Diesel Engine Operating Strategies

PM, NOx and CO2; A Three Dimensional Trade-Off, as opposed to a single-pollutant minimization

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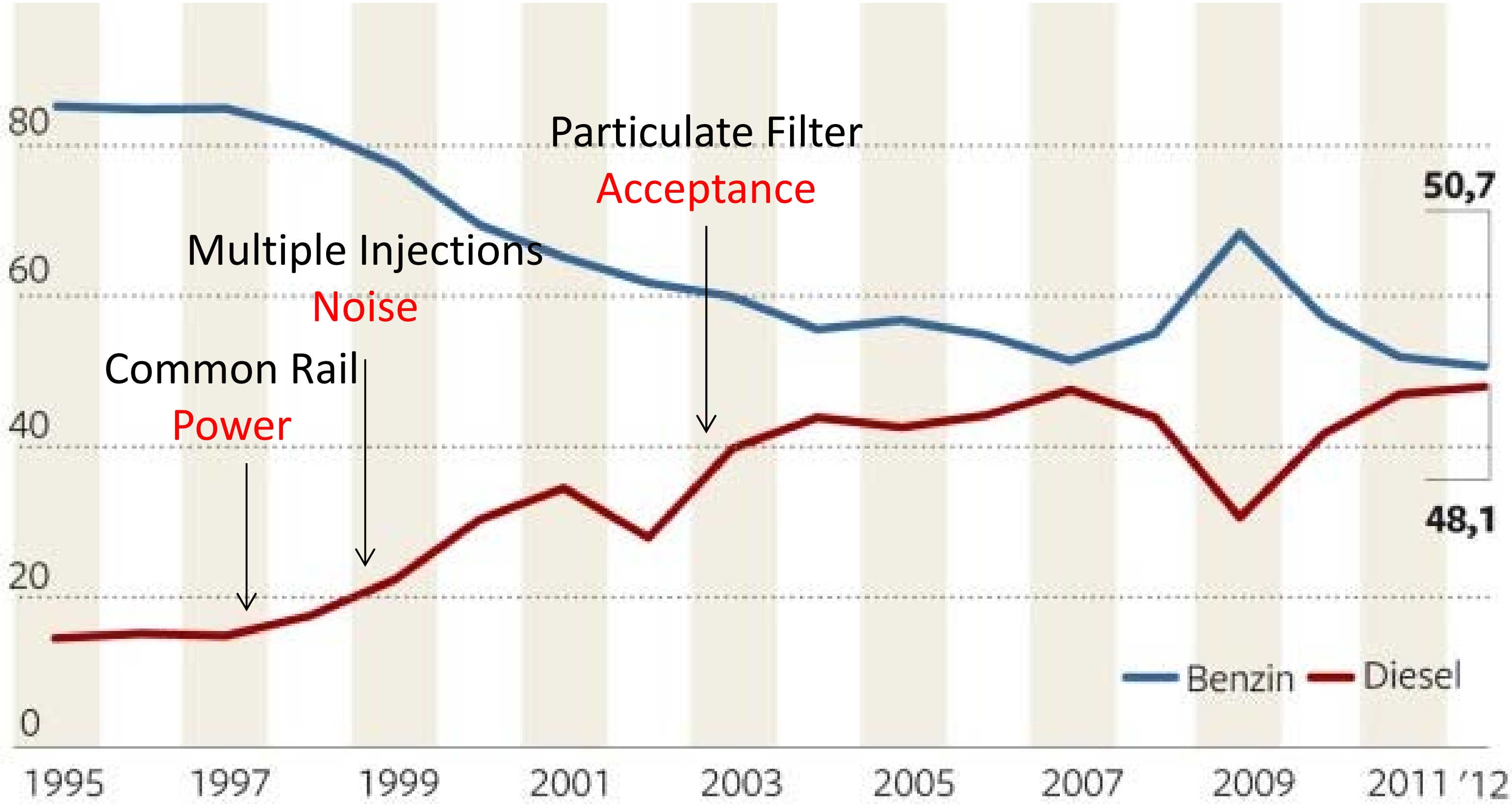
Outline

- Introduction
  - Passenger car Diesel engines in the past 20 years
- Operation Optimization
  - Trade offs of state-of-the-art engines
  - Available tools for most beneficial operation
    - Systematic Optimization
  - Model based approach
- Future solutions

History

Share of Diesel and Gasoline Powered Cars in Germany

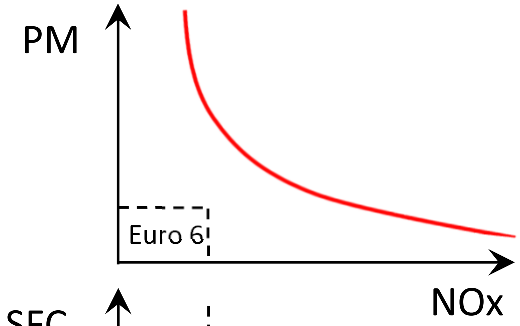


Source: CAR Uni Duisburg Essen

History

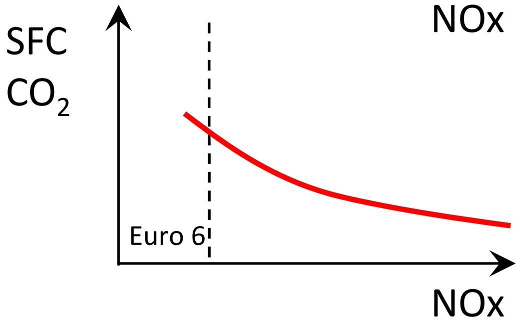
- Complexity / degrees of freedom increased

1996:
Injection timing
EGR Rate
(Waste Gate)

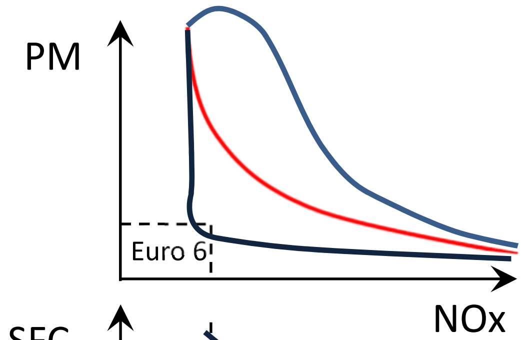


- Exhaust

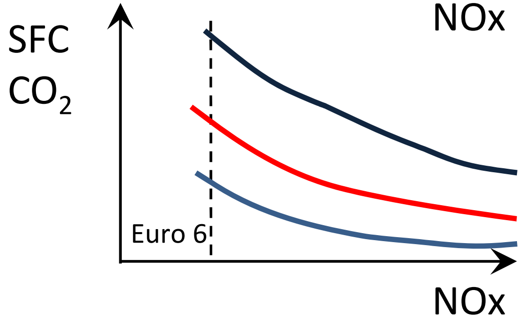
1996:
(DOC)
(O_2 Sensor)



2016:
Injection timing main injection
Injection timing pilot injection
Injection timing post injection
Injection share pilot /main / post
Fuel pressure
Boost pressure
EGR rate
EGR temperature
Share LP / HP EGR
Swirl level
Engine dp



2016:
DPF
DOC
SCR/LNT
O2 Sensor x2
NOx Sensor x2
T Sensor x2
dp Sensor
(Soot Sensor)



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Optimization for 3 Degrees of Freedom

- Goals:
  - All available strategies for PM-Nox-SFC-Trade-off
  - Systematic procedure

- Start-of-injection (SOI)
- Exhaust gas recirculation (EGR)
- Swirl (SWV)

2016:

Injection timing main injection
Injection timing pilot injection
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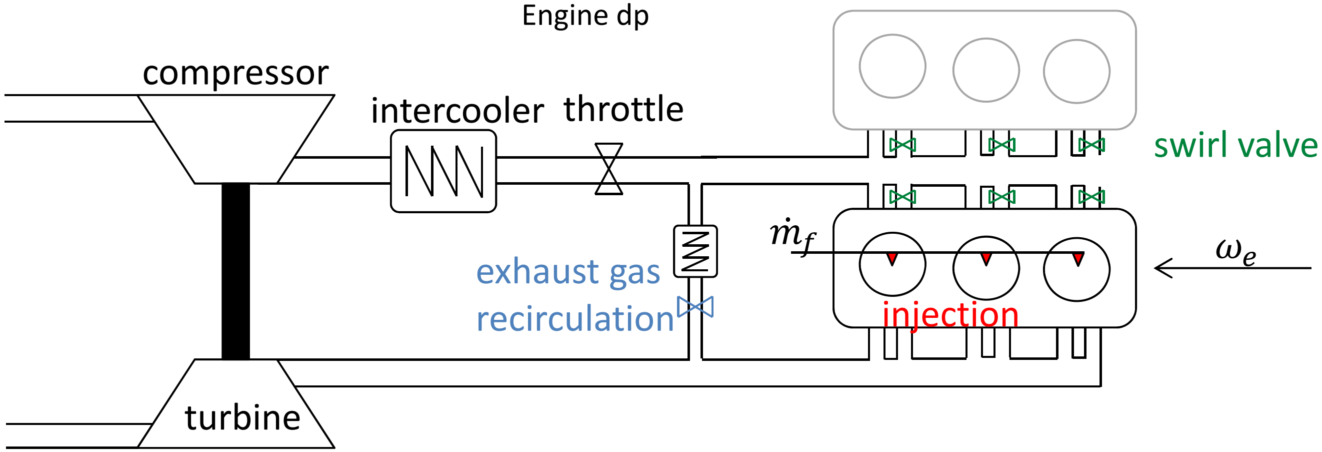

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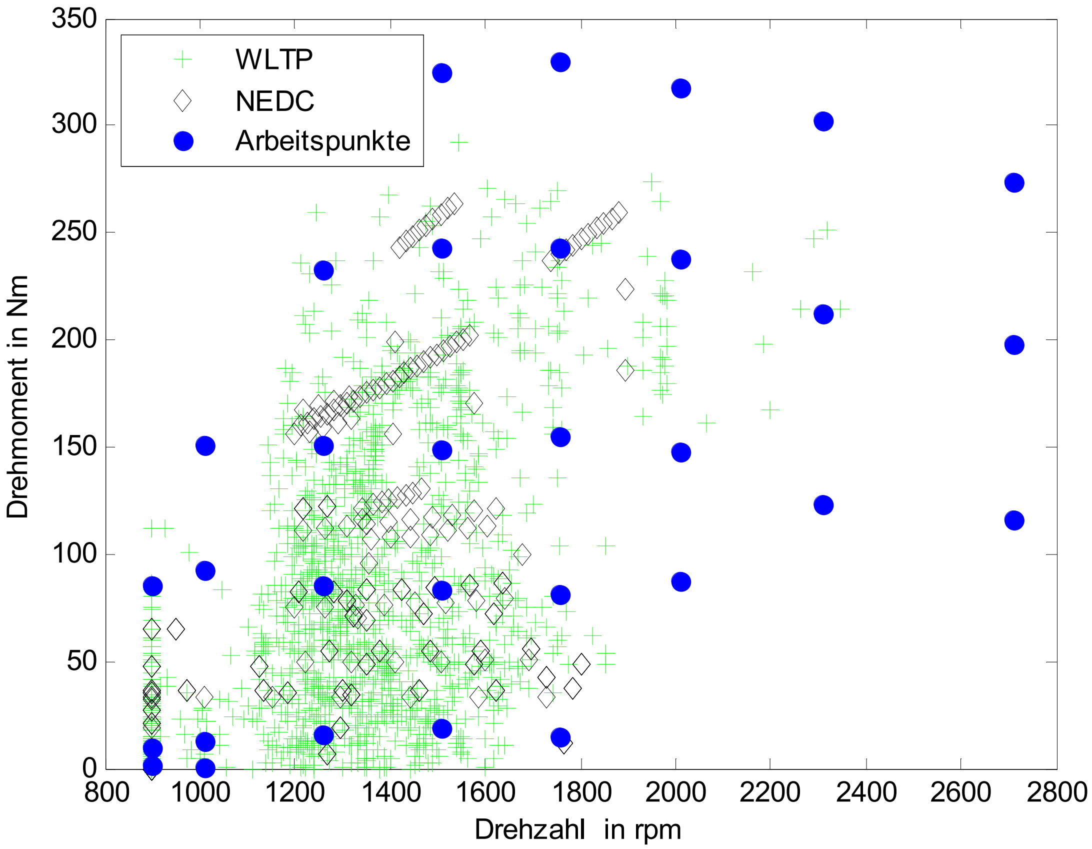
Recorded Measurements



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- # operating conditions = 31
- In every operating point
  - EGR (4 pts)
  - SWV (4 pts)
  - SOI (4 pts)

  = 4*4*4 = 64 pts

Total = 1984 measurements

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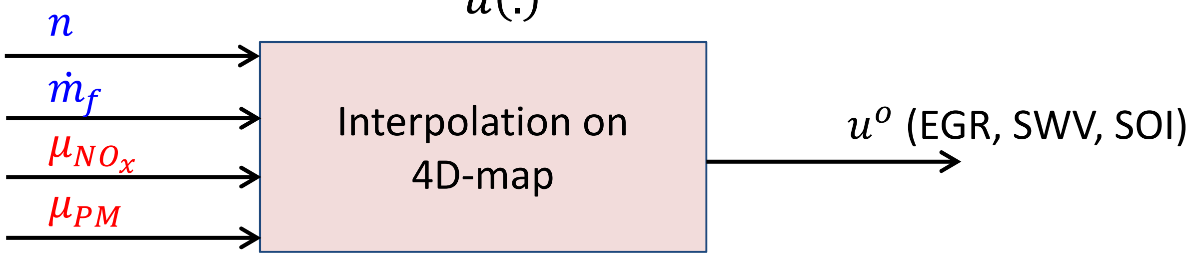
Steady-state optimization

- Optimization criterion:

$$H = (1 - \mu_{NO_x})\underbrace{\left[(1 - \mu_{PM})\dot{m}_f + \mu_{PM}\dot{m}_{PM}\right]}_{\text{Weighting PM vs Fuel}} + \underbrace{\mu_{NO_x}\dot{m}_{NO_x}}_{\text{Weighting NOx vs Fuel/PM}}$$

- Optimum inputs for engine control unit (EGR, SWV, SOI) are a function of operating point and strategy:

$$u^o(n, \dot{m}_f, \mu_{NO_x}, \mu_{PM}) = \underset{u(.)}{\operatorname{argmin}}\{H(n, \dot{m}_f, u, \mu_{NO_x}, \mu_{PM})\}$$



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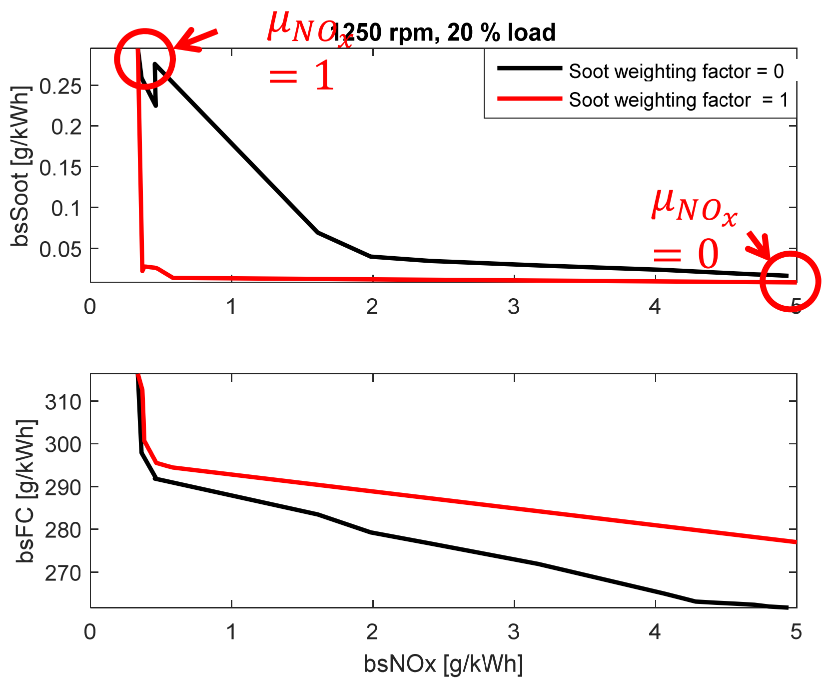
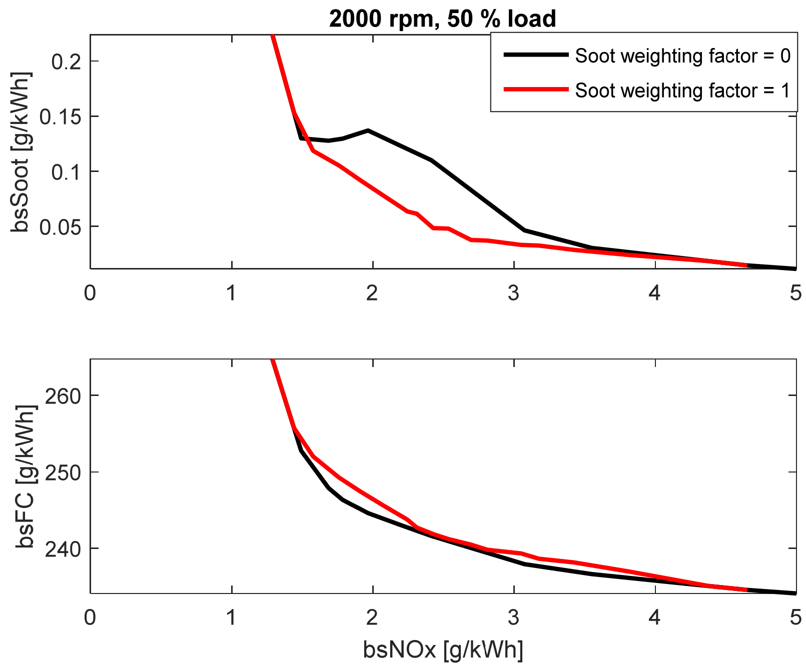
Emission – Efficiency Trade –off

Trade off **surface** at 1250 rpm and low load



Trade off **line** at 2000 rpm and (high) load



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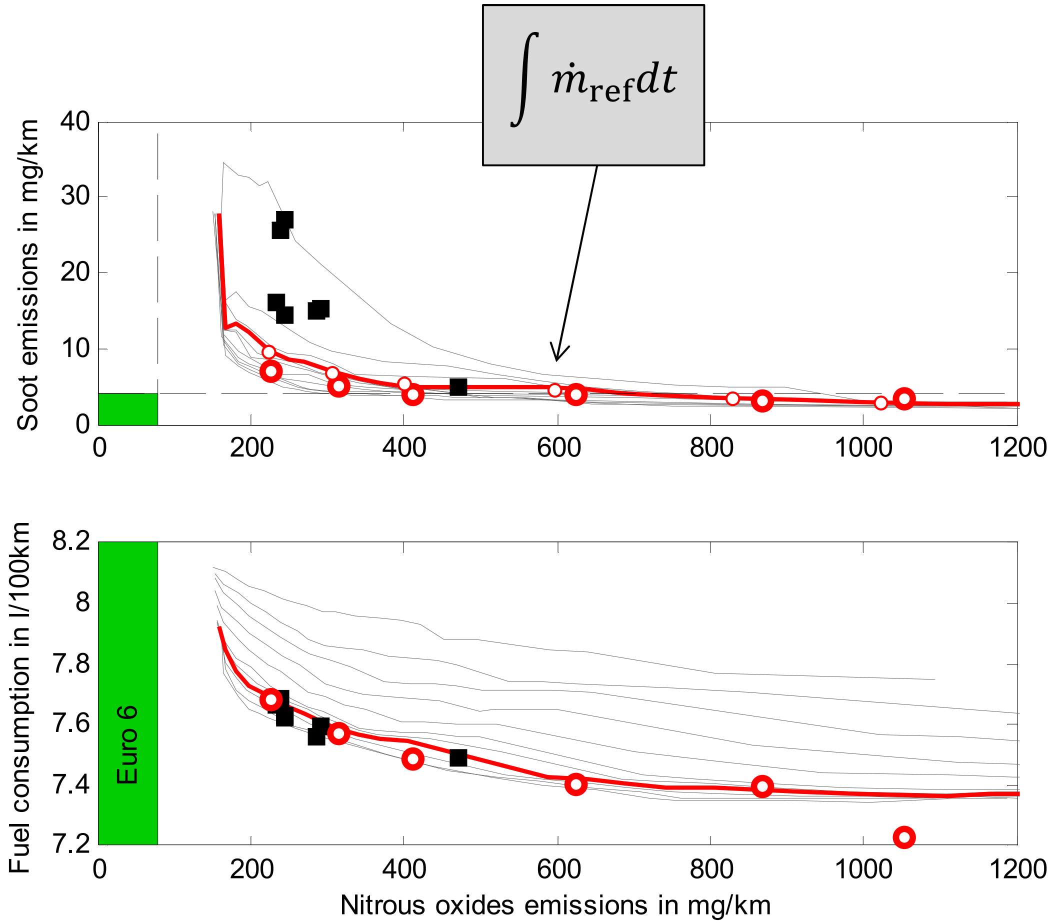
Trade-off in NEDC-Cycle



– Simulation
■ Benchmark
● Optimized

	$\frac{\int \dot{m}_{NO_x}dt - \int \dot{m}_{ref}dt}{\int \dot{m}_{ref}dt}$
1	+3.0%
2	+1.3%
3	+3.4%
4	+4.9%
5	+4.8%
6	+2.7%

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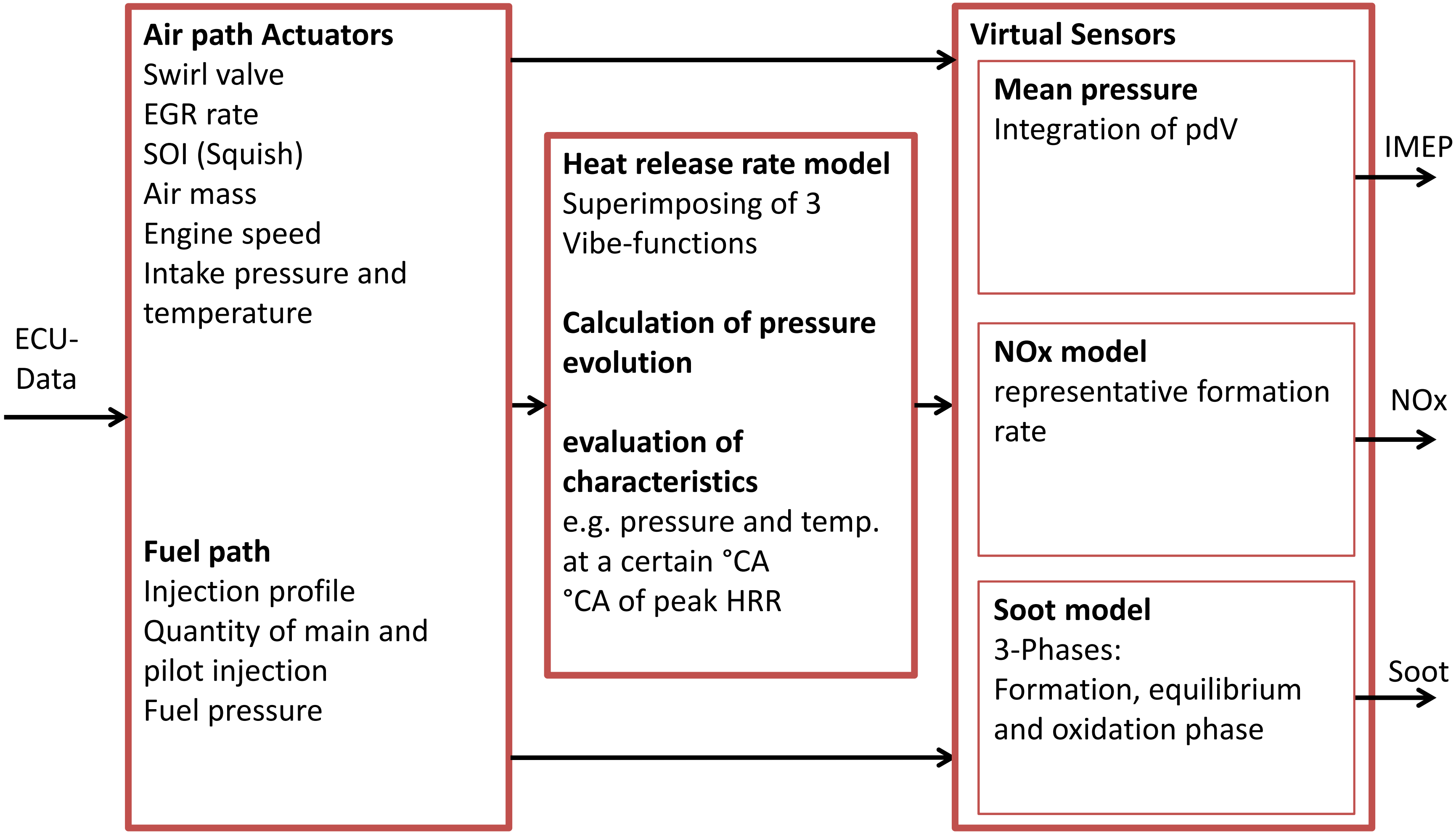
Virtual Sensor Concept



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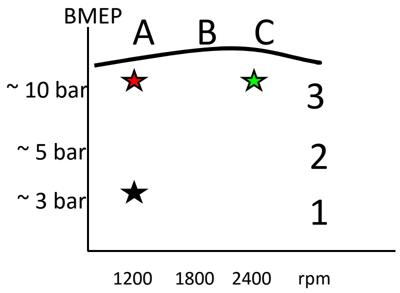
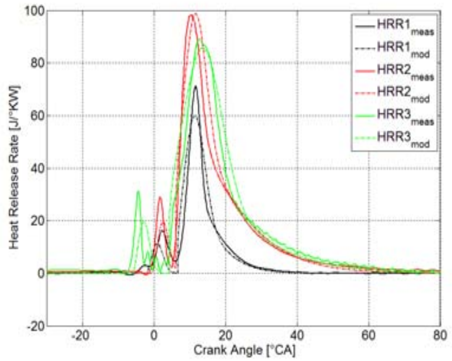
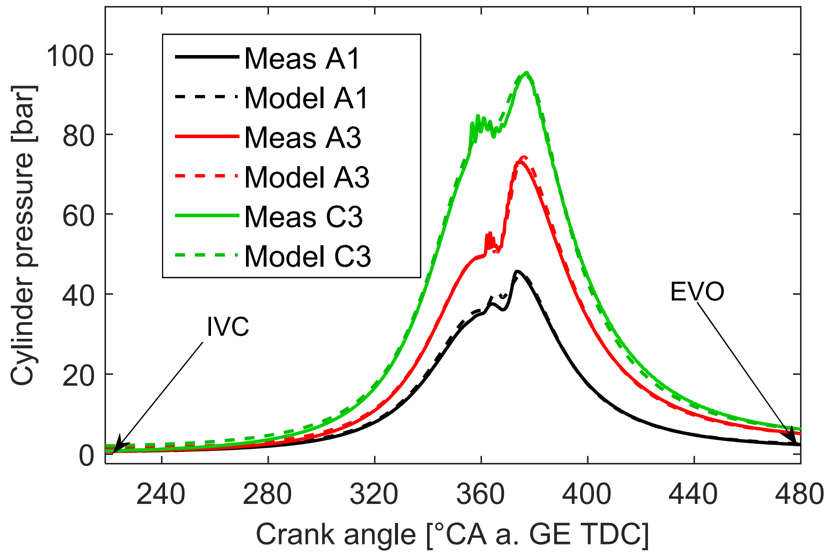
Validation of the Virtual Sensors

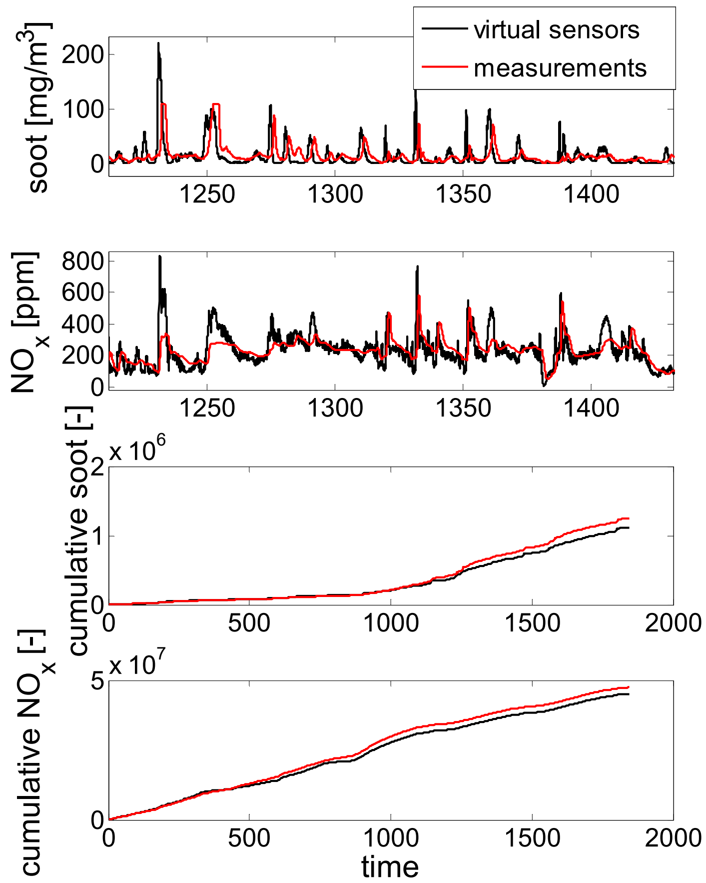




Cylinder Pressure, Measured & Modelled based on HRR



Calculated on-line by ECU



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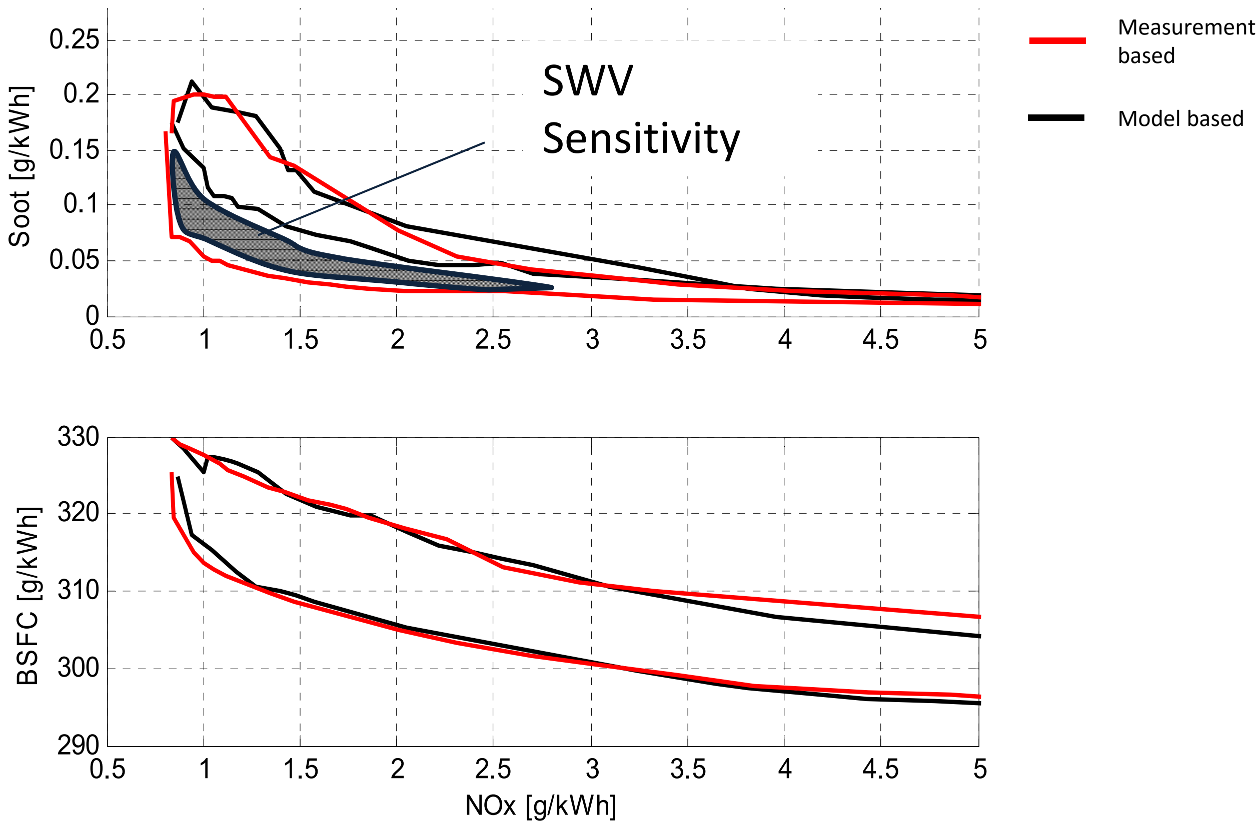
Virtual Sensor based Optimization

- Goal:
  - Replace the 1984 measurement points with model input
  - Easier conversion to a different engine
  - Include more degrees of freedom

- Quality of the solution depending on modelled sensitivity of actuators on emissions



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Conclusion & Outlook

- Optimum Calibration
  - Best available trade-off between soot, NOx and fuel consumption ✓
  - Systematic procedure for optimum ECU calibration ✓
  - Virtual sensor based calibration ✓
    - Using virtual sensors for **Soot + NOx and IMEP** ✓

- Future Work
  - Include more degrees of freedom (i.e boost pressure)
  - Adapt virtual sensors for alternative fuels
  - Include requirements from aftertreatment (i.e. exh. temperature, DPF pressure, regeneration strategy, etc…)
  - Include transient cycles

Acknowledgements

- Co-Authors, for their contributions
- Swiss Federal Office of Energy, for the financial support
- FVV, for the financial support

- You, for your kind attention