Chip Simulation for Virtual ECUs

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Virtual ECUs and Applications
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Contents

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- **Background**
- Concept of model based simulation environment
- Engine simulation model
  - ECU model
  - Combustion model
  - Catalyst model
- RDE simulation combined with vehicle simulation model
- Summary

2018 model new Civic

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Fuel economy (CO_2) Modified NEDC

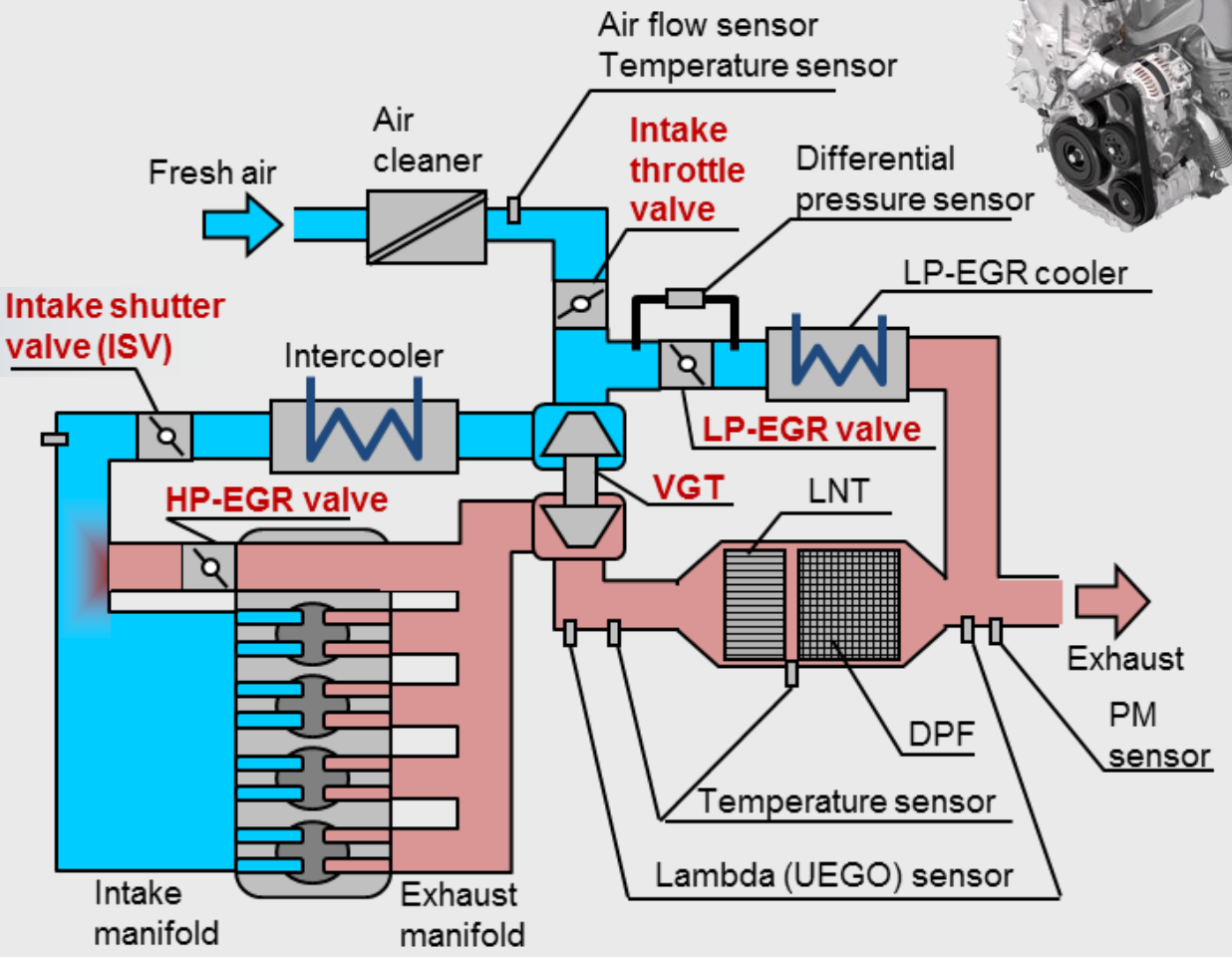
91 g/km (6MT, Sedan)
93 g/km (6MT, Hachback)
109 g/km (9AT)

Exhaust emissions

Euro6d-TEMP

Civic

1.6L diesel engine



Passed RDE regulation and achieved 91 g/km

RDE definition

	Chassis dynamometer	RDE
		 
Vehicle speed profile	Fixed	Depends on vehicle, driver, route, and traffic
Environment (Ta, Pa)	Fixed	Depends on season, weather, wind, and altitude
Road load force	Straight, w/o gradient (w/o PEMS)	Depends on curves, altitude, road surface, passengers, and baggage (with PEMS)
Repeatability	with	w/o

Difficulty to check RDE performance at all conditions during development

Method for calibration and validation

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Validation in real world → Easy to simulate and calibrate

Tests on road	Chassis dynamometer (vehicle) + vehicle simulation	Engine test bed (engine) + vehicle simulation	Model (engine) + vehicle simulation
		EiL (Engine in the Loop)	MiL (Model in the Loop)
 PEMS	 	 	 
Vehicle simulation: consideration of road load force change due to curves, altitude, and road surface (weather, wind)			

Necessity of model utilization for efficient development

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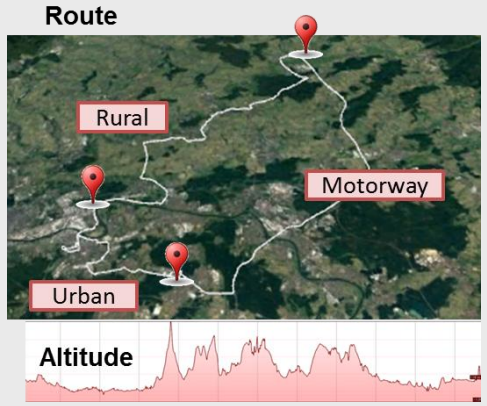
Flowchart of model utilization



Vehicle simulation

(NEDC, WLTC, RDE) etc.

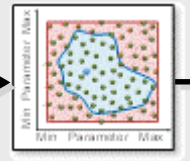
Vehicle model
Driver model
Route model
Traffic model

Ne, Te, Gear, V, etc.

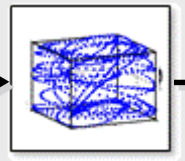
Engine simulation

Experiment definition

Boundary finder

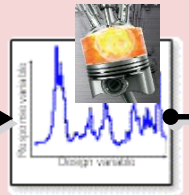


Dynamic DoE



Transient measurement (environmental engine bench)

Dynamic statistical combustion model



ECU model

Catalyst model

Synthetic gas flow test bed

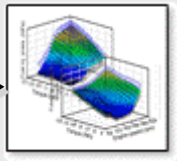
Calibration target

Base maps, environmental corrections, controllers, aftertreatment control etc.

Silver software

.hex
.a2l
.map

Simulation and optimization



Verification

Vehicle test

Coupling of vehicle simulation and engine simulation

Engine simulation model

Vehicle simulation

Ne
Te
Tw
Ta
Pa
Gear
V

ECU model

Combustion model (Dynamic data based statistical model)

Inputs:
Ne (Engine speed)
Te (Brake torque)
Main injection timing
Fuel injection pressure
VGT opening
HP-EGR valve opening
LP-EGR valve opening
Intake throttle valve opening
Intake shutter valve opening
Tw (Coolant temperature)
Ta (Ambient temperature)
Pa (Ambient temperature)
Combustion mode signal

Outputs:
Emissions, temperatures, etc. including sensor values fed back to the ECU model

Catalyst model (LNT physical model)

Engine outlet emissions

Tailpipe emissions

Combination of ECU, combustion, and catalyst models

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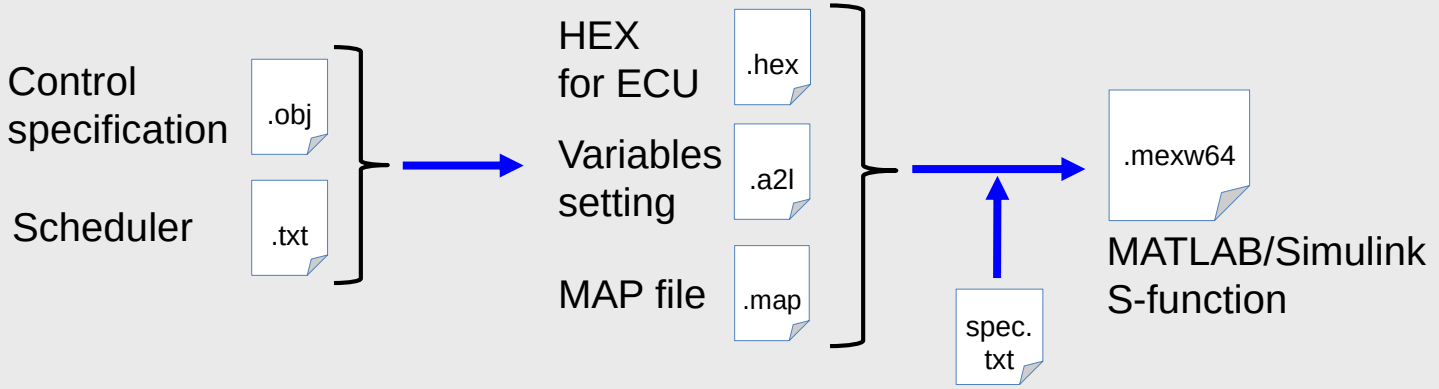
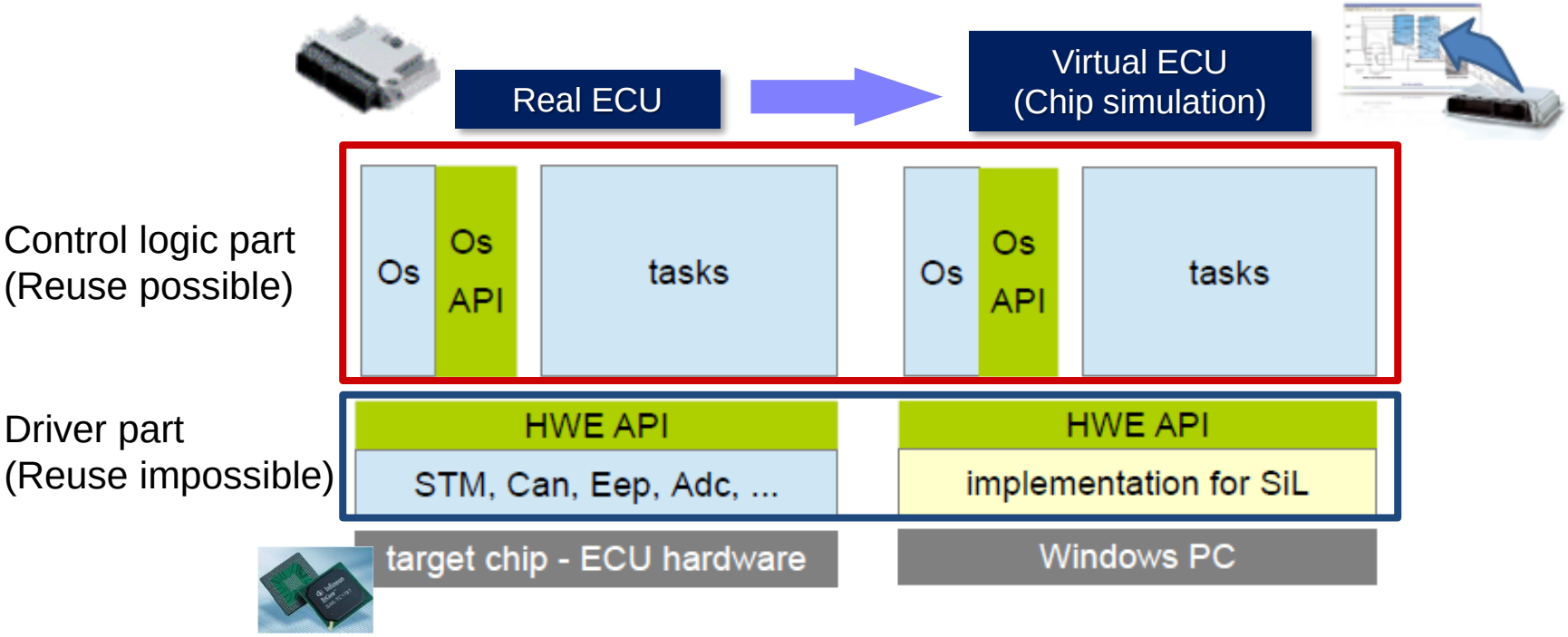
Chip simulation for virtualize an ECU





Simulation based on HEX without control model and C code

Combustion modeling approach

Physical model (0D-3D)	Statistical model (Empirical model, DoE model)
	
Use case: concept study, advanced research	**Use case: calibration, validation**
Necessity of parameters tuning based on measurement data	Necessity of engine hardware and training data
Higher number of adjustment parameters	Lower number of fitting parameters
High predictive accuracy even at model extrapolation region	High predictive accuracy at model interpolation region
High dimension -> low calculation speed	High calculation speed
Suitable for engine hardware development and phenomenological analysis	Suitable for model based engine calibration (optimization)

Statistical model is suitable for efficient calibration at later stage of development

Advantage of dynamic DoE model

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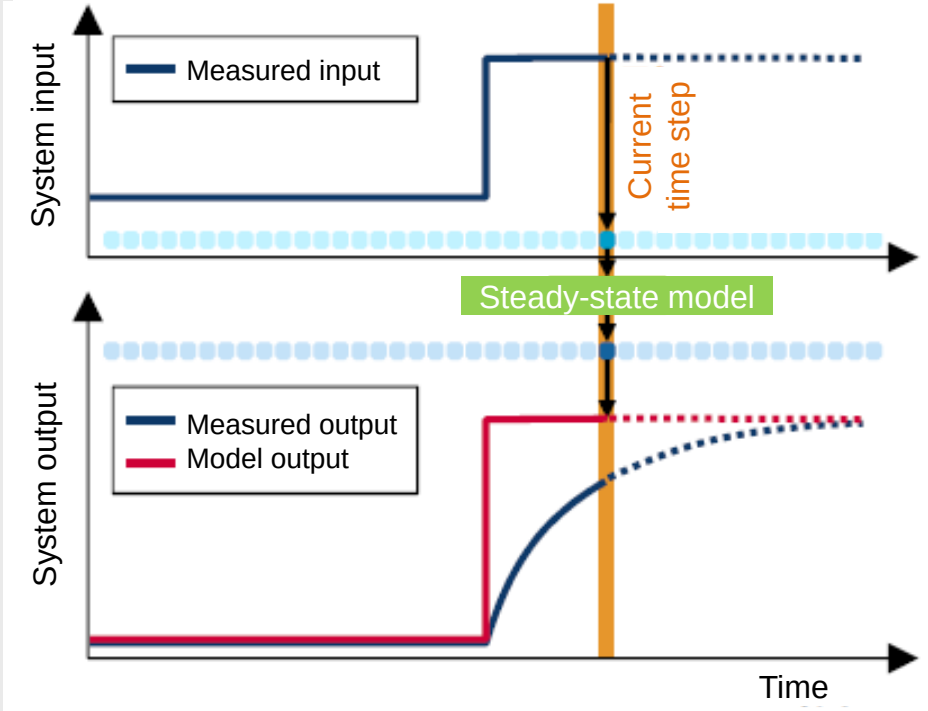
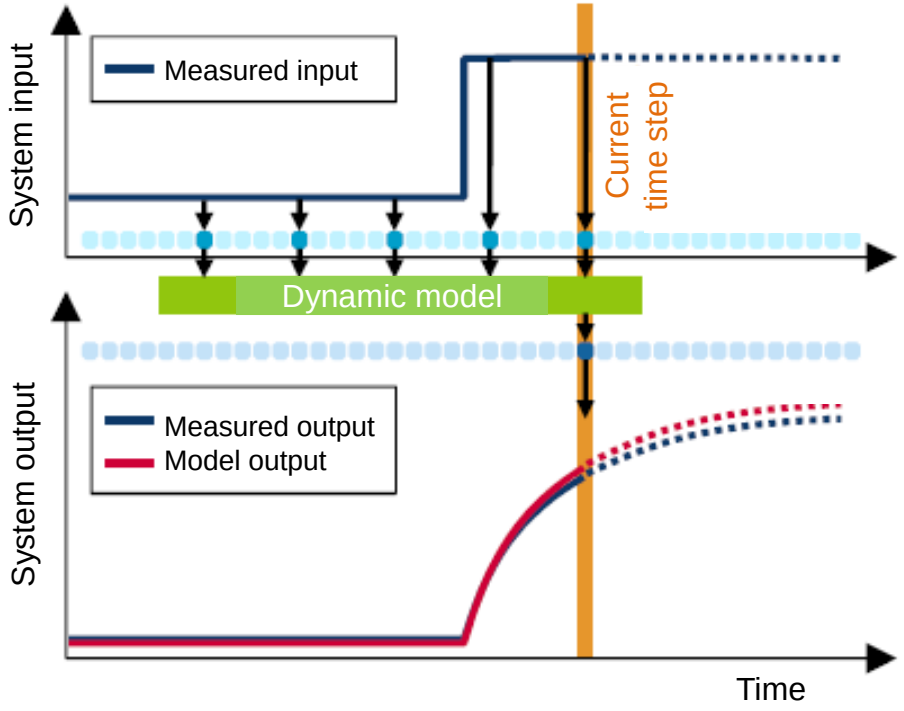
Steady state DoE model



- ✓ Steady state prediction
- ✓ Model fitting based on averaged measurement data

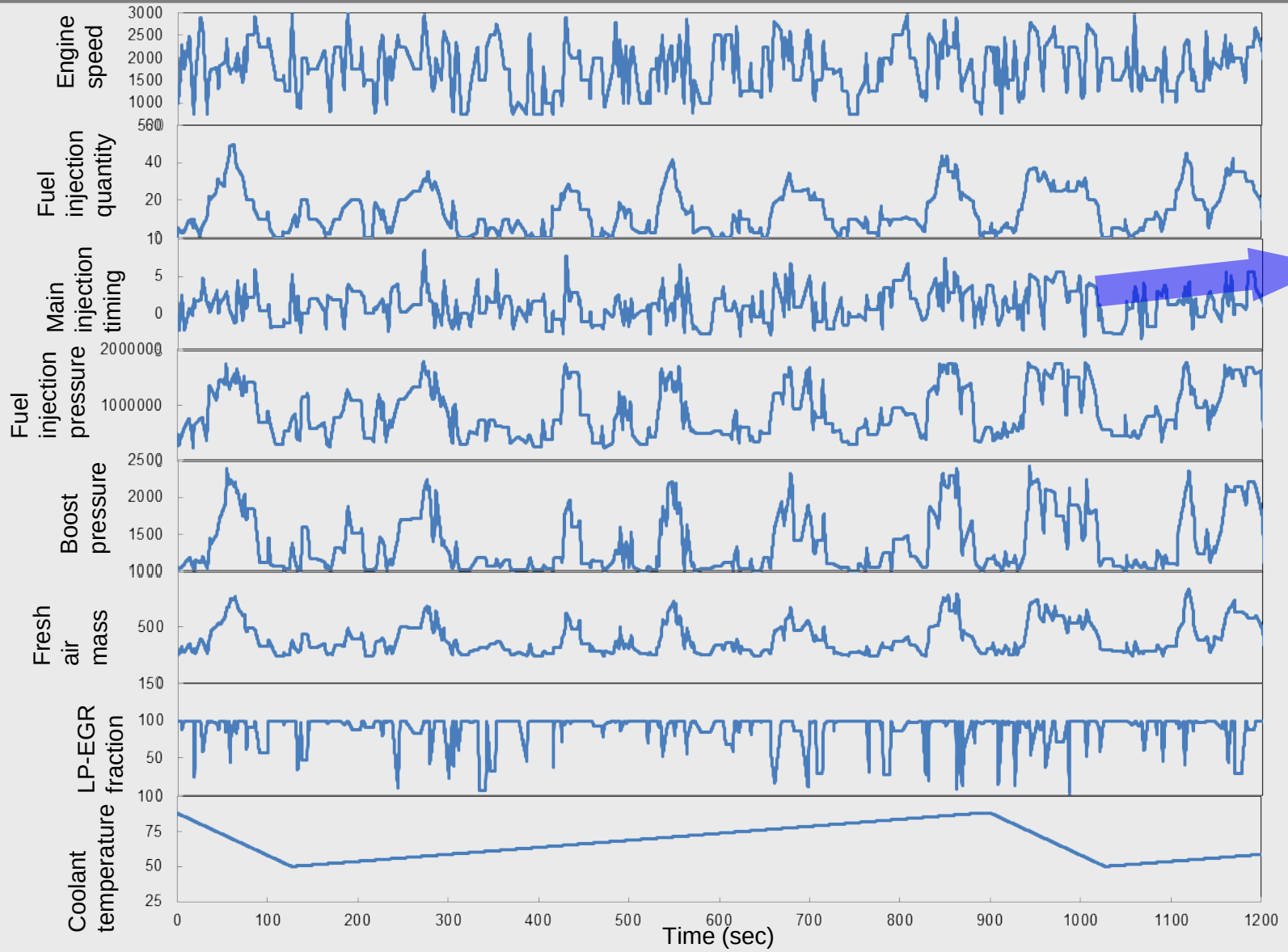
Dynamic DoE model

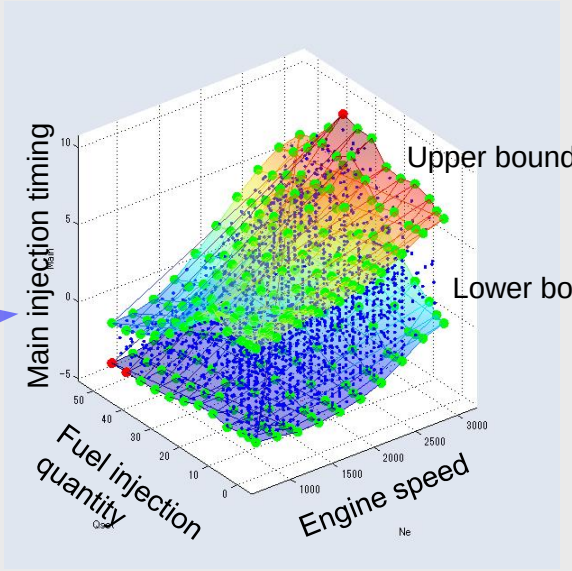


- ✓ Transient prediction including time lag of measurement apparatus
- ✓ Model fitting based on recorder measurement data

Dynamic behavior expression considering histories of system input and output

Dynamic DoE for combustion model





Space filling test design
including steady state test design

Space filling methodology for the Gaussian Process Modeling (GPM)

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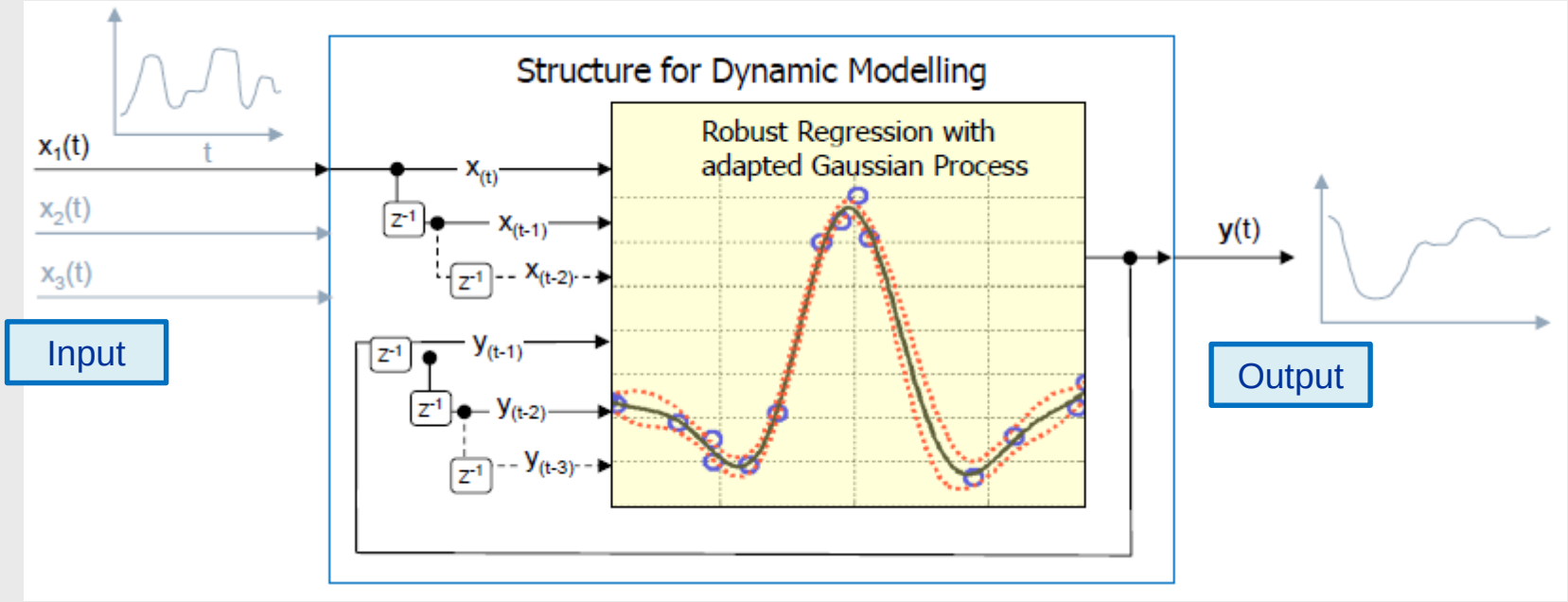
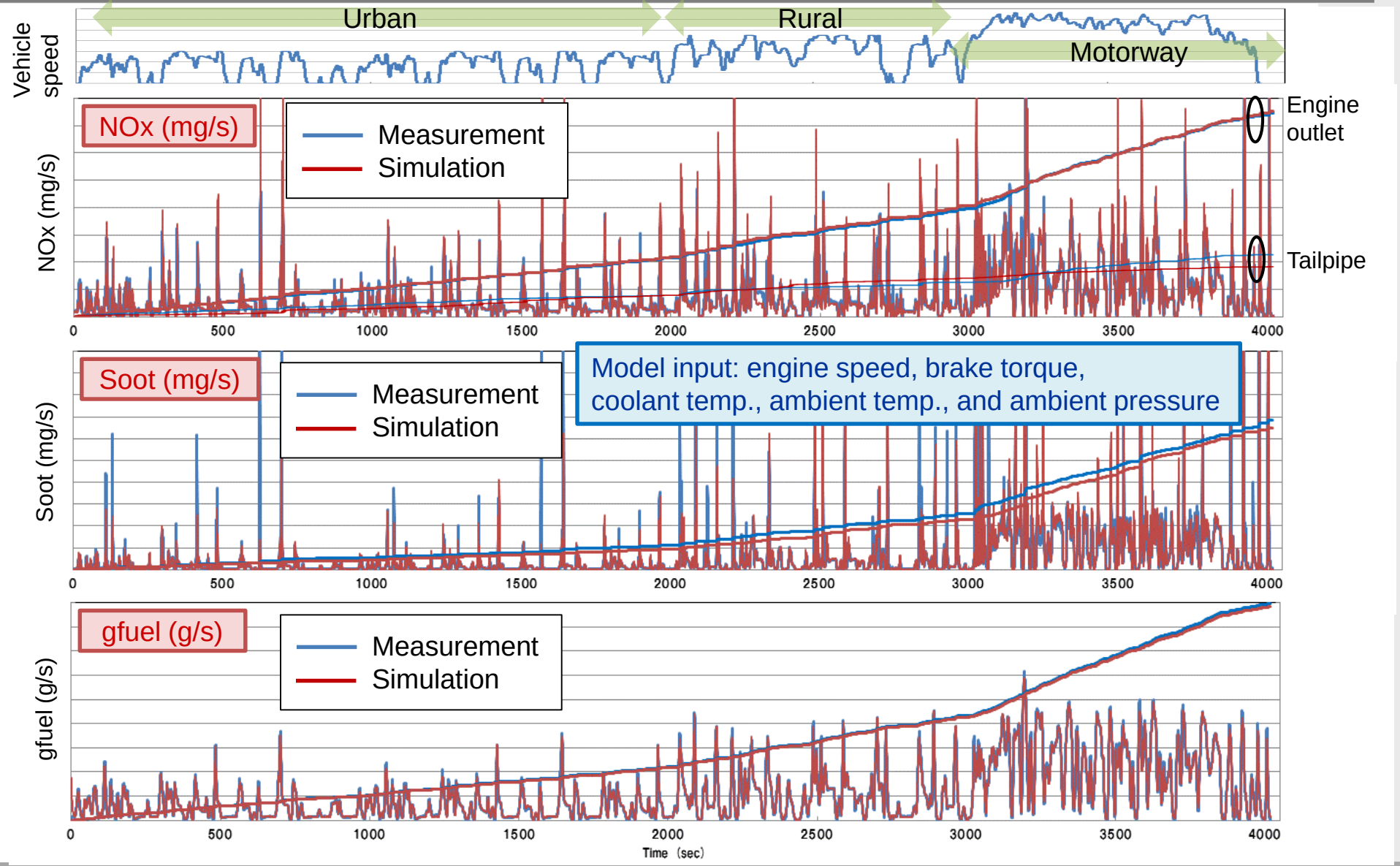
Model structure for learning time dependent behavior:
Regression model with additional inputs and outputs from past time steps



Reference:
T. Huber, M. Hanselmann, and T. Kurse: Use of Data Based Models to Predict Any RDE Cycles - Challenges, Experiences and Results, 8th Emission Control Conference, Dresden (2016)

Predictive accuracy of engine model



Achievement of quantitative emissions prediction at RDE

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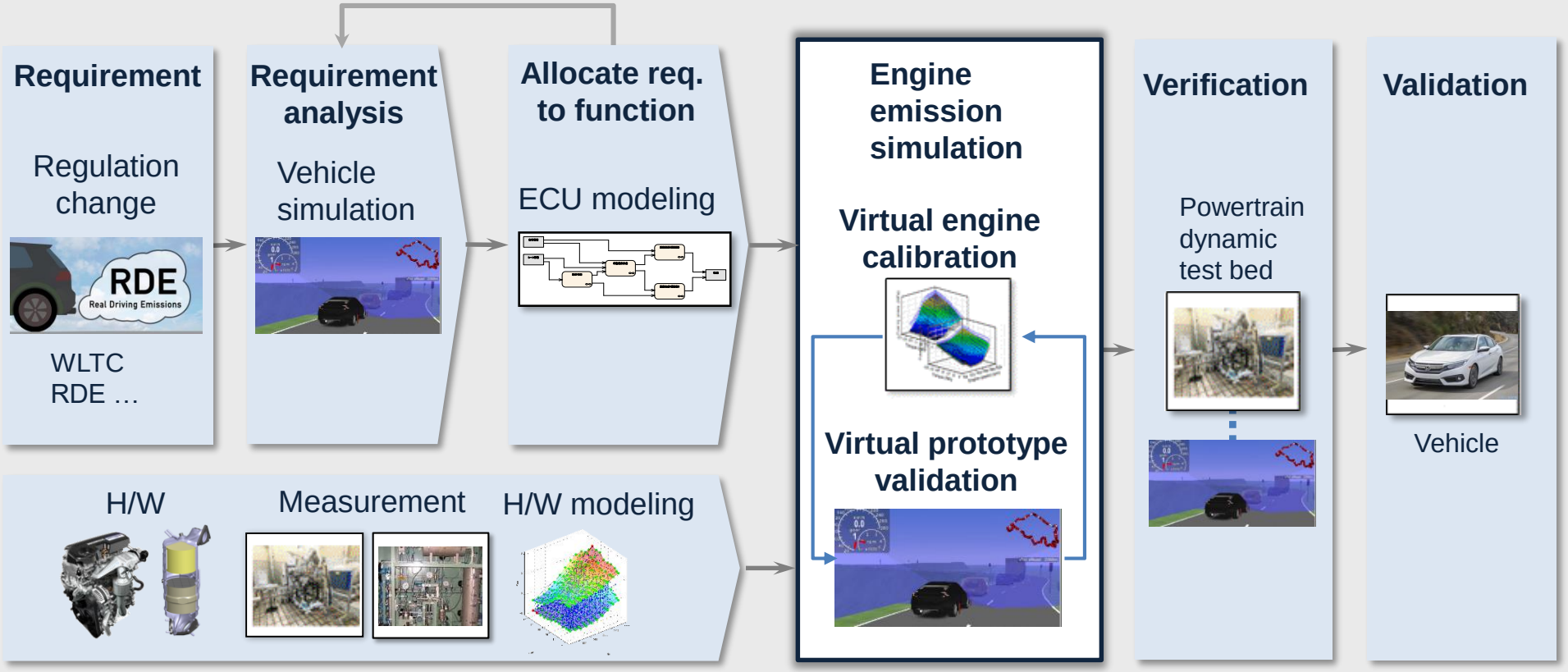
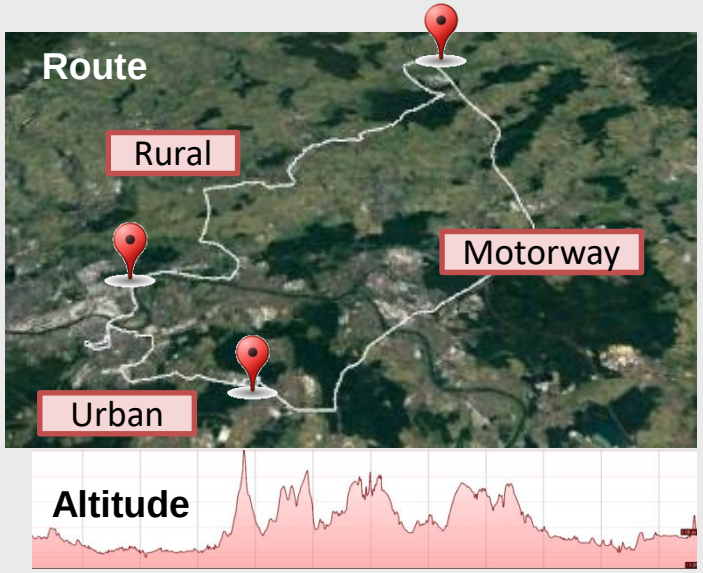
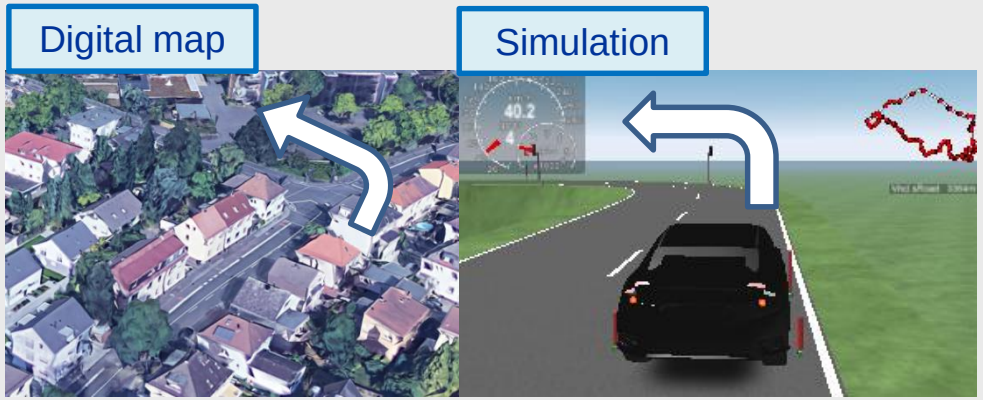
RDE-compliant virtual engine calibration

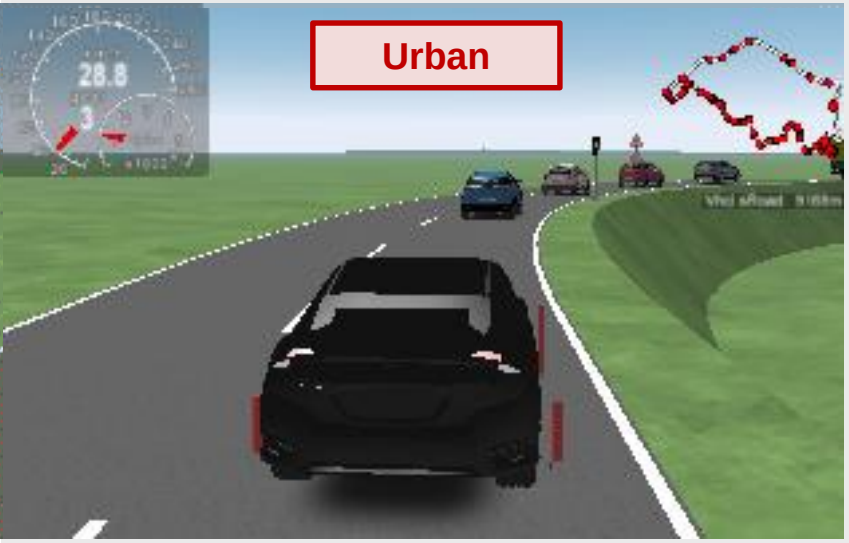


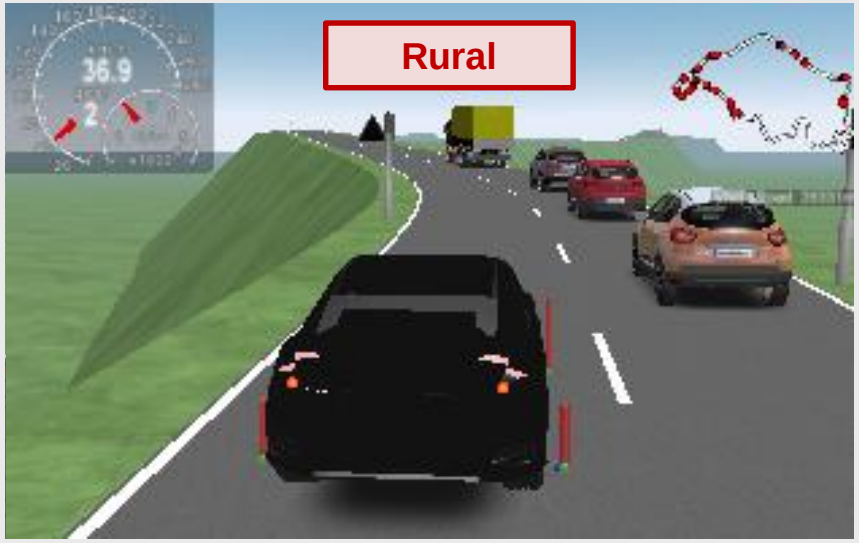
Utilization of virtual calibration and validation

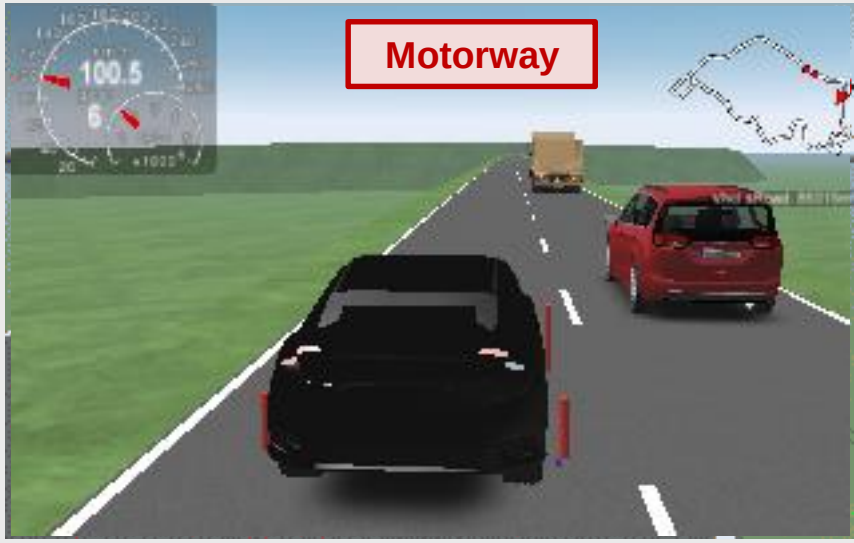
Vehicle simulation for RDE route











Generation of vehicle speed by vehicle, driver, route, and traffic models

Model based RDE performance evaluation

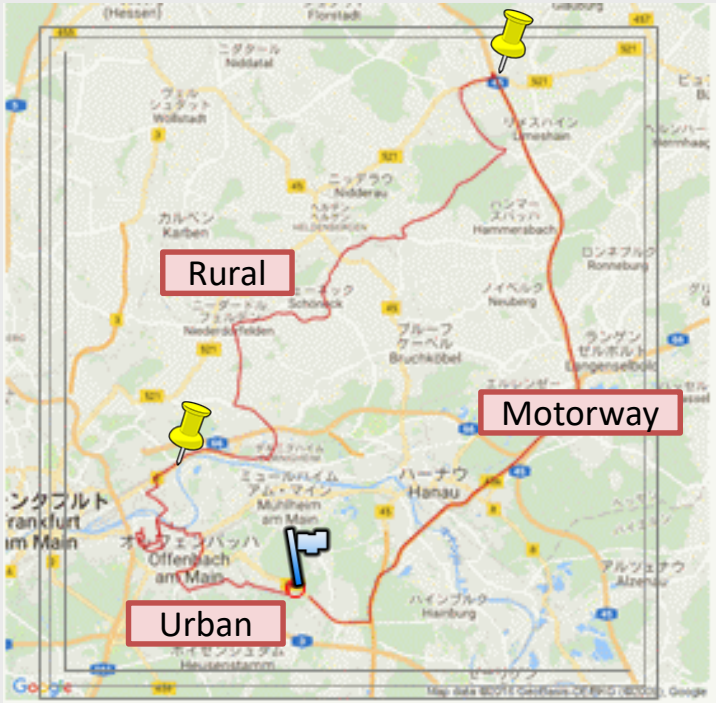
Vehicle, driver, route, and traffic models

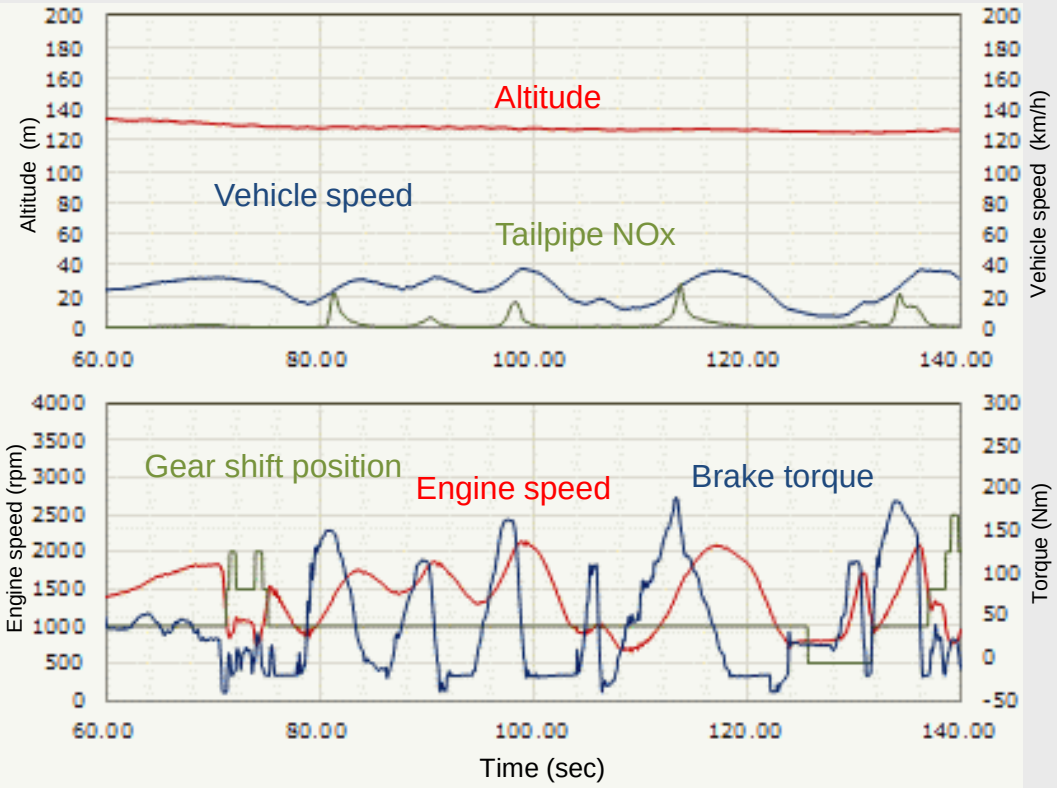
↓ ←Vehicle simulation

Vehicle speed, engine speed, brake torque, and gear shift position

↓ ←Engine simulation

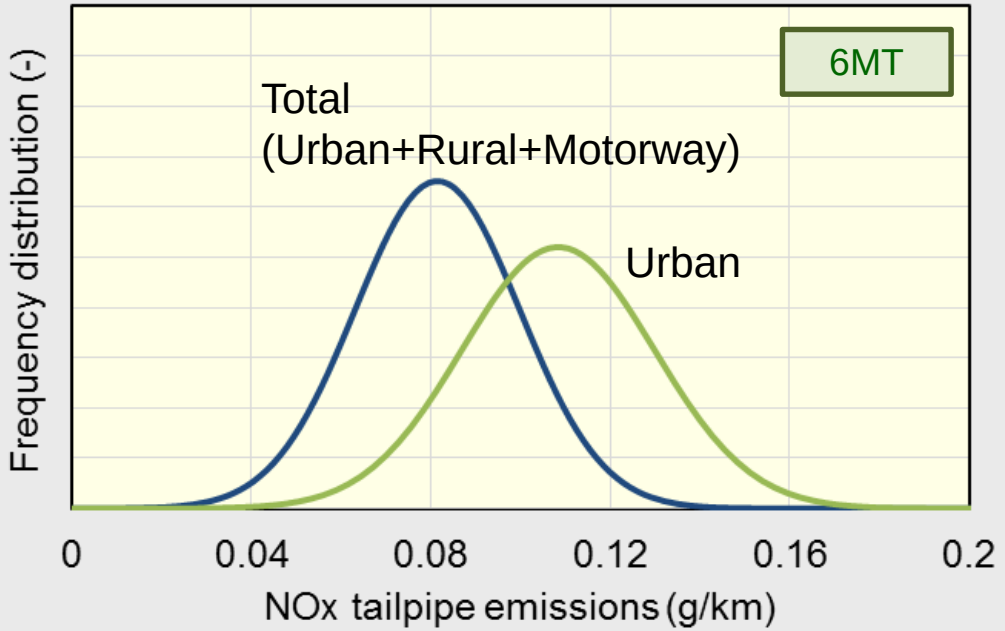
NOx, Soot, CO_2 etc.



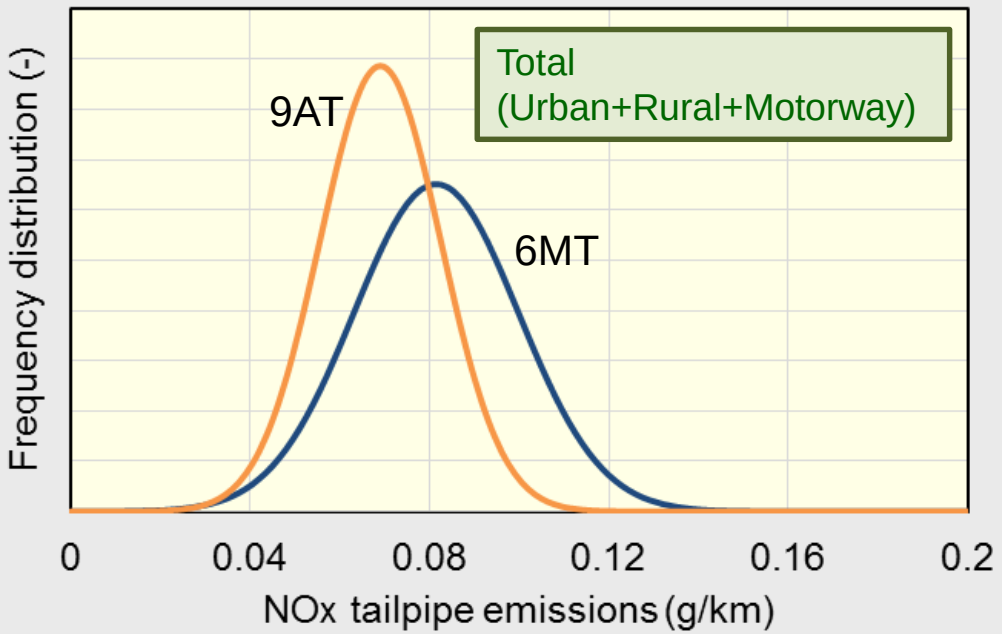


Achievement of emission prediction with vehicle and engine simulation

Evaluation of emission robustness



Simulation



Validity confirmation of hardware selection and calibration data settings

Summary

It is a challenge to sufficiently validate RDE performance under all conditions through road tests during vehicle development due to wide range of validating conditions.

A model based development technology was established to simulate, verify and calibrate the emissions performance of a vehicle.

RDE performance could be accurately predicted by coupling a vehicle driving simulation with an engine simulation that includes an ECU model, combustion model (dynamic data based statistical model), and exhaust aftertreatment catalyst model.

Use of the simulation model enabled robust validation of RDE performance under various conditions that assume driving on actual roads.

Thank you very much for your kind attention.

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