Model based development and calibration

Innovative ways to increase calibration quality within the limits of acceptable development effort!
MODEL BASED DEVELOPMENT

Challenges
Next steps EC/ JRC:
- Definition of PEMS boundaries (temperature, idling, altitude, inclination, …)
- Beginning of 2013: Screening of small fleet
- PEMS most likely to come, methodology to be defined until mid 2013
- Definition how EC will survey ISC (in addition to OEM tests)
ENGINE SPEED / LOAD DISTRIBUTION
EXAMPLES OF REAL WORLD DRIVING VS. TEST

RDE
PEMS

<100 km/h
dynamic Driver

NEDC

<100 km/h
moderate Driver

WLTP
Load Collective NEDC vs. RDE

Options for RDE:

- **Random test cycle:** Chassis Dyno Simulation
- **PEMS:** Measurement in customer driving with PEMS

→ Decision open
MODEL BASED DEVELOPMENT

Intention
Challenges in the Powertrain Development and AVLs Solutions

- CO2 / Fuel Consumption
- Real Driving Emissions
- Broad Vehicle Portfolio

AVL Solutions
- Clustering of hardware and engineering activities
- Reduced test facilities/variant through front-loading
- Multi-variant simulation with the same engine family (RDE, OBD, EAS)
- Improved quality and robustness through additional virtual validation
- Independence of environmental testing from seasonal conditions and vehicles availability

Model-Based Development

Reduction of development costs
Reduction of development time
Keep quality standards
Model Based Development
What is it?

• Model based development using a **real time capable engine model**

• Starting from **concept** phase until **SOP** calibration

• Engine model based on semi-physical modeling approach
  
  → **empirical model components derived from AVL experience and test bed data**
  
  → **physical components increase the range of application due to better extrapolation**

• Easy usability due to the use of suitable simulation environments

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Increasing system robustness within given development duration and budget by transferring development from real to virtual testing
## Definitions - Model Accuracy Levels

<table>
<thead>
<tr>
<th>Maturity Level</th>
<th>Description</th>
<th>Use Cases</th>
</tr>
</thead>
</table>
| Level 1       | Only the main geometrical data of the engine are used as input for model set-up | • Concept study and decision  
• ECU algorithm design  
• Exhaust gas aftertreatment (EAS) concept |
| Level 2       | Measurement data is used to make a refinement of the model to increase accuracy. | • Pre-Calibration: the possible calibration tasks depends on focus of the model parameterization  
• Used for specific calibration tasks |
| Level 3       | Model is adapted to steady state and transient data, measured at AVL. Highest accuracy which is needed for model based calibration. | • Variant calibration support  
• Ambient correction calibration (altitude/hot/cold)  
• EAS calibration strategy  
• OBD calibration support  
• Robustness investigations  
• ECU algorithm verification |
Model based Development Modelling Process

Virtual

MoBEO
basic model setup

MoBEO
refined model setup

Semi-physical
Basic Model without measurement data

Semi-physical
Thermodynamic NOx-Emission EAS System (DOC, DPF, SCR, NLT)

Empirical
static global
HC, CO, Soot, SPL...

Combined-model
Increased number of engine specific outputs

HiL Setup

MiL Setup

Model-based calibration of various variants
Variant specific hardware change (e.g. intake piping, …)
(No combustion HW change)

Robustness analysis

Pre-calibration

Testbed results

DoE Test Results

Model refinement

Field data

First engine run

Base engine testbed development

DoE Measurements

Field data

Emission validation

Environmental validation

Real
Model Accuracy
High model accuracy as base for model based calibration

Typical deviations of the cycle emissions and fuel consumption as well as achievable temperature accuracy:

- Fuel Consumption < 3%
- NOx Emission < 5%
- Insoluble Particulate Emission < 10%
- Temperature Intake Side < 10°C
- Temperature Exhaust Side < 20°C
Model Accuracy

High model accuracy as base for model based calibration

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MODEL BASED DEVELOPMENT
Application Environment
<table>
<thead>
<tr>
<th>Model in the Loop (MiL)</th>
<th>Hardware in the Loop (HiL)</th>
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</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td></td>
</tr>
<tr>
<td>+ Simulation faster than real time (app. 5 times)</td>
<td>+ All ECU functions available</td>
</tr>
<tr>
<td>+ No hardware parts needed</td>
<td>+ Pre-Calibration of all ECU functions possible</td>
</tr>
<tr>
<td>+ Simulation on normal PC possible</td>
<td>+ Possibility of ECU software and dataset validation</td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
<td></td>
</tr>
<tr>
<td>- Setup of software ECU time consuming</td>
<td>- Only real time simulation possible</td>
</tr>
<tr>
<td>- typically not all ECU functionalities available</td>
<td>- Need of hardware in the loop test bed</td>
</tr>
<tr>
<td>- Hard to achieve equal control behaviour as real engine</td>
<td>- Need of hardware parts</td>
</tr>
</tbody>
</table>

→ Both environments can be used for pre-calibration of specific tasks
Suitable Application Environment – As Prerequisite to Integrated a Model Based Calibration Methodology in an exciting Application Team

Standard Hardware-in-the-Loop test bed

- HiL operation system
- HiL automation system
- Calibration software (INCA,..)

Advanced AVL Hardware-in-the-Loop test bed extended with

- Advanced semi-physical powertrain model
- PUMA & CAMEO
  - Same interface for the calibration engineer as real test bed
- PUMA Host Connection
  - Simulation results stored in same format as real test data
- Post-Processing
  - Same CONCERTO Layouts can be used for data analyzing
- Calibration Software (INCA,..)
Application – From Virtual Test Bed to SOP

Virtual Test Beds as Extension of Real Test Facilities
MODEL BASED DEVELOPMENT

Use - Cases
Model Based Development
Concept Investigations

Model based concept investigations

- Assessment of technology route
- Simulation of transient behaviour of engine in early concept phase on MiL environment
- Definition of possible concepts considering the interaction between
  - engine
  - exhaust aftertreatment system
  - software and calibration
  - Sensors and actuators
  - environmental conditions

Vehicle & drivetrain simulation
Model Based Development Concept Investigations – DPF Soot Loading

**Boundary conditions:**
Tier4i engine
NO\textsubscript{X}/soot ratio < 10 [g/g]

If NO\textsubscript{X}/soot ratio increases
DPF soot load in balance point will be lowered.

Low engine out total soot emissions
allows also for conditions were
no CRT effect is observable a long operation
without DPF regeneration.
Soot Model accuracy can be reduced to a worst case scenario.

Simulation of specific duty cycles for different applications with respect to DPF soot loading behavior on HiL system → Calibration validation
Model Based Development Calibration of Ambient Corrections

Simulation of full load altitude operation for validation of ambient correction and engine protection functions

970 mbar = 350 m (Graz)
750 mbar = 2500 m
660 mbar = 3500 m
540 mbar = 5000 m

Limits for component protection
Model Based Development
Calibration of Component Protection Functions

Simulation of engine failure at full load for validation of engine protection functions

Limits for component protection
Ideas for Application of Model-Based-Development in OBD Calibration

**Validation of calibration**
- Functional check of calibration (Tested-Flag, P-Codes, etc.)
- Check of IUMPRs at different driving profiles (e.g. using same calibration for a commercial truck and a city bus)
- Robustness investigation and tolerances
- ...

**Pre-calibration**
- Pre-calibration of thresholds, enable/release conditions, debouncing
- Simulation of fault-parts (e.g. EGR-orifice, broken DPF, etc.)
- Multi-Variant calibration (e.g. adjustment from lead-calibration to a follow-up variant)
- ...

Evaluation and R&D projects currently ongoing
Calibration on Hardware-in-the-Loop test beds

Virtual Test Beds as Extension of Real Test Facilities

Powertrain calibration tasks for HiL test bed

- Pre-calibration of different calibration work packages
- Calibration for non-standard ambient conditions
- Calibration of component protection
- Vehicle/Engine derivate calibration
- RDE – Real Driving Emission evaluation
- Real world fuel consumption optimization
- Sensitivity studies taking into account system interactions
- Software and dataset validation
Front-Loading Example

Ideal Lead Variant Calibration Project (i.e. no relevant H/W changes)
Multi-variant projects can be addressed by: an extension of the test environment through HiL (MiL/SiL) Testing

- Keep calibration quality through additional HiL testing, though high number of variants
- Multi-variant simulation (calibration clustering, RDE, EAS, OBD)
- Keep test facilities usage by a feasible level
- Make environmental testing more flexible and efficient
Calibration Process and Dataset Management

Validation by:
1. Dataset Management (Dataset Merging, Clustering, Tracing)
2. Automated HiL Dataset validation und consideration of different production tolerances in advance to dataset freeze
3. A extensive model based fleet validation with active search for critical events.
Conclusion - *Innovative ways to increase calibration quality within the limits of acceptable development effort!*

- Shifting of development tasks in earlier phases and well proven concept decisions
- Reduction of project duration due to additional virtual test facilities
  - Independent from environmental conditions
  - Independent from vehicle availability
  - Higher efficiency for real testing
- **High dataset quality due to good monitoring and solid validation**
Thank you for your attention