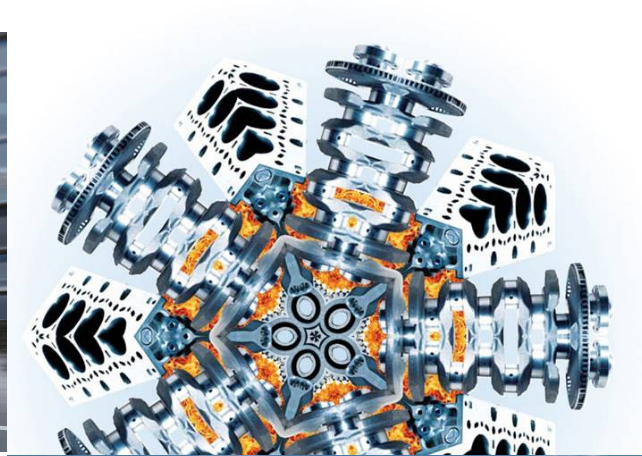
Model based development and calibration

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



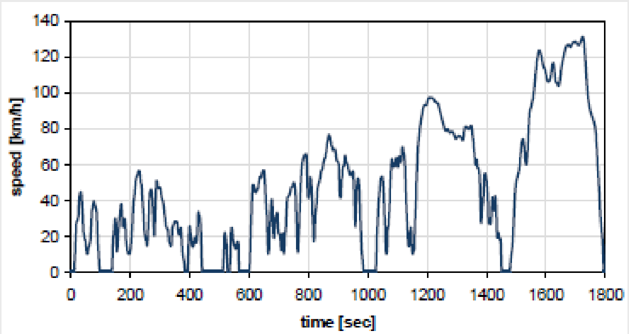
MODEL BASED DEVELOPMENT

Challanges

EUROPEAN EMISSION LEGISLATION PASSENGER CARS

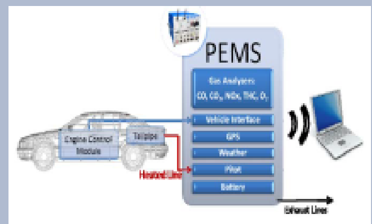
WLTP
(World light duty test procedure)

	WLTC	NEDC
acceleration	1,8 m/s²	1,0m/s²
mean velocity	46 km/h	33 km/h
idle share	13 %	23%



PEMS
(portable emission measurement system)

- on-board measurement
- real on-road driving
- real temperature cond.

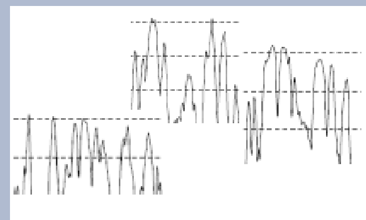


Currently no PN-measurement

OR

RTC
(random test cycles)

- vehicle @ dyno
- random based on EU-database (20.000 trips)

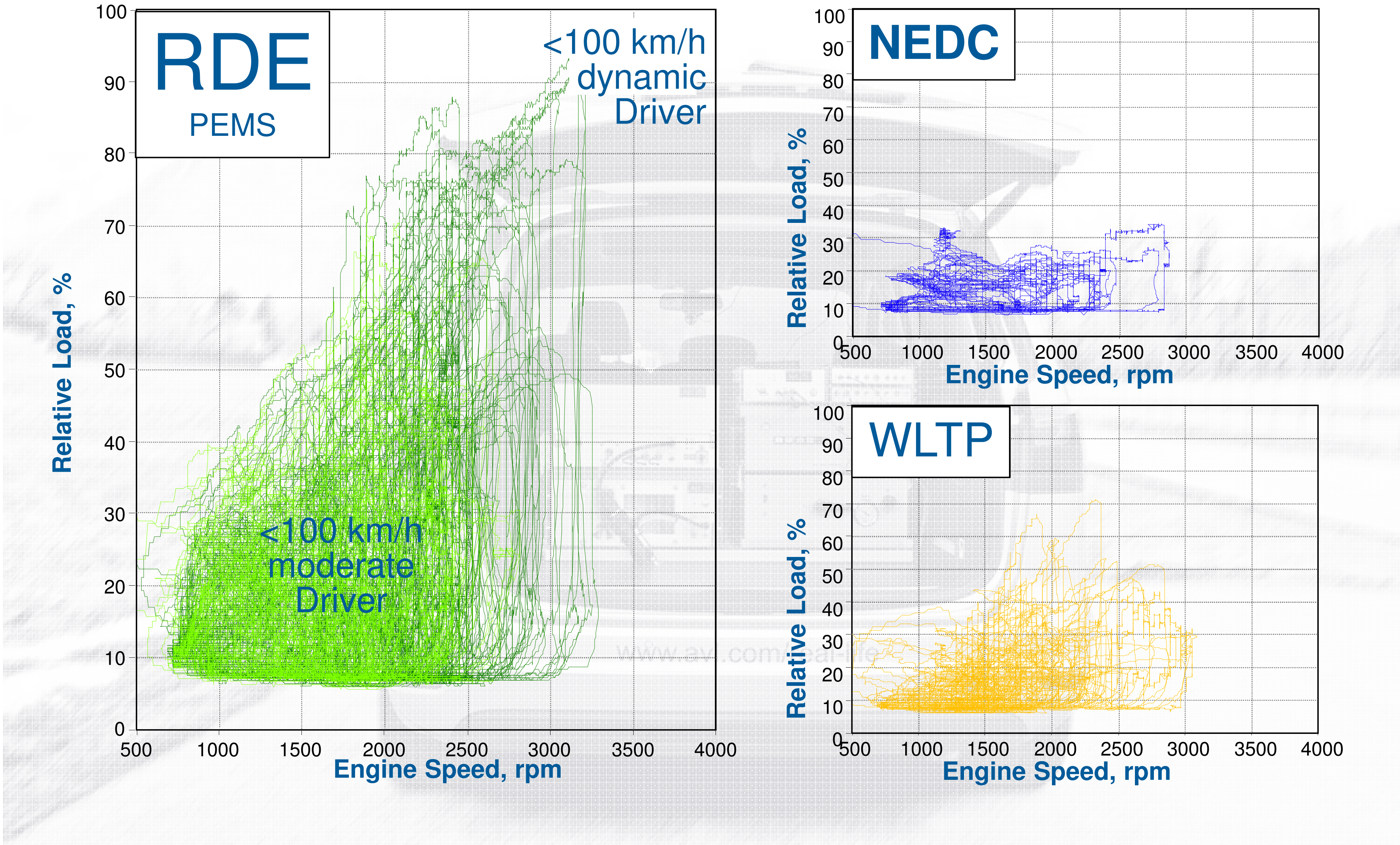


Currently limited ambient temperature

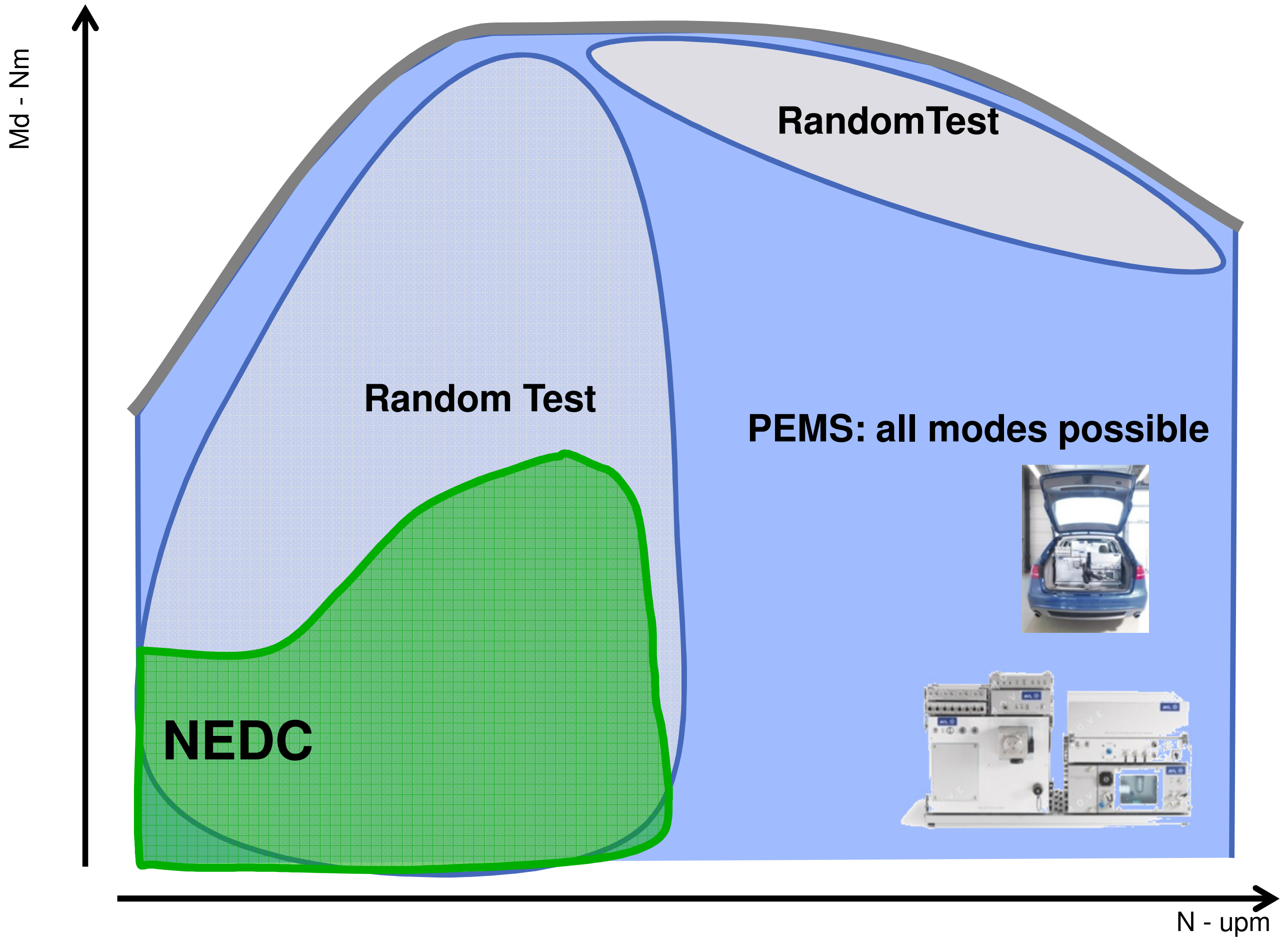
Next steps EC/ JRC:

- 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



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

AVL

CO2 / Fuel Consumption

Real Driving Emissions

Broad Vehicle Portfolio

Increased system complexity (EAS, OBD, Hybridization)

€ Reduction of development costs

Reduction of development time

Keep quality standards

AVL Solutions

Clustering of hardware and engineering activities

Reduced test facilities/variant through front-loading

Independence of environmental testing from seasonal conditions and vehicles availability

Multi-variant simulation with the same engine family (RDE, OBD, EAS)

Improved quality and robustness through additional virtual validation

Model-Based Development

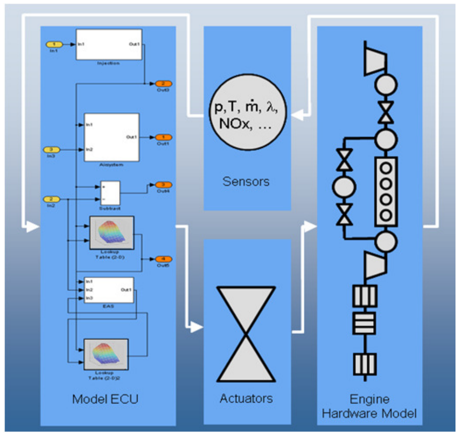
Model Based Development
What is it?

- 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

Increasing system robustness within given development duration and budget by transferring development from real to virtual testing

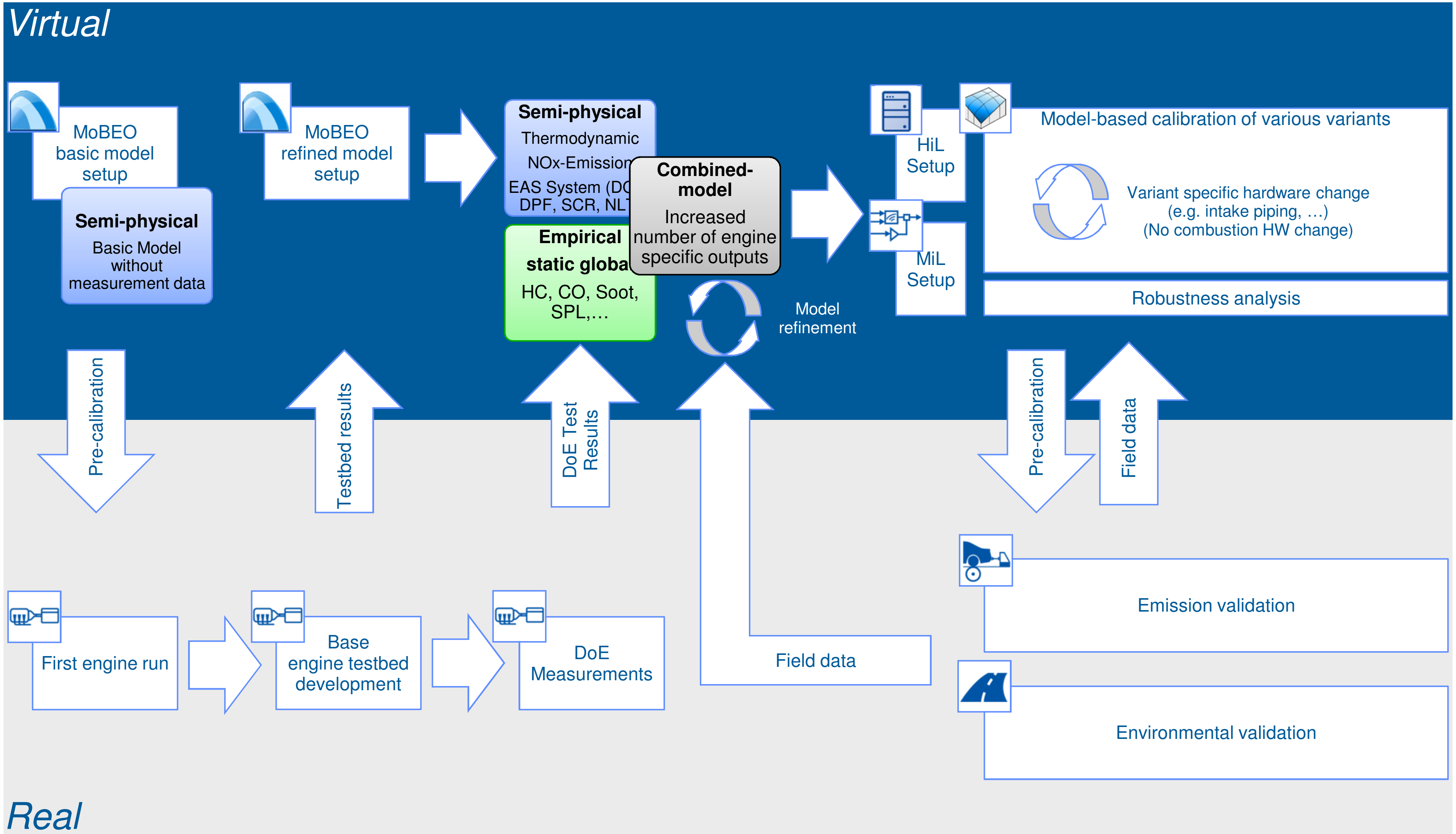


Definitions - Model Accuracy Levels

Maturity Level	Description	Use Cases
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

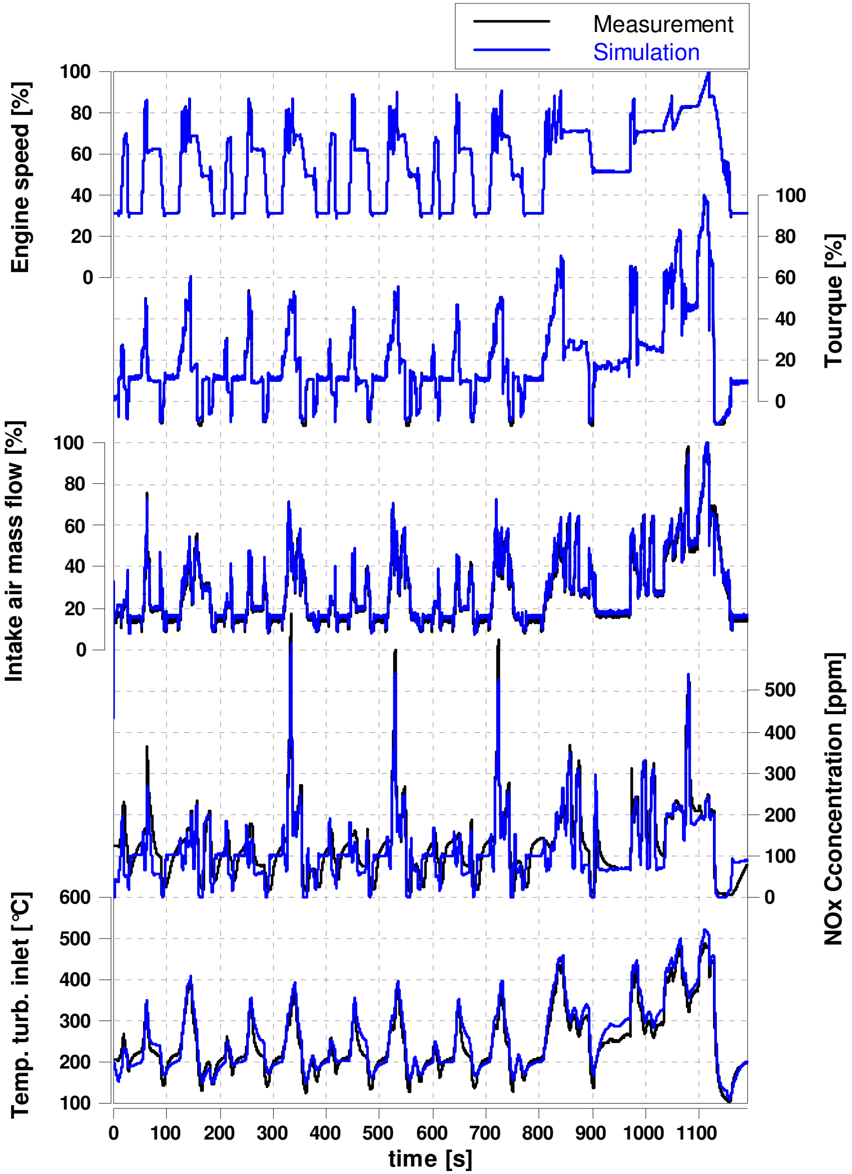
Model based Development
Modelling Process

AVL

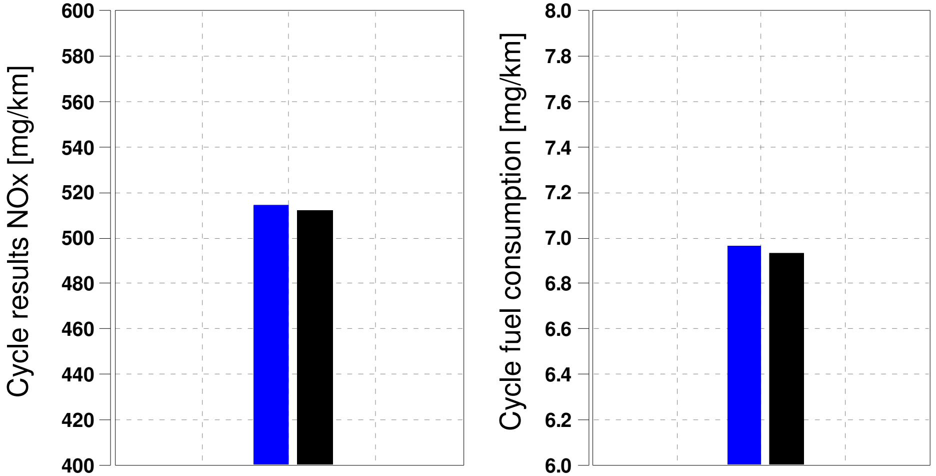


Model Accuracy

High model accuracy as base for model based calibration



Cycle results - NEDC

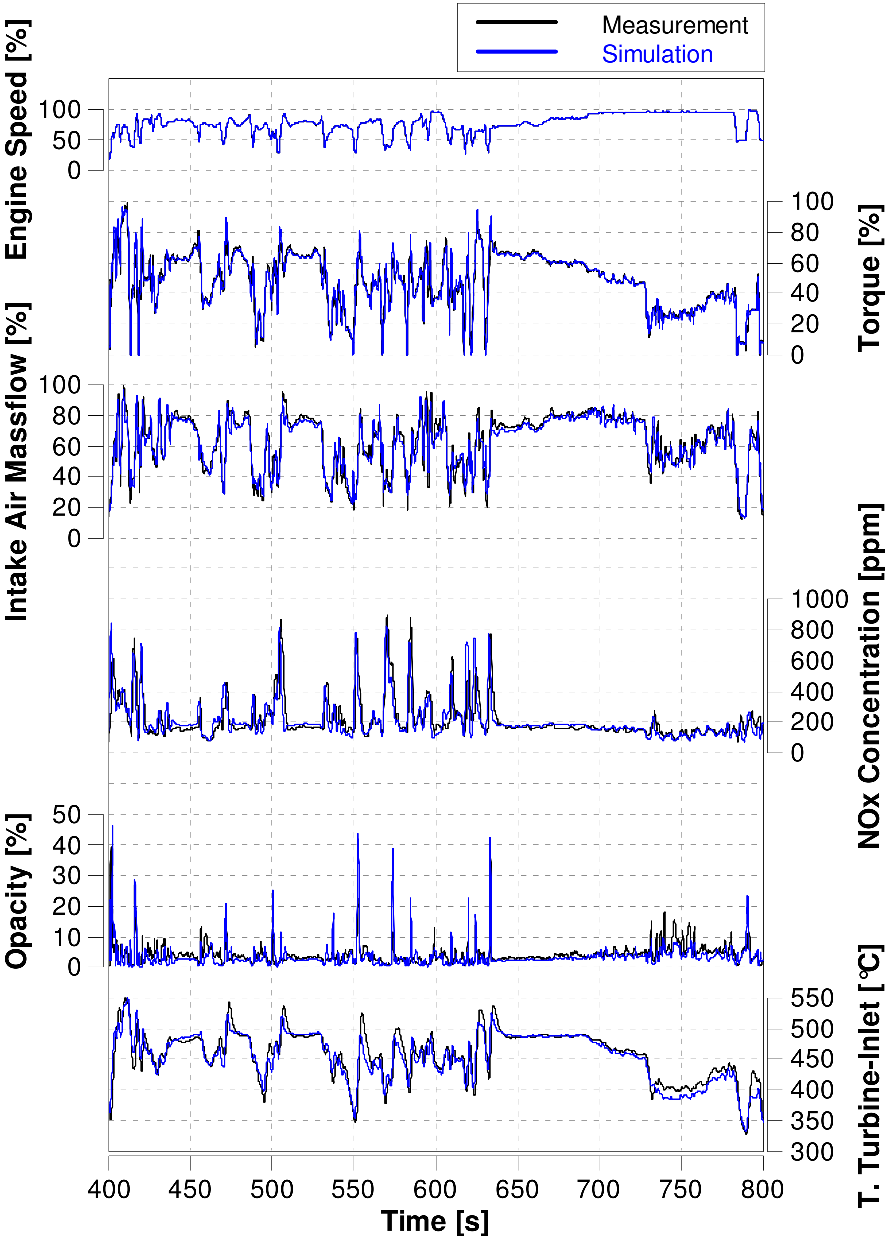


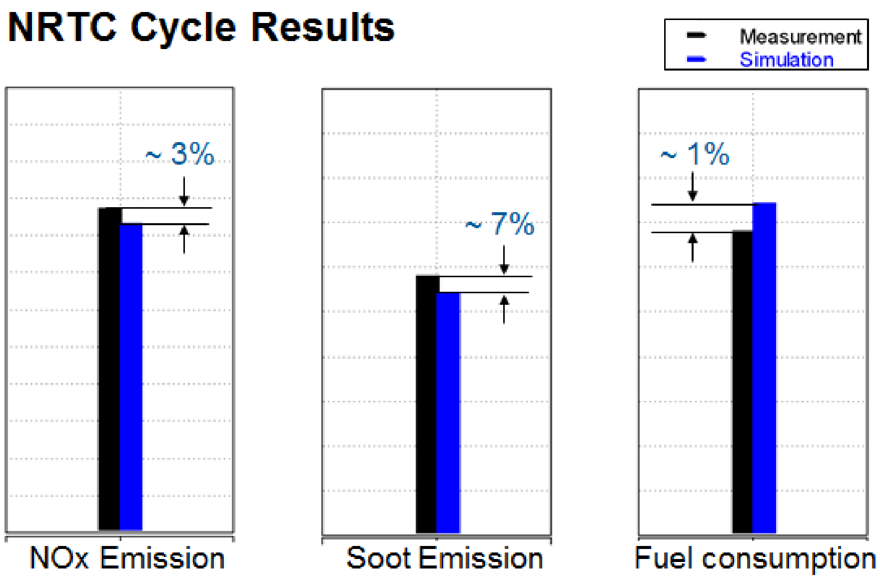
Typical deviations of the cycle emissions and fuel consumption as well as achievable temperature accuracy:

- Fuel Consumption < 3%
- NOx Emission < 5%
- Insoluble Particulate Emission < 10%
- Temperature Intake Side < 10℃
- Temperature Exhaust Side < 20℃

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 BASED DEVELOPMENT

Application Environment

Model Based Development
Virtual test beds – Comparison Simulation Environment

Model in the Loop (MiL)

Advantages

+ Simulation faster than real time (app. 5 times)
+ No hardware parts needed
+ Simulation on normal PC possible

Disadvantages

- Setup of software ECU time consuming
- typically not all ECU functionalities available
- Hard to achieve equal control behaviour as real engine

Hardware in the Loop (HiL)

Advantages

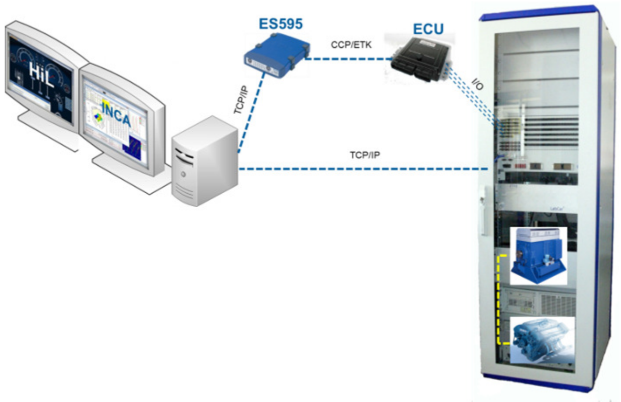
+ All ECU functions available
+ Pre-Calibration of all ECU functions possible
+ Possibility of ECU software and dataset validation

Disadvantages

- Only real time simulation possible
- Need of hardware in the loop test bed
- Need of hardware parts

→ **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

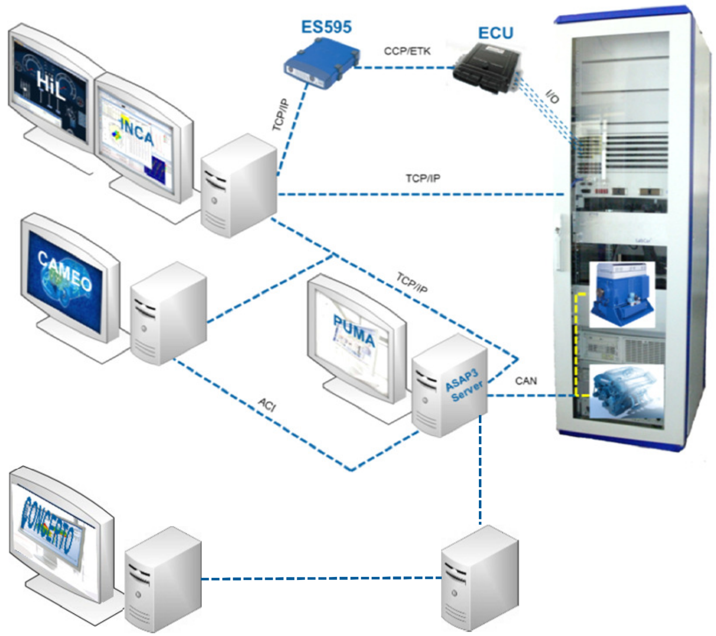
→ PUMA Host Connection

Simulation results stored in same format as real test data

→ Post-Processing

Same CONCERTO Layouts can be used for data analyzing

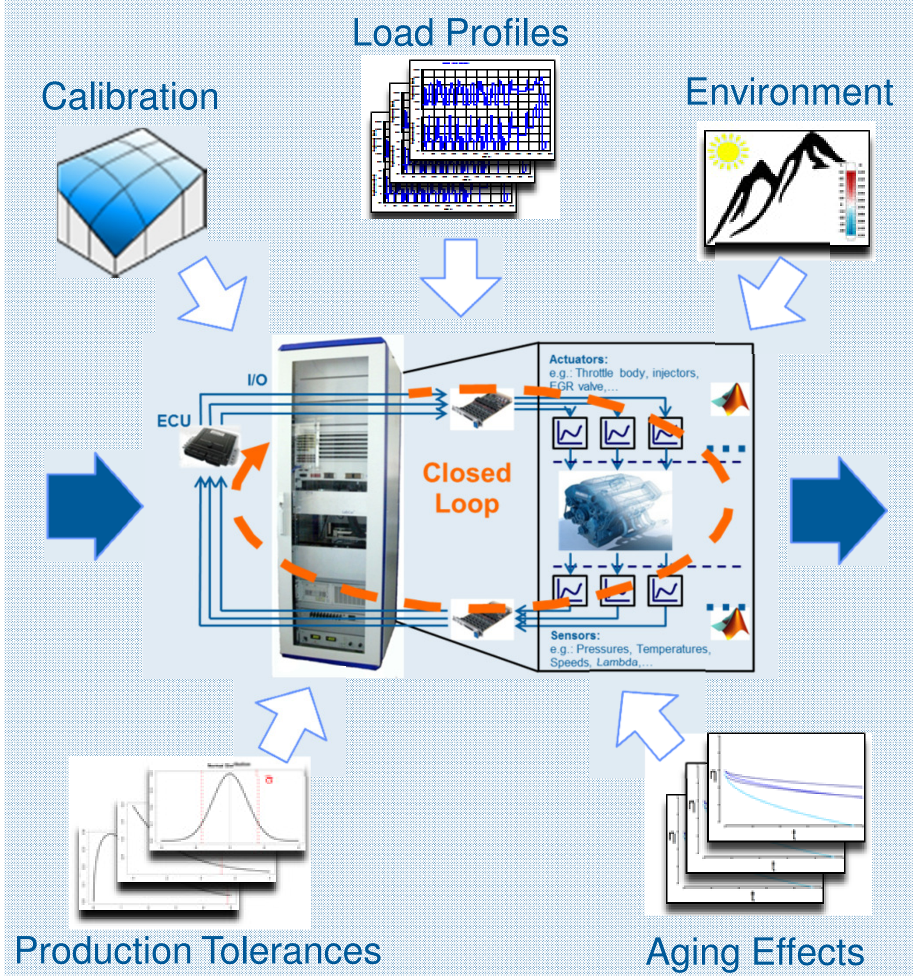
→ Calibration Software (INCA,…)



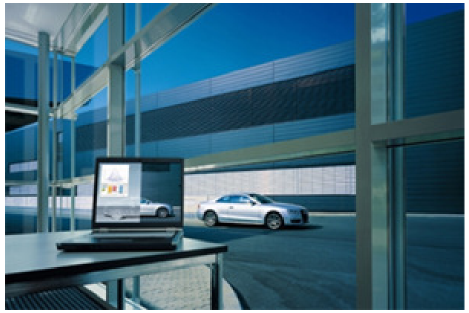
Application – From Virtual Test Bed to SOP

Virtual Test Beds as Extension of Real Test Facilities

Test Bed



Virtual Test Bed



Vehicle Validation

MODEL BASED DEVELOPMENT

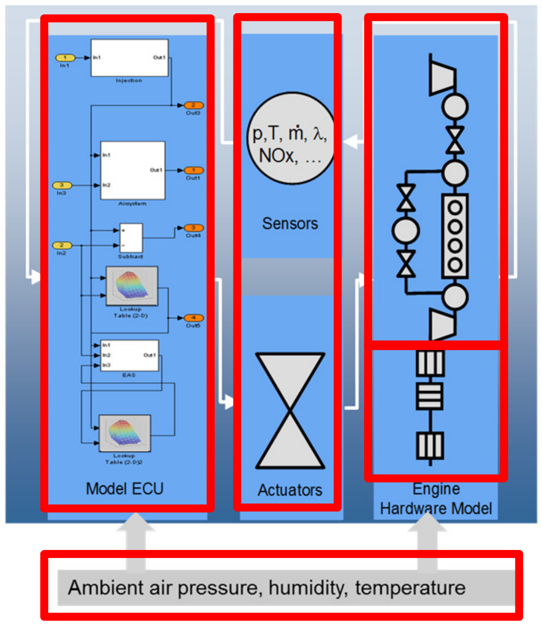
Use - Cases

Model Based Development
Concept Investigations

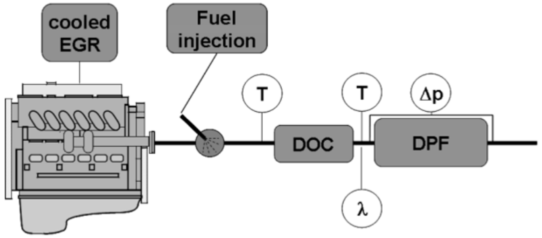
Model based concept investigations

- 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



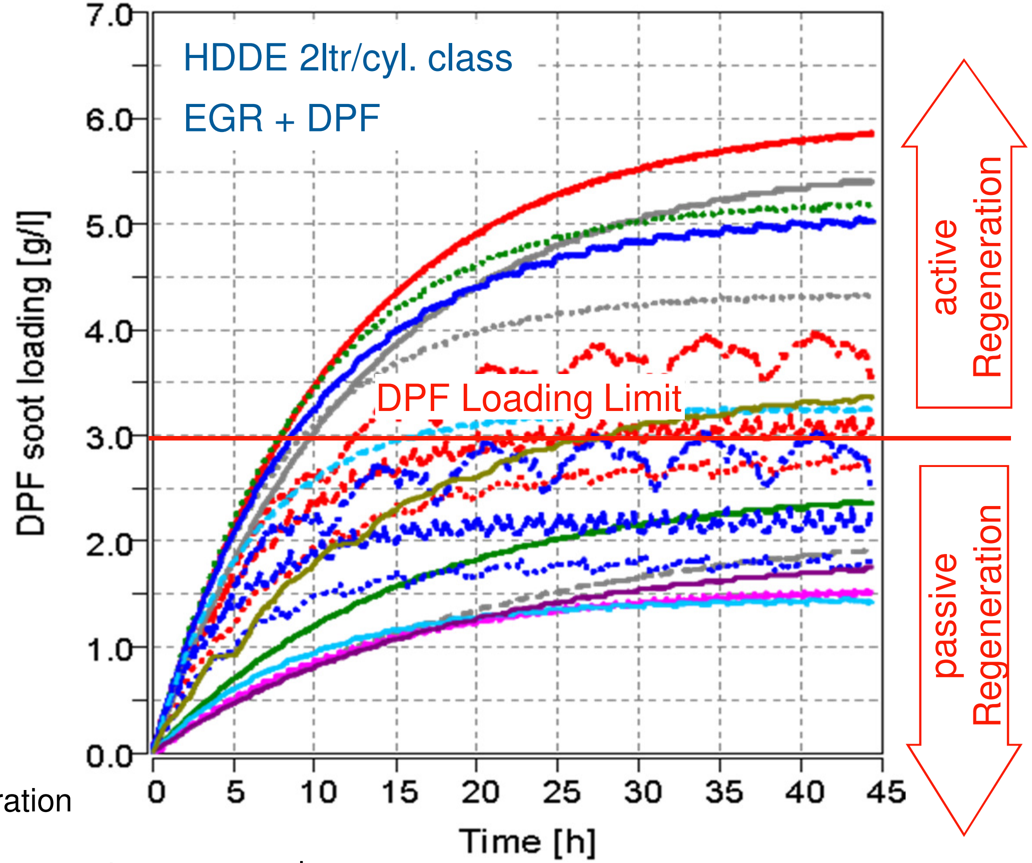
Model Based Development
Concept Investigations – DPF Soot Loading

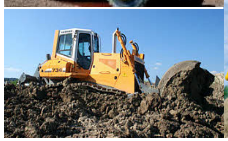


Boundary conditions:
Tier4i engine
NO_X/soot ratio < 10 [g/g]

If NO_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.





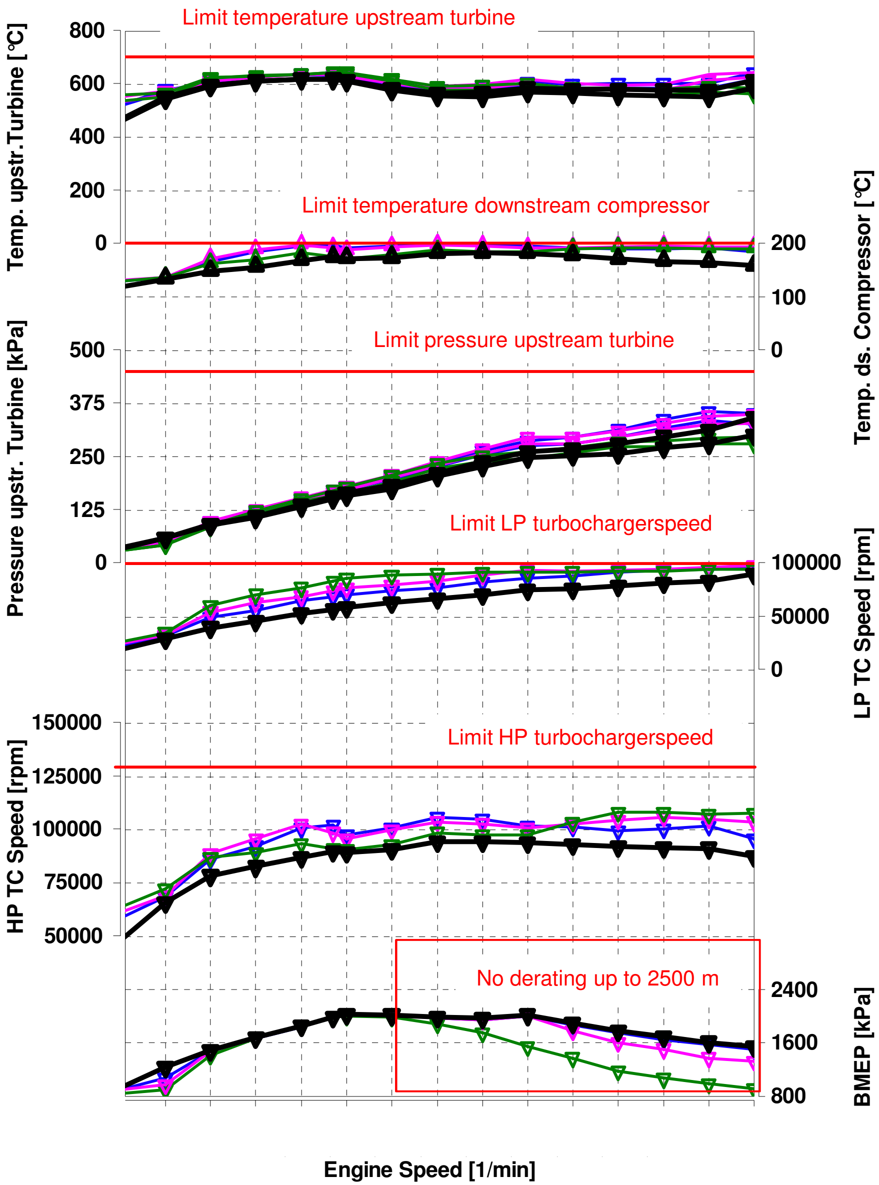
Simulation of specific duty cycles for different applications with respect to DPF soot loading behavior on HiL system → Calibration validation

Model Based Development
Calibration of Ambient Corrections

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

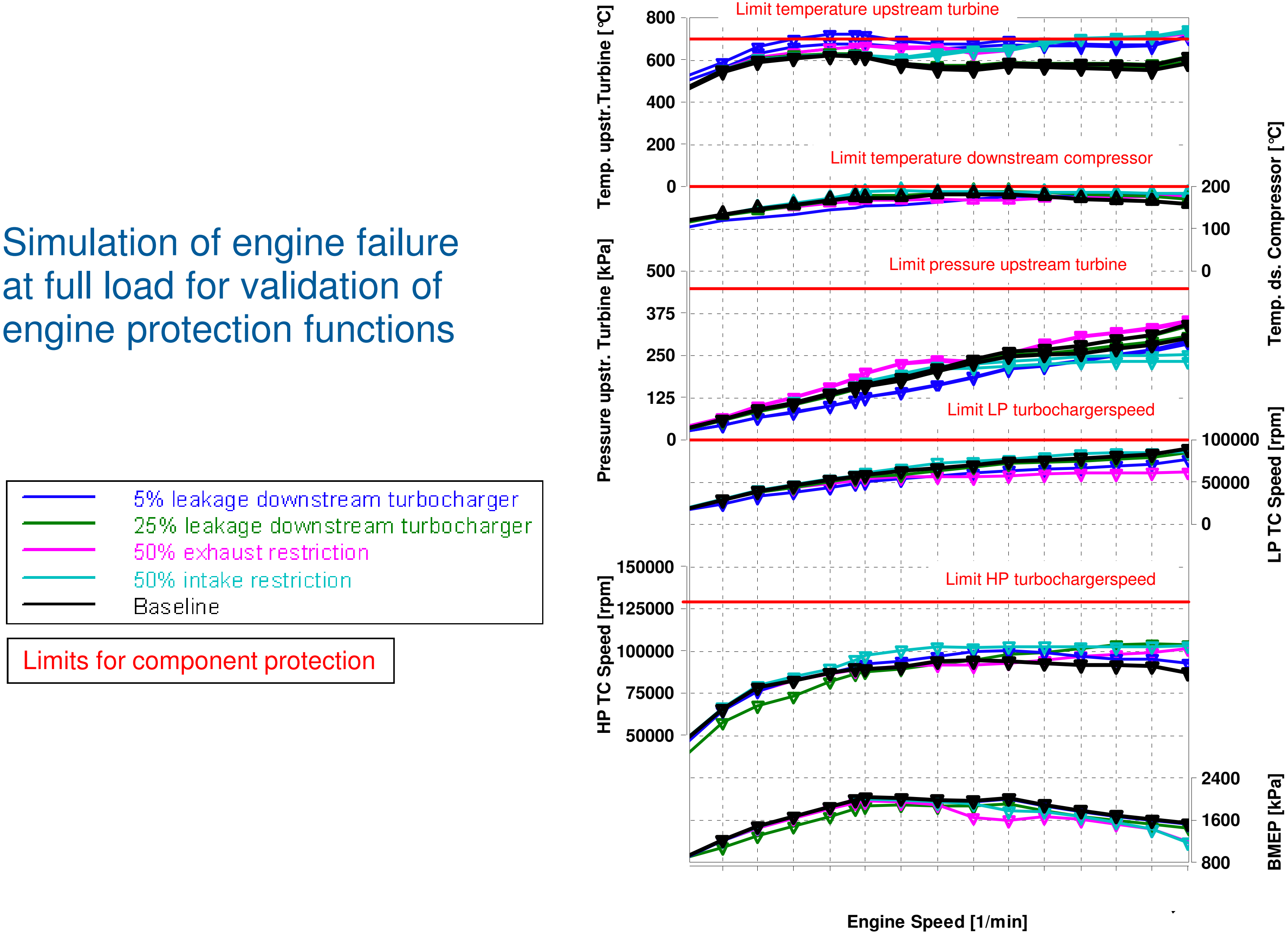
970mbar = 350m (Graz)
750mbar = 2500m
660mbar = 3500m
540mbar = 5000m

Limits for component protection

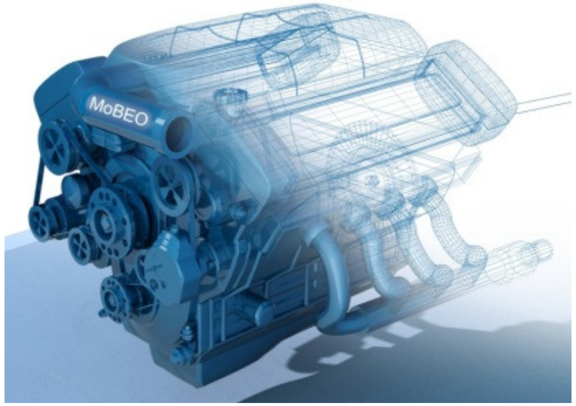


Model Based Development
Calibration of Component Protection Functions

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



Ideas for Application of Model-Based-Development in OBD Calibration



Validation of calibration

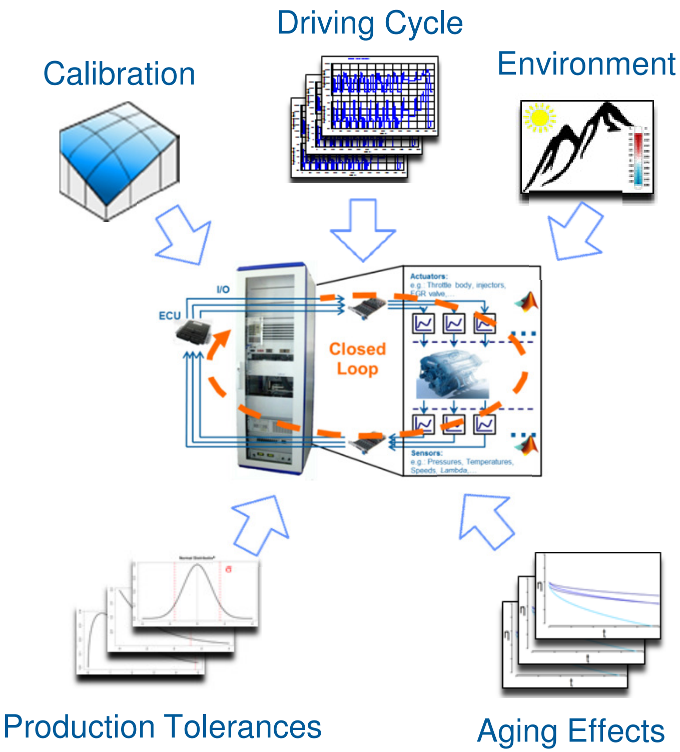
- Functional check of calibration (Tested-Flag, P-Codes, etc.)
- Check of IUMPRs at different driving profiles (e.g. using same calibration for a commercial truck and a city bus)
- Robustness investigation and tolerances
- …

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



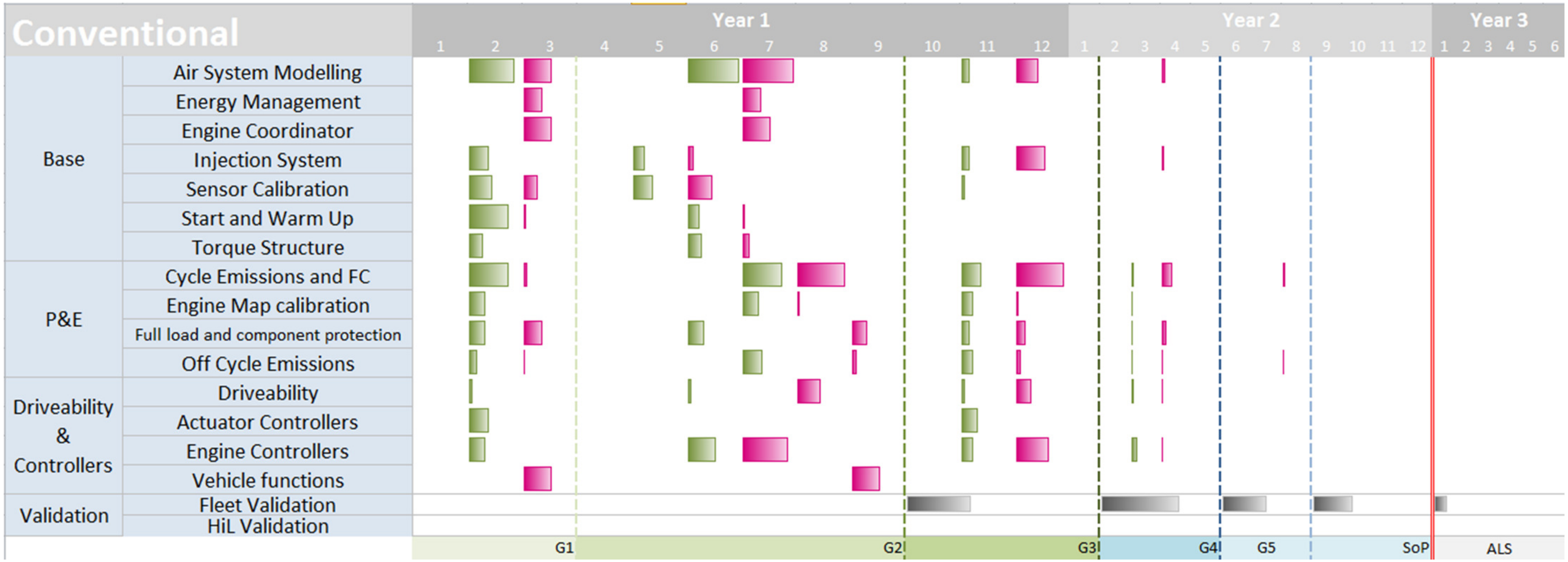
Powertrain calibration tasks for HiL test bed

- 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

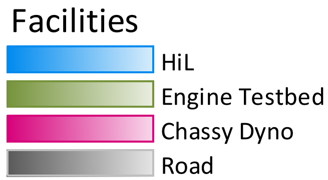
Ideal Lead Variant Calibration Project (i.e. no relevant H/W changes)

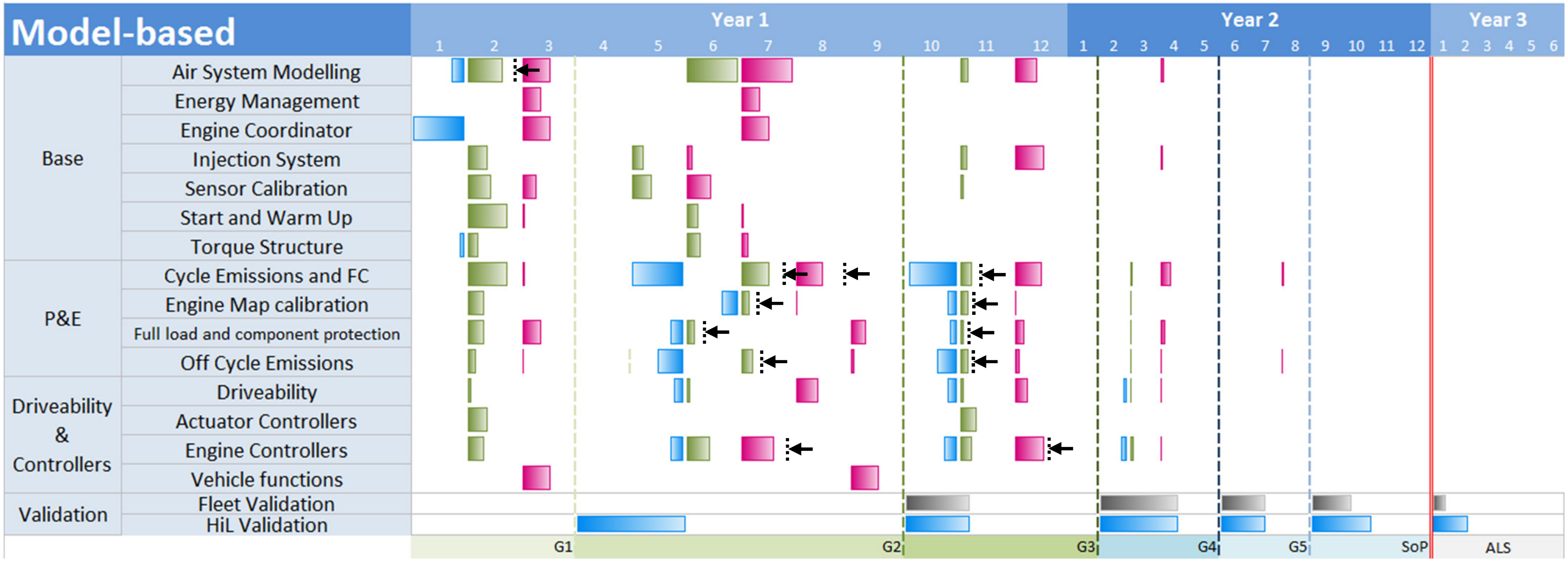
Facilities
HiL
Engine Testbed
Chassy Dyno
Road



Front-Loading Example

Ideal Lead Variant Calibration Project (i.e. no relevant H/W changes)

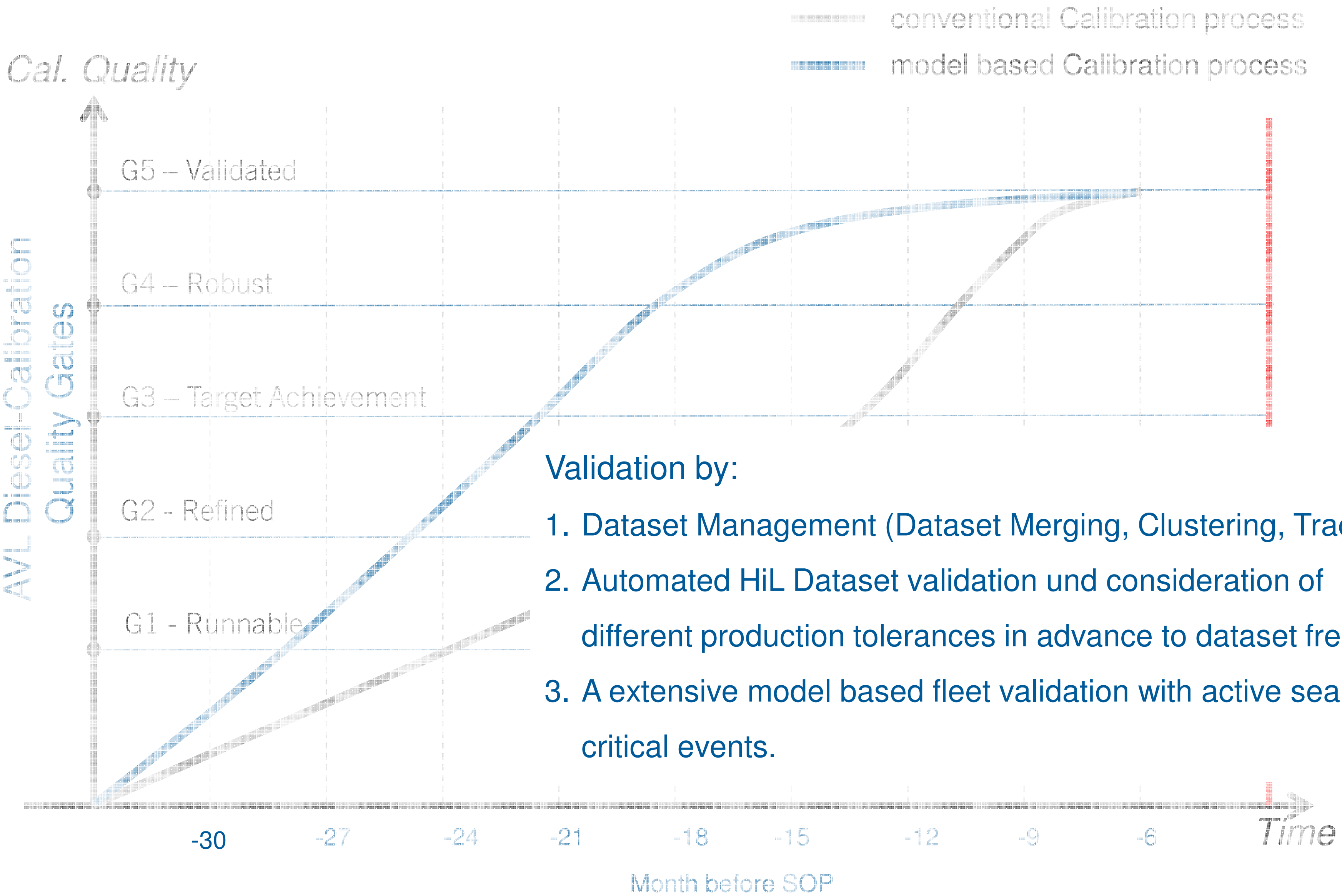




Multi-variant projects can be addressed by: an extension of the test environment through HiL (MiL/SiL) Testing

- 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.

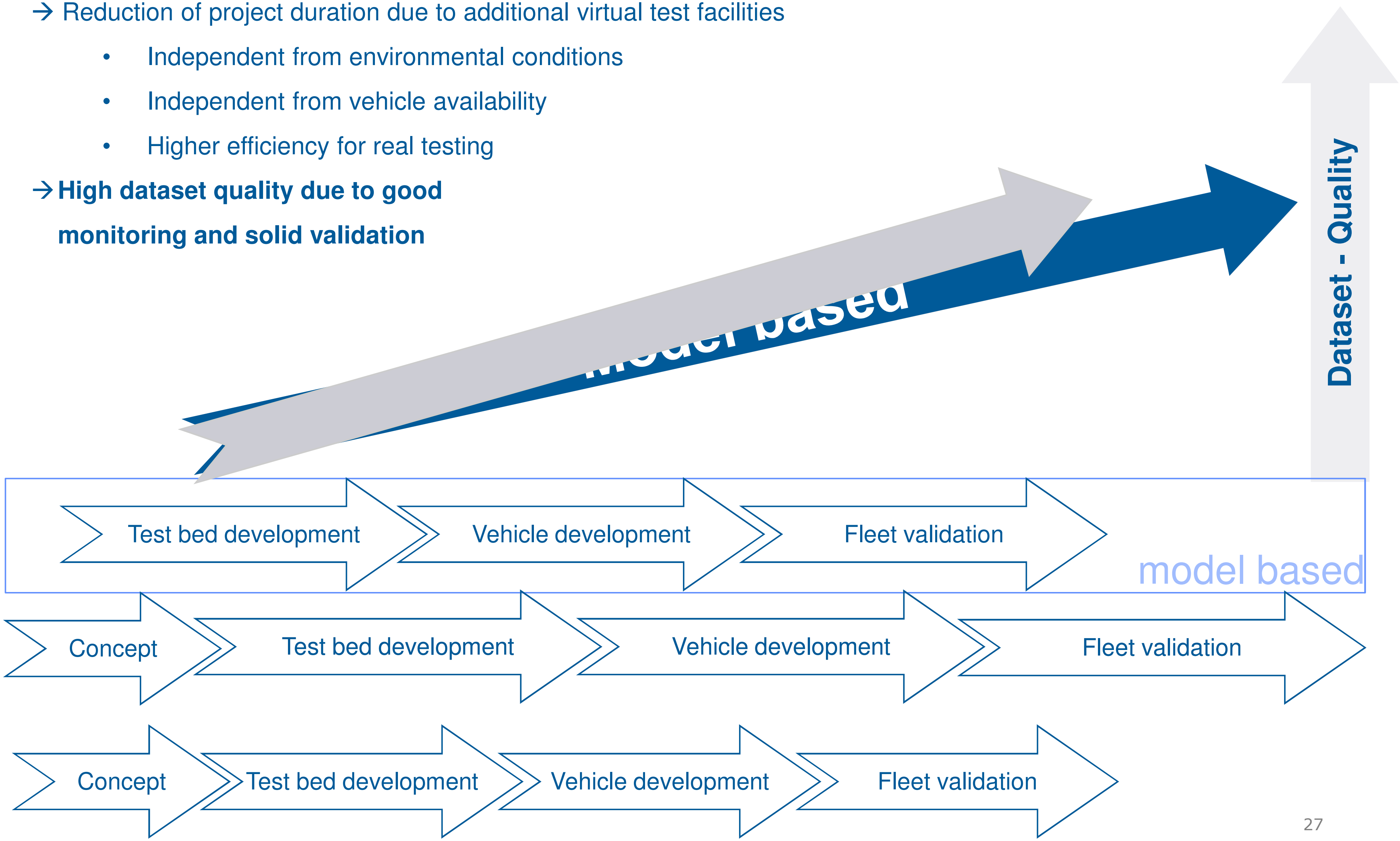
Conclusion - *Innovative ways to increase calibration quality within the limits of acceptable development effort!*

→ 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**



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