PORSCHE

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Engine Base Calibration: A Model Based Approach

Mathworks Automotive Conference 2018

Porsche Engineering

driving technologies

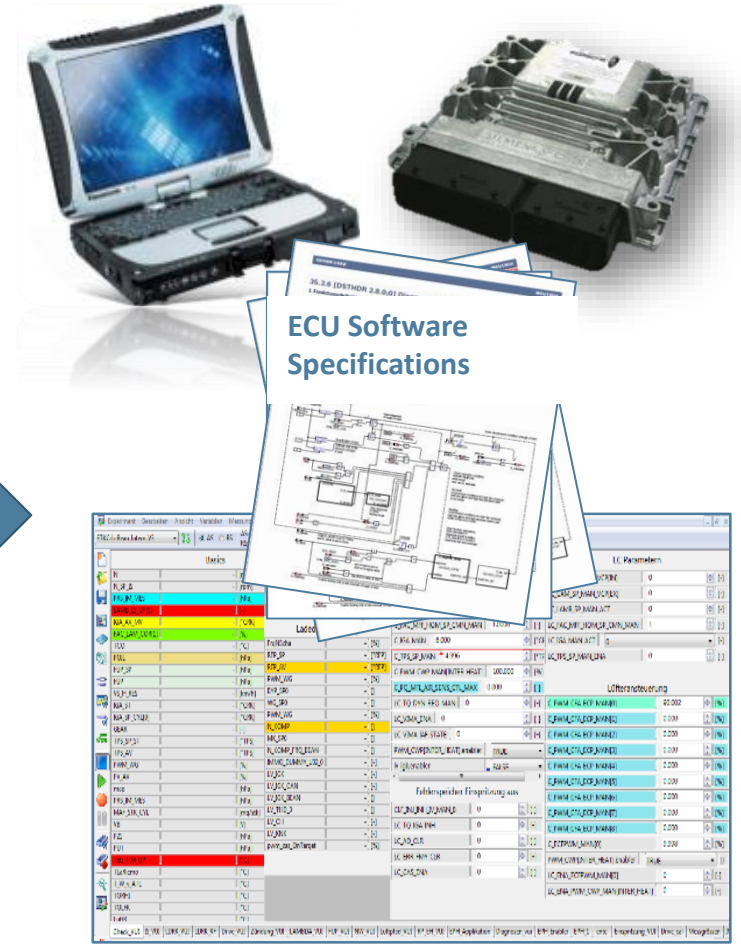
Engine Base Calibration: A Model Based Approach

Contents

Introduction

Tough emissions and performance targets require extremely accurate calibration

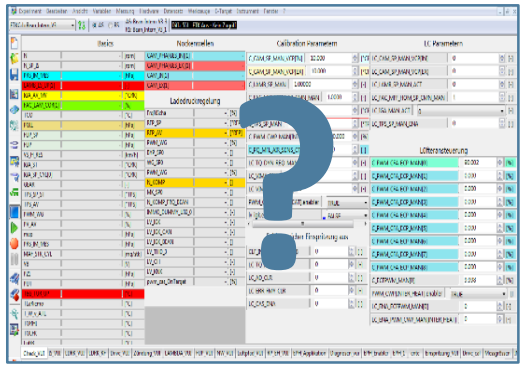
World premiere	15 September 2015, Frankfurt International Automobile Exhibition			
Market launch	12 December 2015			
Highlights	Fresh-air enjoyment with driving pleasure and everyday practicality			
	911 Carrera	**911 Carrera S**	**911 Carrera 4**	**911 Carrera 4S**
Drive system	3.0-litre twin-turbo flat six-cylinder engine	3.0-litre twin-turbo flat six-cylinder engine	3.0-litre twin-turbo flat six-cylinder engine	3.0-litre twin-turbo flat six-cylinder engine
	272 kW (370 hp)	309 kW (420 hp)	272 kW (370 hp)	309 kW (420 hp)
Acceleration 0 - 100 km/h (with PDK)	4.6 s	4.3 s	4.5 s	4.0 s
Fuel consumption and CO_2 emissions	combined: 9.0 - 7.5 l/100 km			
	combined: 208 - 172 g/km			

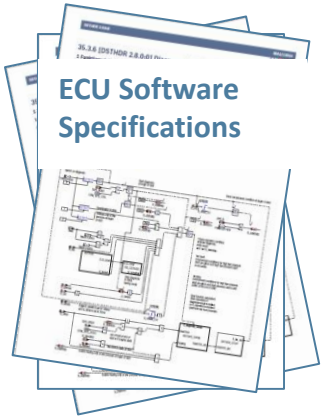


Introduction

Base calibration challenges

- Very tough targets for calibration accuracy
- Very complex ECU functionalities
- High costs for testing
- Tough times schedules
- **Meet the specific targets with customized engineered tools**

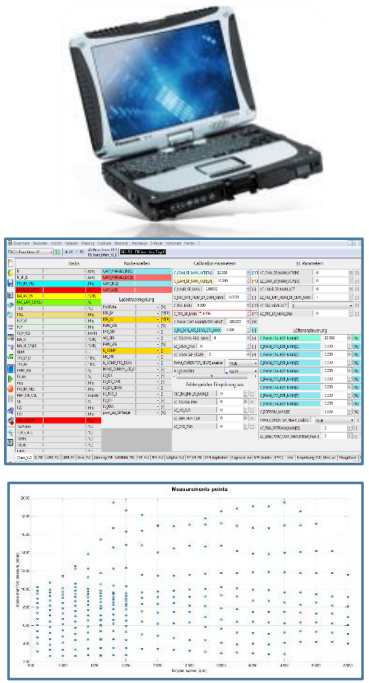




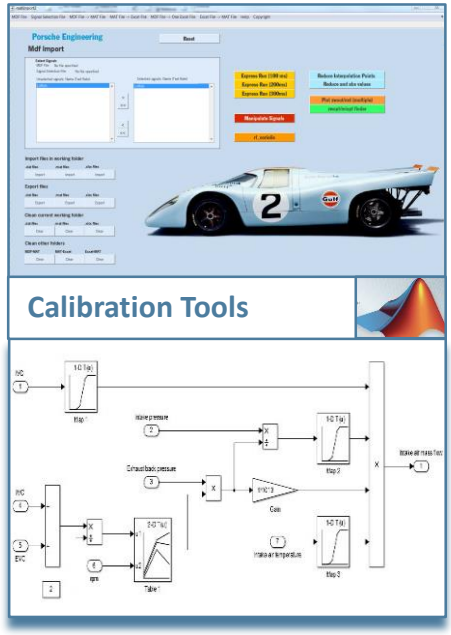
Introduction

Optimize calibration tasks with customized engineered tools

Measurements



Calibration with customized tools

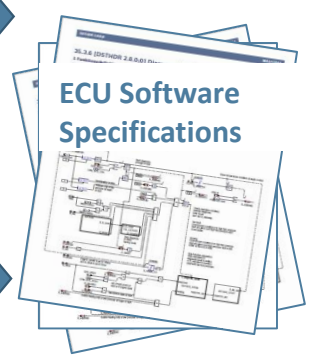


Meet the targets

Time ↓↓

Costs ↓↓

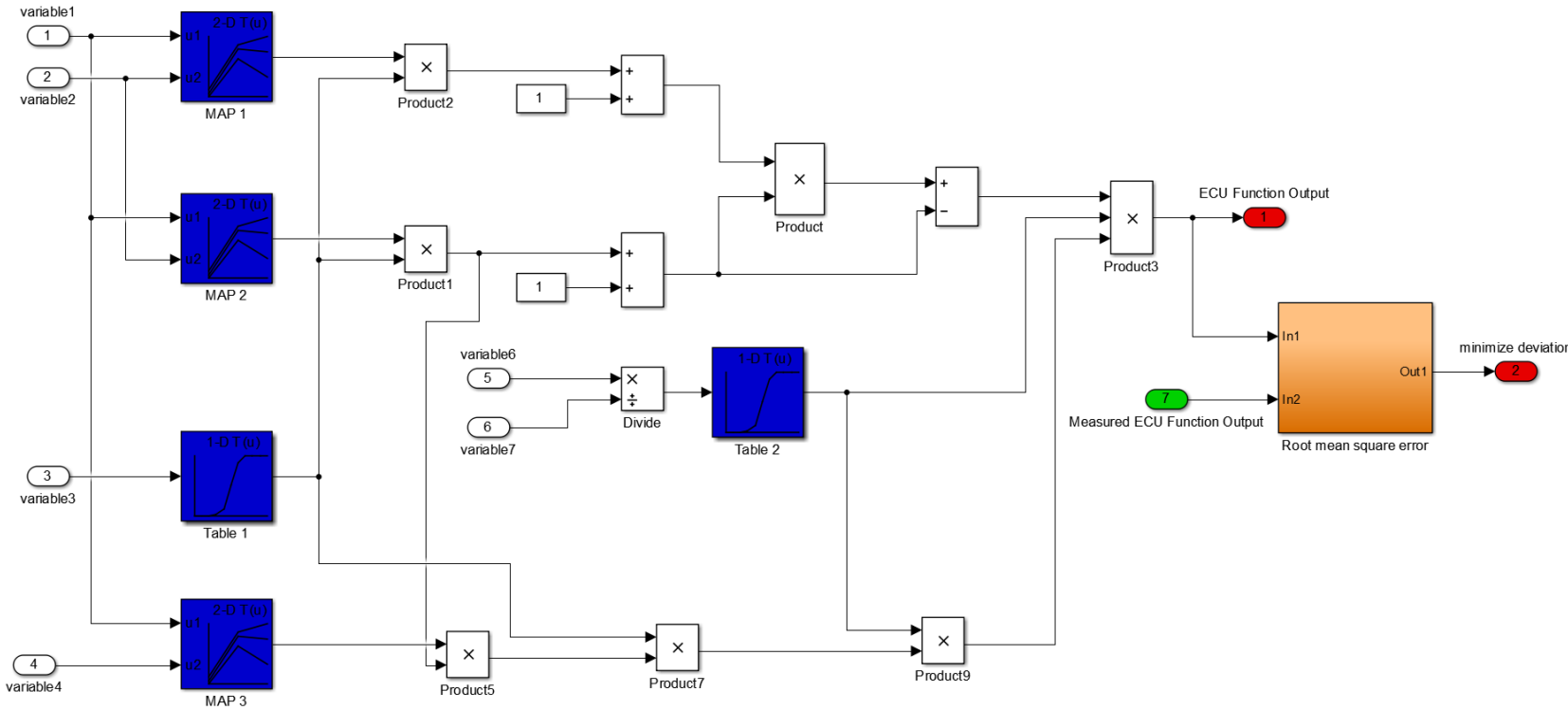
Quality ↑↑



Conventional Methodology

Use of a solver to minimize error with least squares algorithm

> Maps are calibrated using a solver which minimize the root mean square error between ECU model output value and its corresponding measured physical value



Conventional Methodology

Use of a solver to minimize error with least squares algorithm

Benefits:

- Simple algorithm
- Easy to implement in Excel or Matlab

Disadvantages:

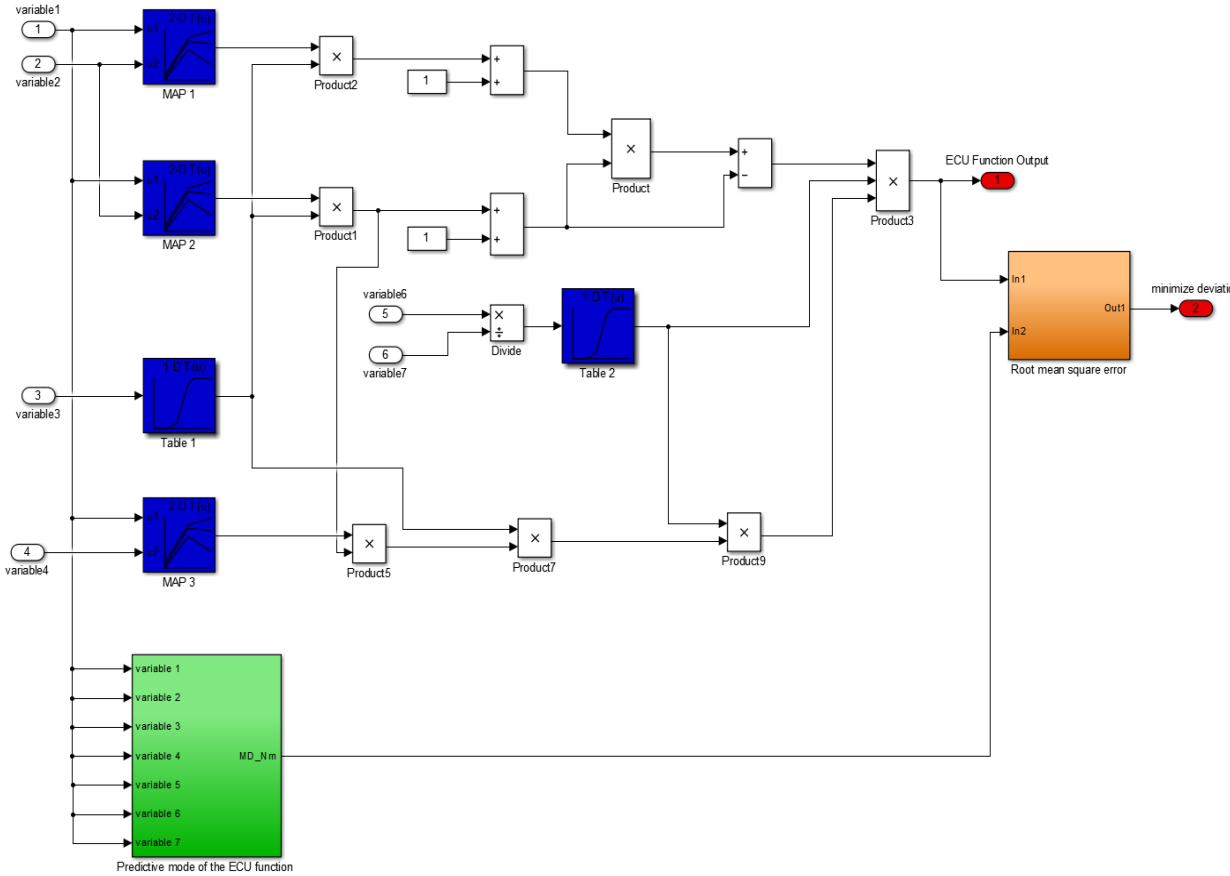
- Lot of measurements necessary
- Point by point calibration:
  - Solution values can strongly deviate from each other from operating point to operating point
  - Discontinuous map progressions → Maps must be smoothed → loss of calibration accuracy
  - Relationship between physics and original measured data become less precise
  - Non accurate interpolation and extrapolation of map break points

→ New approaches are necessary to improve the calibration task!

Model Based Alternative Methodologies

Support solver with supervised machine learning and artificial neuronal networks (ANN)

- Creation of a predective ANN model of the complete function/ sub function
- The physical non measured values are partly substituted by predictive model values using ANN
- Predictive accurate calculation of the function outputs values for every break points of the maps
- Similary to the conventional approach the maps are calibrated with a solver which minimizes the root mean square error between the ECU function output value and the output value of an ANN model.



Model Based Alternative Methodologies

Support solver with supervised machine learning and artificial neuronal networks

Benefits:

- Predictive accurate calculation of the function outputs values for every break points of the maps
- Predictive calculation of ECU function output values for non measured Inputs values
- Predictive model enables critical analysis and understanding of the modelled function
- Use of a simple solver based on mean square method

Disadvantages:

- Training of ANN is complex
- Point by point calibration accuracy is improved compared to conventional methodology but maps still need no be smoothed

→ Look for a more suitable alternative approach.

Model Based Alternative Methodologies

Path inversion and regression models

- What are the ideal requirements for a very efficient calibration?
  - To know the values of the In- & Ouputs of the map

    > Calculation of the output of the map by inverting the function calculation path

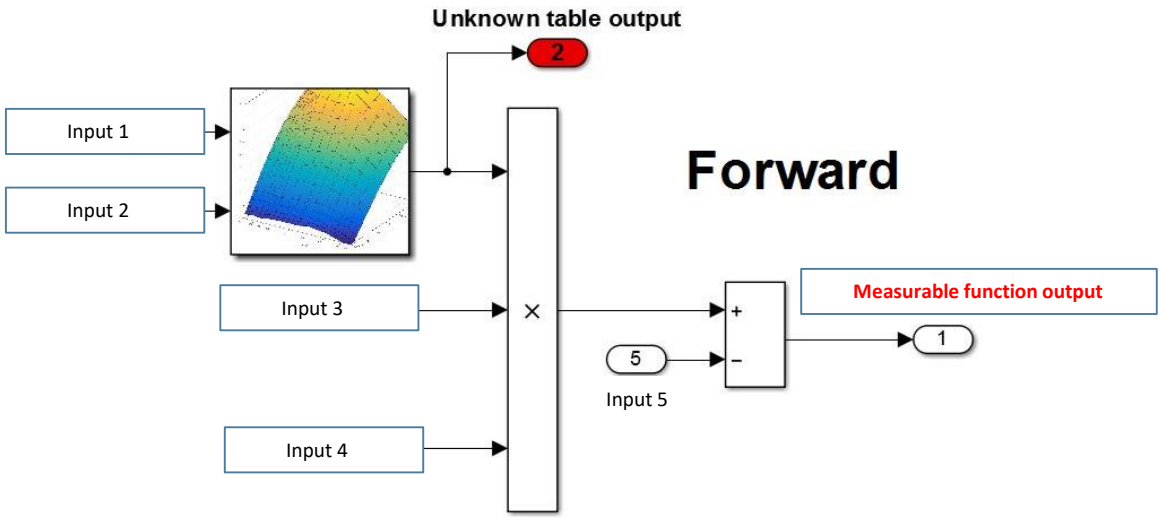
  - To know the relationship between the In- and Ouputs of the map

    > Set up of **Regression models**

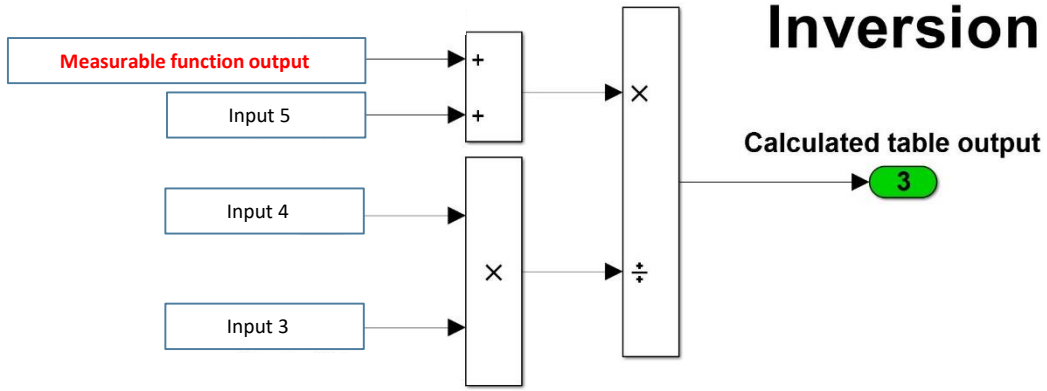
- Porsche Engineering alternative calibration approach is based **on path inversion calculation** and **regression models**

Model Based Alternative Methodologies

Path inversion and regression models



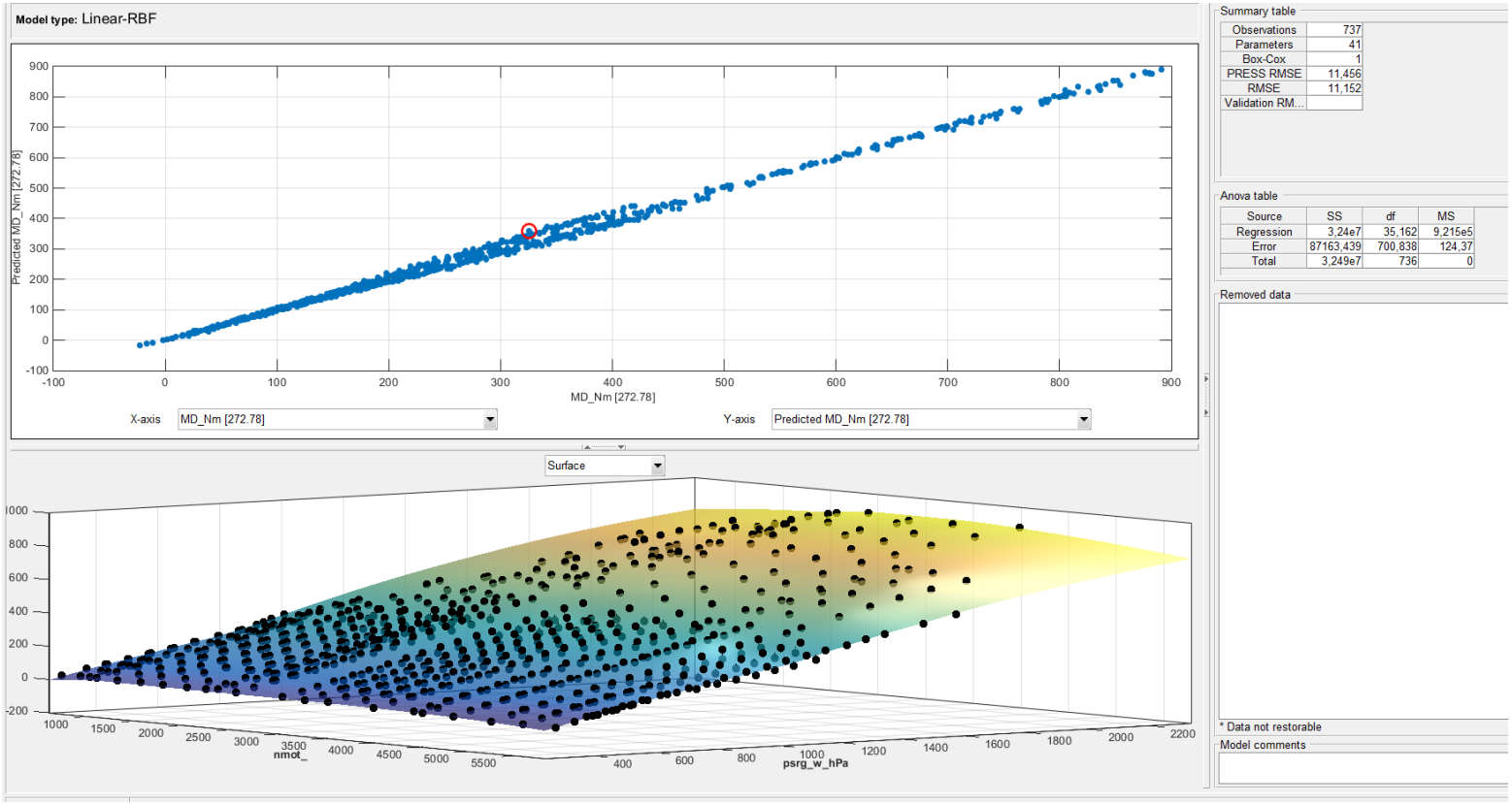
Inversion of the calculation path



Model Based Alternative Methodologies

Path inversion and regression models

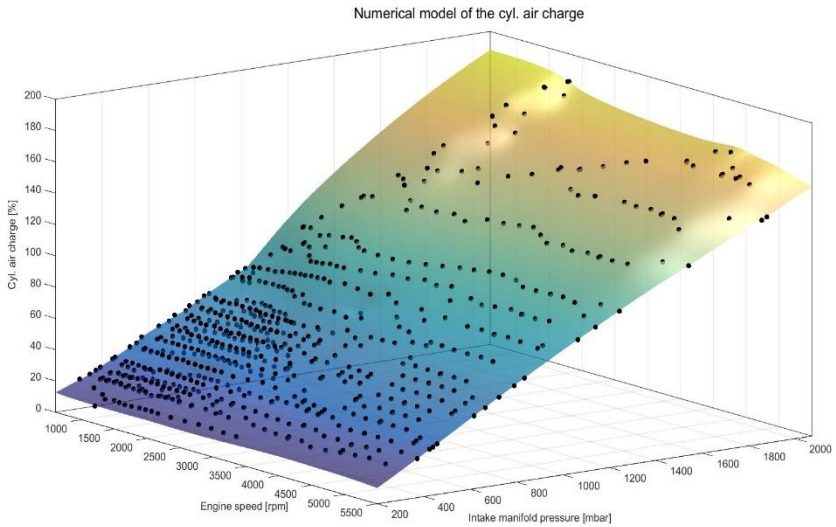
Create regression models to define a mathematical relationship between map inputs and map outputs



Model Based Alternative Methodologies

Path inversion and regression models

- Maps/tables calibration based on regression models
- Table break points optimisation
- Check the maps/tables from a thermodynamical point of view



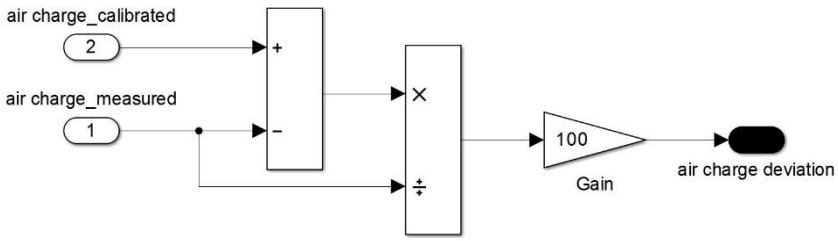
rl_w \ n...	400	600	1000	1250	1500	1750	2000	2500	3000	3500	4000	4500	5(
10,008	3,26	3,701	4,121	3,381	3,708	4,444	4,646	4,863	4,928	4,805	5,321	5,421	
15	5,473	5,921	6,461	5,656	6,121	6,673	6,731	6,959	7,033	6,842	7,494	7,651	
19,992	7,713	8,162	8,726	8,56	8,792	8,79	8,76	9,085	9,185	8,986	9,72	9,919	
30	12,306	12,769	13,235	12,998	12,894	12,498	12,764	13,469	13,682	13,422	14,367	14,589	
40,008	17,06	17,637	17,978	17,77	17,552	16,907	17,059	18,126	18,516	17,788	19,382	19,421	
60	26,639	27,742	27,933	27,965	28,593	28,497	28,038	29,084	29,572	29,462	31,199	29,22	
79,992	34,9	36,113	36,962	37,057	37,855	38,312	36,802	38,411	39,431	40,278	40,324	38,437	
100,008	42,529	44,083	45,042	46,997	48,21	47,19	48,495	47,433	47,162	49,739	49,46	47,311	
120	49,601	51,527	54,967	56,422	56,405	56,468	58,837	59,303	57,873	60,955	59,404	56,013	
139,992	55,8	57,963	61,996	64,017	64,517	66,657	69,194	69,186	67,345	68,592	68,076	64,118	
160,008	60,988	63,247	67,499	69,815	71,447	74,488	78,094	77,647	76,261	77,445	77,539	70,888	
180	65,214	67,512	71,959	74,664	77,554	82,489	83,644	83,045	82,073	81,77	80,124	75,071	
199,992	68,532	70,81	75,28	78,047	80,844	83,536	85,235	85,796	85,181	84,109	81,765	77,449	
220,008	70,991	73,169	77,375	79,864	82,168	84,138	85,585	86,81	86,543	85,27	82,789	78,913	

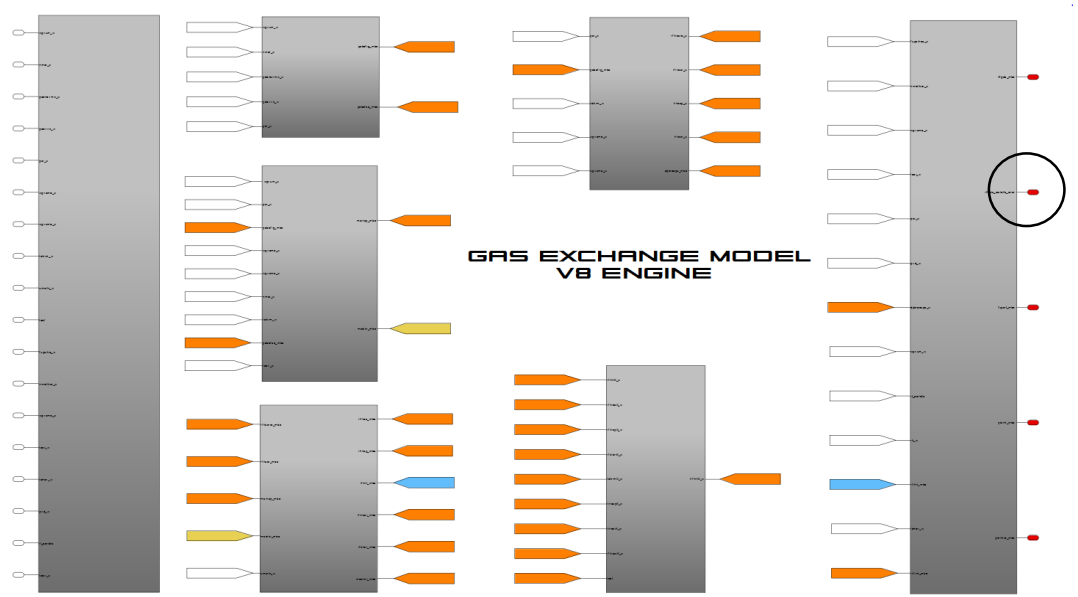
Model-based table calibration

Model Based Alternative Methodologies

Path inversion and regression models

- Load the model based calibration maps in a Simulink which depicts exactly the calculation logic of the ECU Function
- Perform a systematic analysis of the expected calibration deviation





Summary

Engine base calibration: a model based approach

- The combination of strong methodologies together with regressions models based on modern and intelligent algorithms (ANN, RBF functions,etc…) open new opportunities in calibration accuracy
- A model based approach in calibration save time and costs for testing
- Calibration of the maps with regression models -> no point by point calibration of the map
- Very accurate calculation of interpolated/extrapolated table values thanks to the predictive and regression models
- Model based calibration is also suitable for the calibration of dynamic functionalities and function development

Thank you very much for your attention!