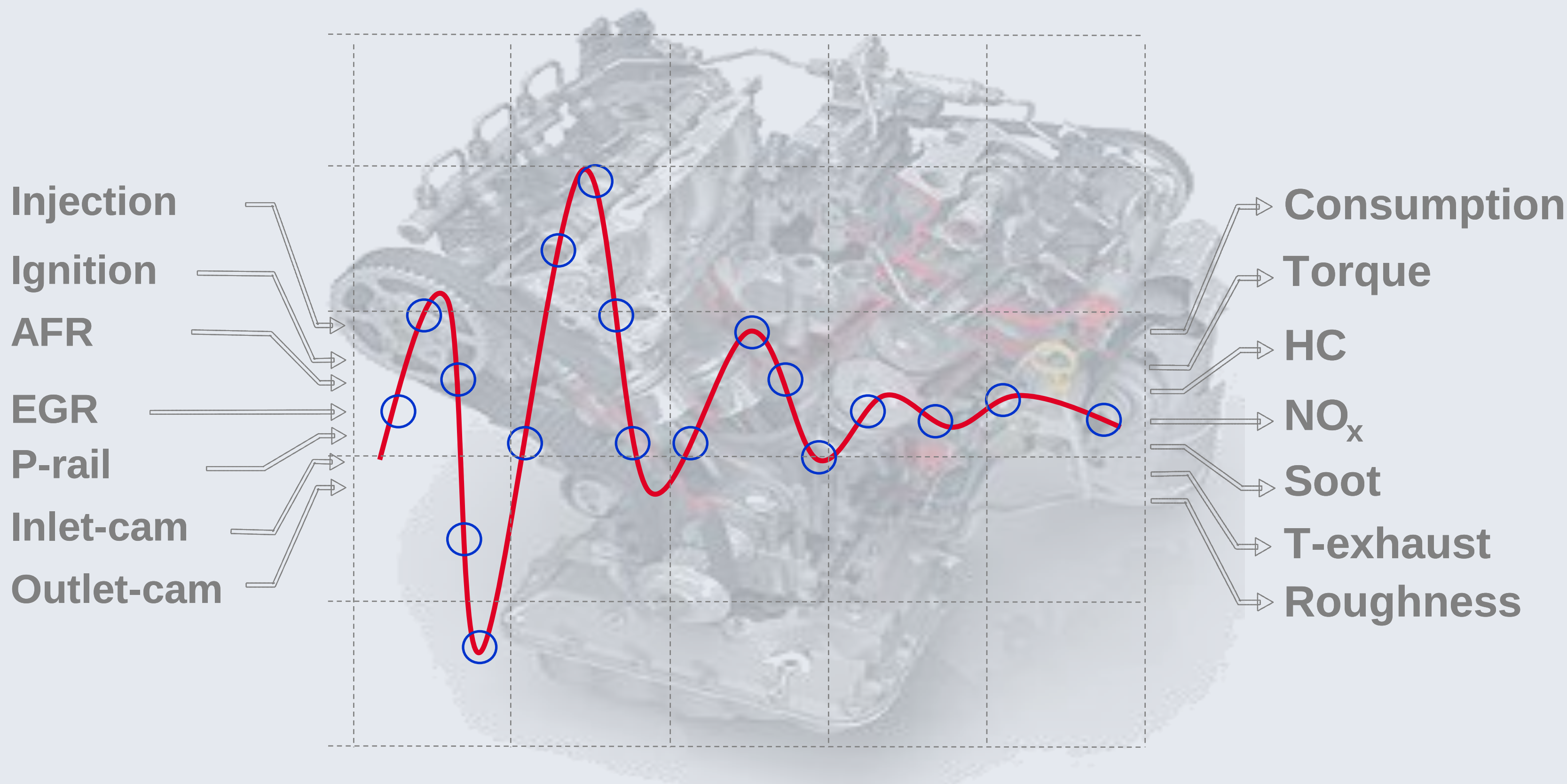
Statistical Modeling and Optimization Approaches for Development of Fuel-Efficient Vehicles



$$y(\vec{x}) = \sum_{i=1}^{N} C_i \cdot e^{-\frac{1}{2}\sum_{l=1}^{D}\frac{(X_{il}-x_l)^2}{r_l^2}}$$

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Manager – Technical Sales, Support & marketing
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Agenda

- **About ETAS**
- **Challenges of today's ECU Calibration & Engine Development**
- **Model based Calibration**
- **Case Study**

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Leading Provider of Solutions and Services for Embedded Systems

- ETAS with over 850 associates is part of the Bosch Group
- Present in 13 countries with 23 offices
- ETAS subsidiary ESCRYPT is a specialist for embedded systems security

Numbers apply for ETAS and ESCRYPT

ETAS Customers and Domains

Trusted by OEMs, tier one and ECU suppliers, as well as engineering service providers:

Commercial Vehicles
Automotive
Heavy Duty Engines
Railway
Powertrain
Construction Machines
Consumer Electronics
Off-Highway

ESCRYPT Customers and Domains

The ESCRYPT customer base includes:

Automotive
Mobile Machines & Transportation
Energy
Consumer Electronics
Mobile Devices
Industrial Automation
Financial & Government Logistics
Health Care

Corporate Profile
Our Solutions Portfolio

Software Engineering	Test and Validation	Measurement, Calibration, Diagnostics	Embedded Security	Real Time Applications

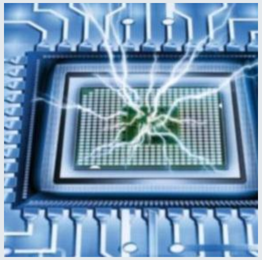
ETAS Products

Consulting and Engineering Services

Virtualization Technology







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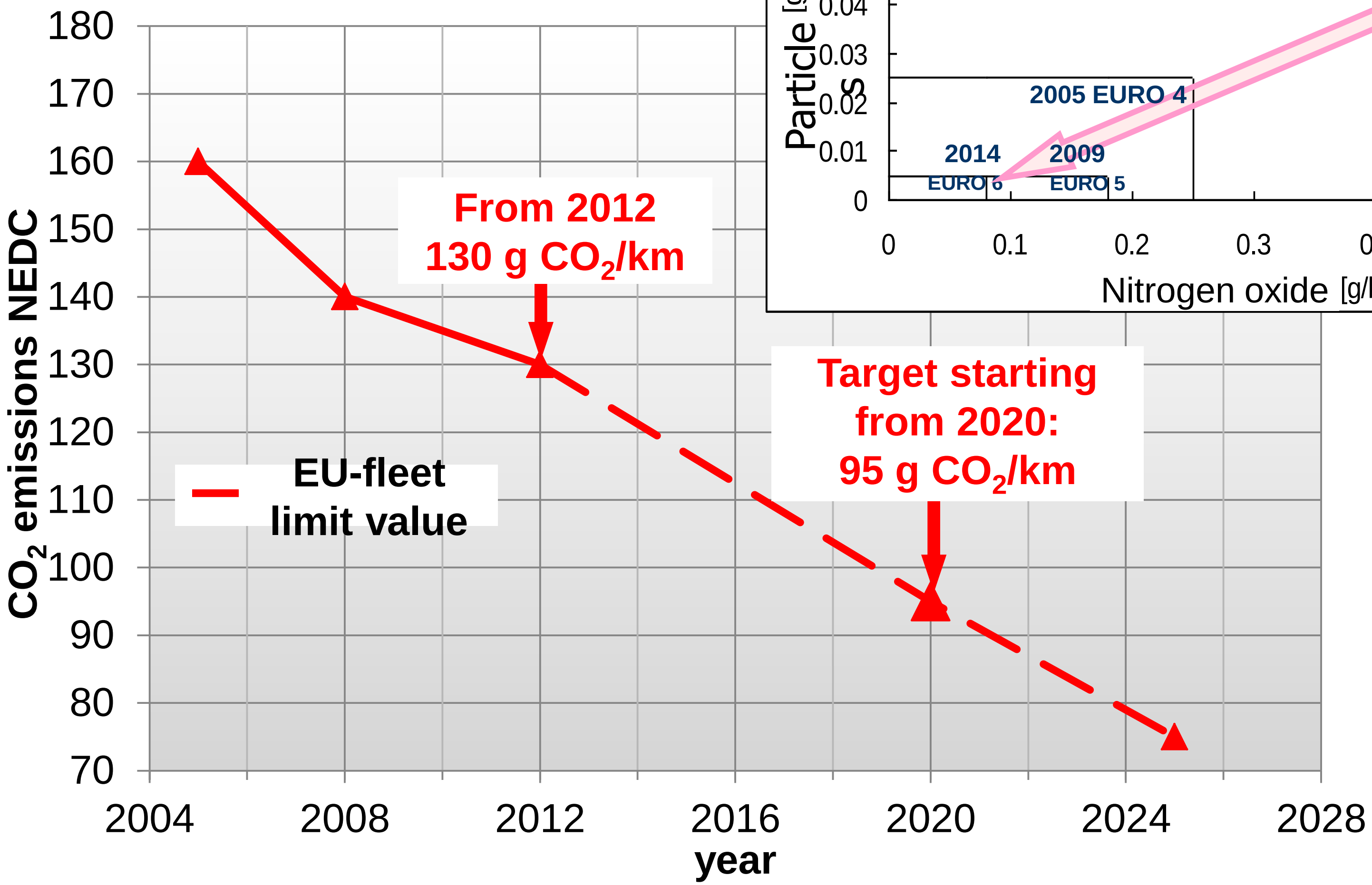
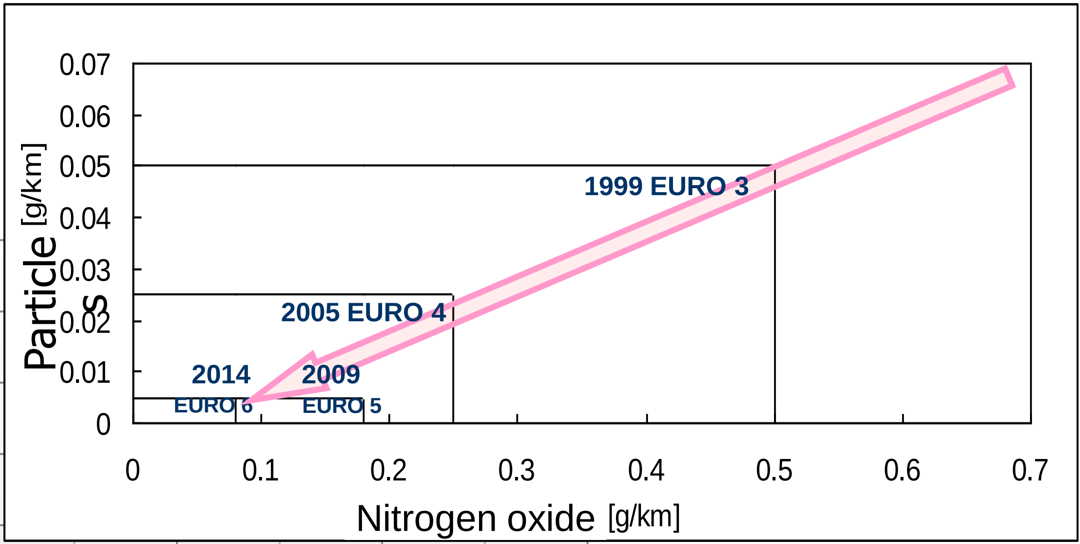
Challenges of today's ECU Calibration & Engine Development
Stringent Regulations





<u>Classical calibration procedure:</u> Full factorial variation of all combinations

⇨ Exponential increase with variable valve timing (VVT)

Without VVT:
~ **250 MP**

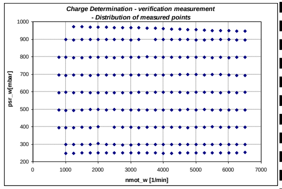
~10h

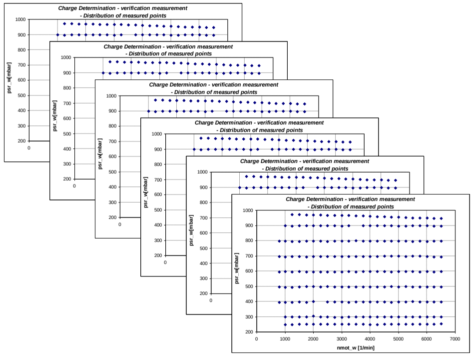
Engine with 1 variable Camshaft: **~2.500 MP**

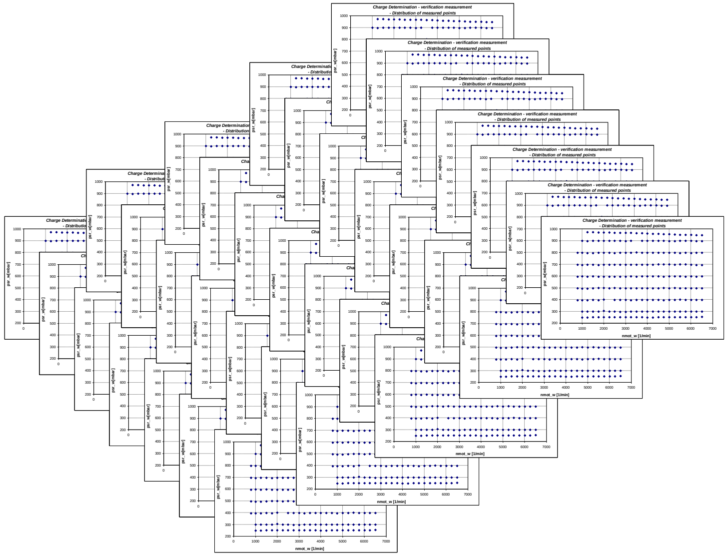
~ 100h

Engine with 2 variable Camshafts: **~25,000 MP**

~1000h







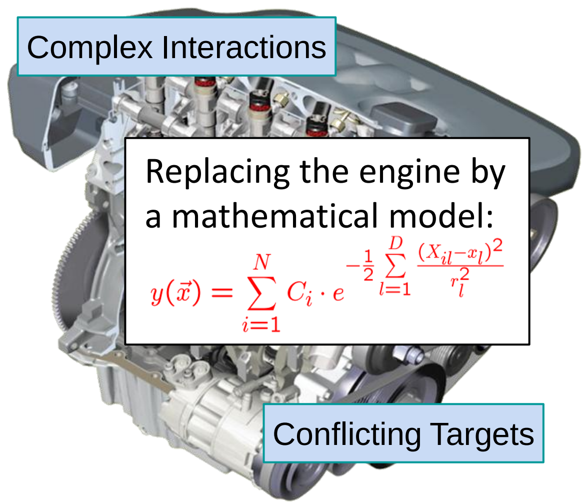
Challenges of today's ECU Calibration & Engine Development
Conflicting targets

ETAS

Example: Modern Gasoline Engine

Operating Range:
- Speed
- Load

Engine Parameter:
- Injection Timing
- Ignition Timing
- Fuel Pressure
- Exhaust Gas Recirculation
- Exhaust Camshaft
- Intake Camshaft
- Swirl Valve



Complex Interactions

Replacing the engine by a mathematical model:

$$y(\vec{x}) = \sum_{i=1}^{N} C_i \cdot e^{-\frac{1}{2}\sum_{l=1}^{D}\frac{(X_{il}-x_l)^2}{r_l^2}}$$

Conflicting Targets

Targets:
- Consumption/CO_2
- Emissions:
  - Soot / Particle
  - NO_x
  - HC
- Stability (CoV)
- Noise
- Exhaust-Temperature
- …

Classical Procedure:

⇨ Full variation of all input parameters result in exponential increase of measurement effort!

Virtual Calibration with ASCMO:

⇨ Creation of an engine model based on few specific measurements

⇨ Optimization of the calibration parameter based on the model (manual or with optimizers)

Agenda

ETAS

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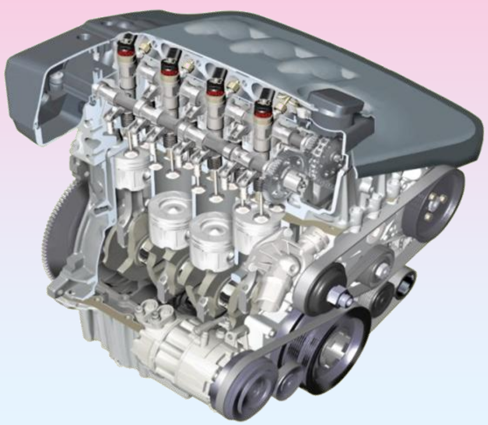
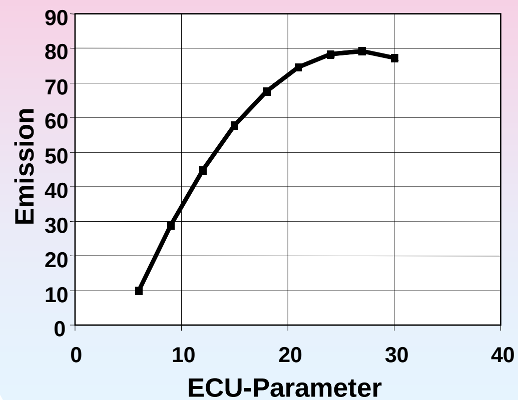
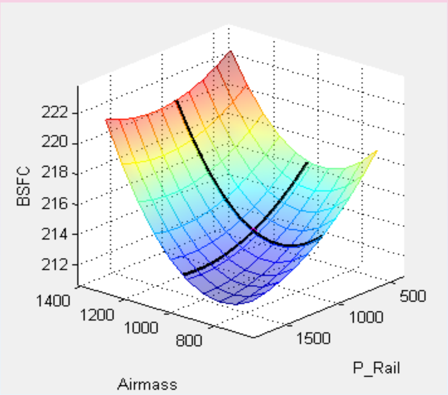
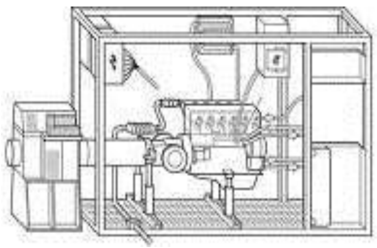
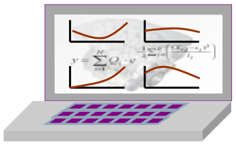
Measuring at the Real Engine → **Calculation of an Engine Model** → **Calibrate at the Virtual Engine**

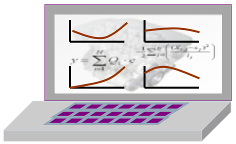


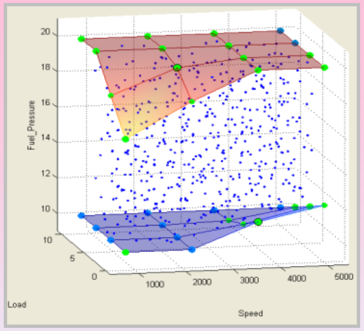






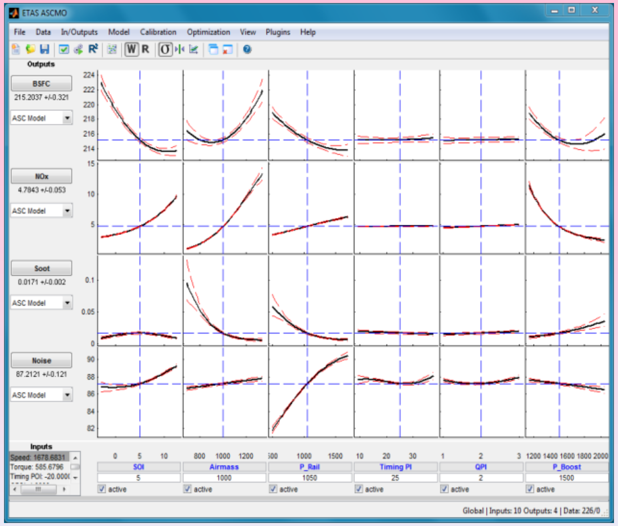






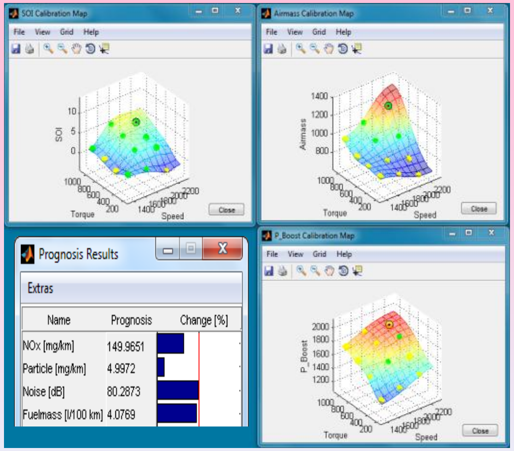
Test planning

- Robust
- Scalable
- Easy to use



Modeling

- Highest possible accuracy
- Automated model calculation
- No specific mathematical expertise necessary



Map optimization

- Global: for whole driving cycles
- Considering map-smoothness and gradients

Principle and advantages of Statistical machine learning methods

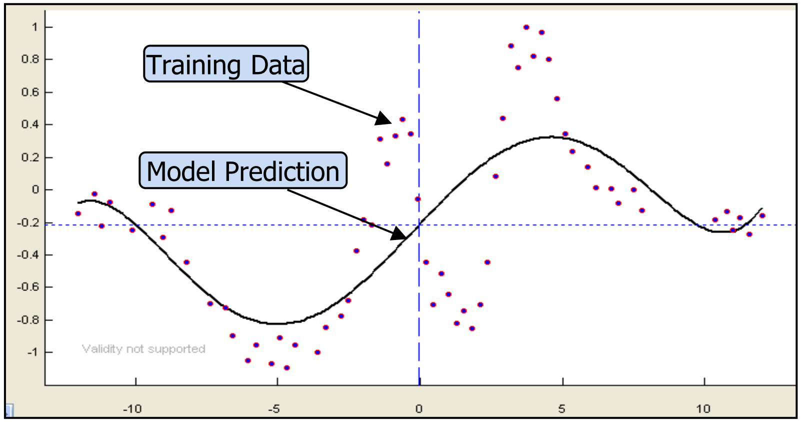
Polynomials or Neuronal Nets

Principle:

- Search in a given class of functions (polynomial, neuronal net, ...)
- Fit the model parameter by experts and validation measurements

Disadvantages:

- Limited flexibility & danger of over-fitting
- High expertise and assumptions necessary



Modeling a complex 1-D signal with classical DoE-Models („Advanced Polynomials")

Statistical machine learning methods

Principle:

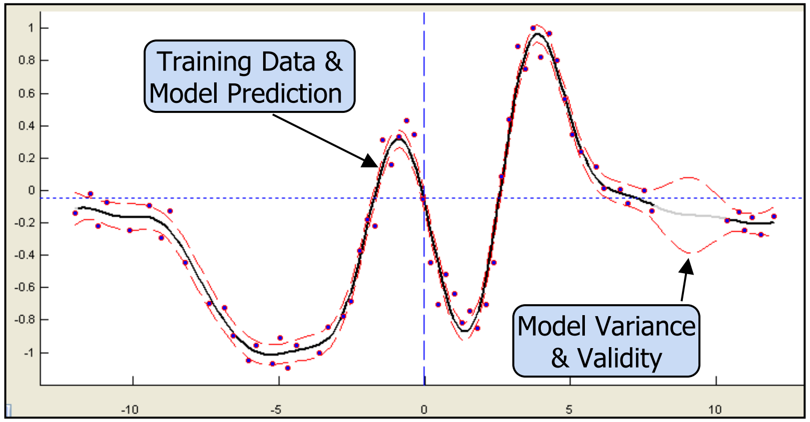
Search in a complete function space:

$$y(\vec{x}) = \sum_{i=1}^{N} C_i \cdot e^{-\frac{1}{2}\sum_{l=1}^{D}\frac{(X_{il}-x_l)^2}{r_l^2}}$$

- Automatic determination of the most likely function

Advantages

- High flexibility without assumptions or expertise
- Gives local confidence interval (model variance)
- Robust against outliers

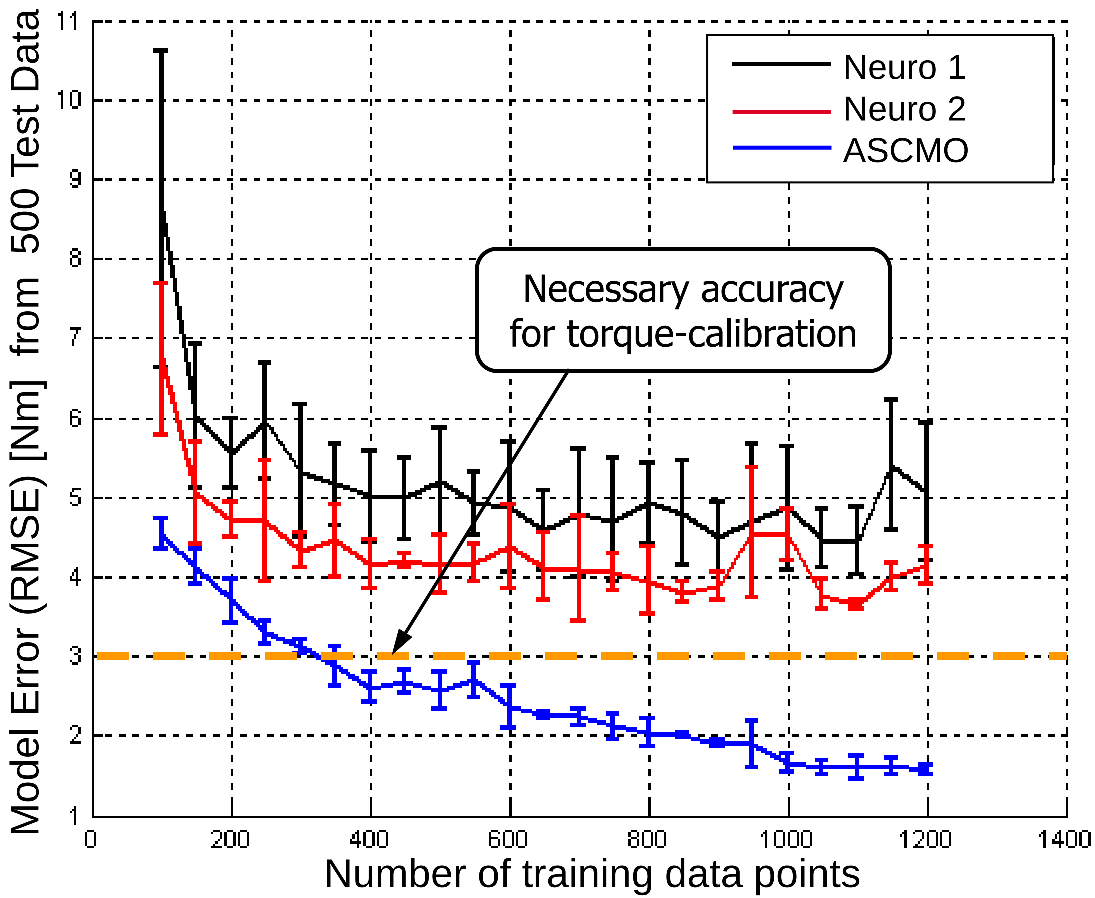


Modeling a complex 1-D signal with new statistical machine learning methods

Model based Calibration

Data from Gasoline Engine

ETAS



Benchmark:
Comparison of two different neuronal nets from commercial tools against ASCMO

Example:
Torque-modelling for a gasoline engine with variable in- & outlet-cam in the whole operating range (speed/load)

6 Parameter:
speed, load, 2 cams, AFR and ignition

Shown:
Evolution of model-error depending on number of training data:
Neural Net: **black** + **red**
ASCMO-approach: **blue**

⇨ Neural Net: insufficient accuracy even with > 1000 training data points
⇨ ASCMO: sufficient accuracy reached with 300 training data points

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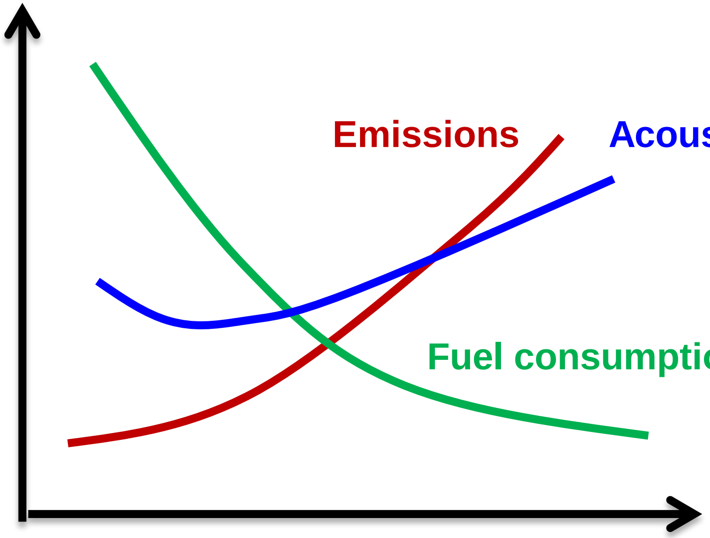
Parameters:
Engine speed
Injection quantity
Start of injection
Charge pressure
Air mass
Rail pressure
Swirl flap
Variable valve drive
Low pressure EGR
Exhaust gas damper
Quantity and position:
- Pre-injections
- Post-injections

Target variables:
Fuel consumption
Exhaust gas emissions
Response behaviour
Noise emissions
Power characteristics

Boundary conditions:
Component protection
Legal specifications

Optimization of multiple criteria trade-off



Source: Volkswagen

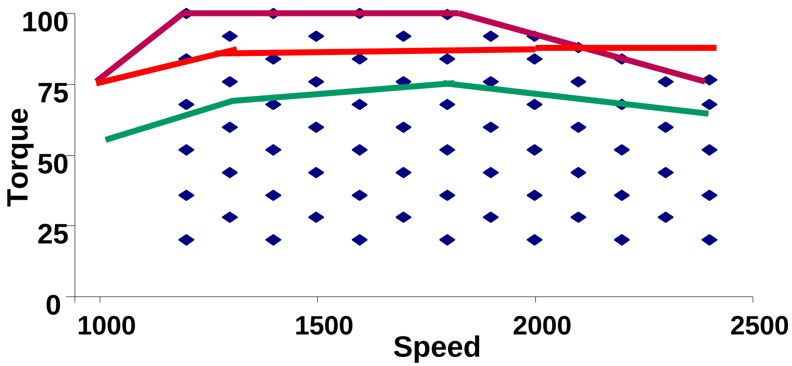
Case Study
Challenges II/II

Broad operating region:

Vehicle types: Compact car to SUV

Variants: Eco / Comfort / Sport

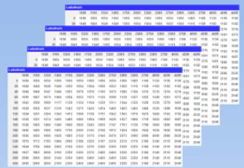
Transmission: Manual/Automatic

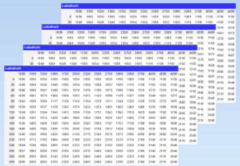


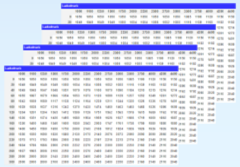
Vehicle

Engine/gearbox combination

Calibration version

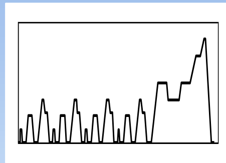




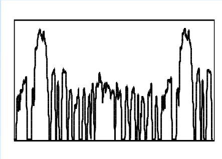


Cycle

NEDC



US 07



Emissions/ fuel consumption

NO_X = 0.12 g/km

HC = 0.03 g/km

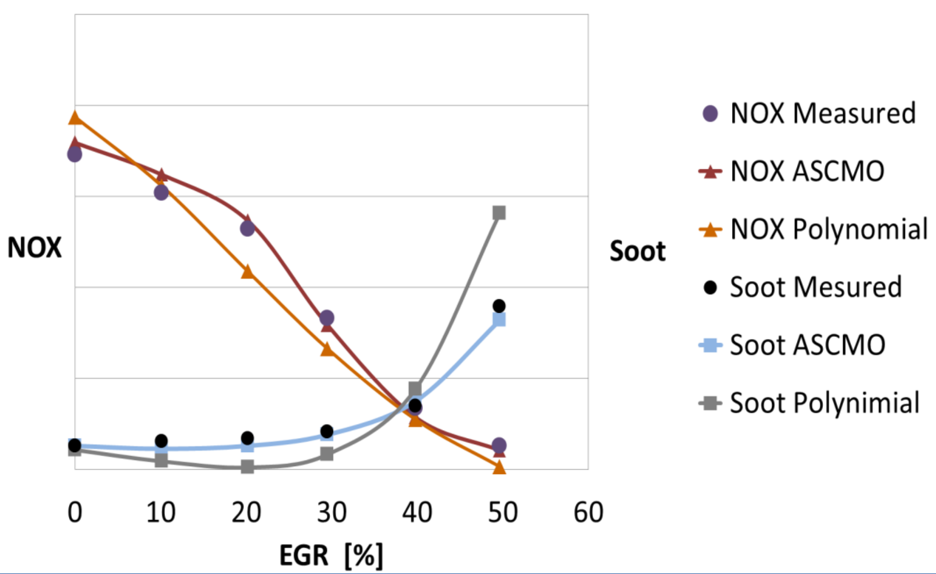
Part = 0.001 g/km

CO_2 = 99 g/km

Source: Volkswagen

Case Study
Results

Validation measurement: EGR-Variation



Model data set:

- 12 parameters
- Operating area: NEDC
- 600 measurement points
- Accuracy: model of fuel consumption <= 1%

Evaluation of the model quality:

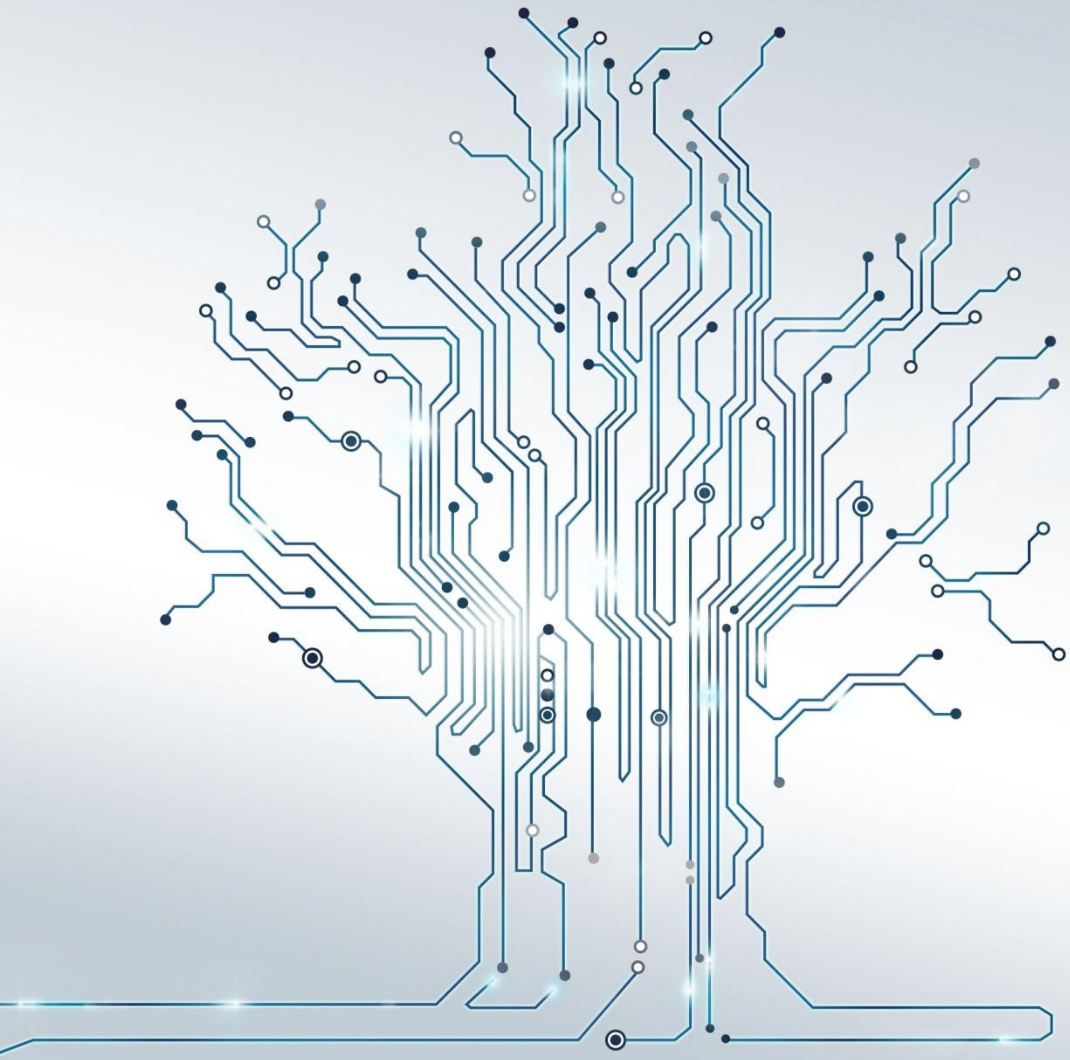
- Gaussian model: Highest quality
- Manifold opportunities to plausible the model

Results:

- By using the global engine model with ASCMO the fuel consumption could be **reduced by 2 – 4 %**
- **Reduce particulate emission** of a diesel engine by adding a post injection to an existing calibration concept **without increasing of fuel consumption**.
- Classical approach would require at least **8 weeks for the necessary 10 parameter** but with the use of ASCMO global model with **400 data points could be optimised in 1.5 days**.
- With ETAS ASCMO, application engineers are able to use **DoE independently**
- Since the launch of ETAS ASCMO, the number of **DoE users has been increasing** rapidly

Source: Volkswagen

Statistical Modeling and Optimization Approaches for Development of Fuel-Efficient Vehicles



Thank you

Muchas gracias

谢谢

Tack så mycket

Děkuji

धन्यवाद

Mille Grazie

Merci

ขอบคุณ

Hvala

sağ olun

감사합니다.

有難うございました

Спасибо!

Kiitos

Д‘якую

Vielen Dank