GM Holden Ltd

Cold Engine Emissions Optimization Using Model Based Calibration

19th – 20th June 2007

International Automotive Conference

Dr. Clive Tindle
General Motors Holden Ltd.

Overview

- Cold engine emissions.
- What is model-based calibration?
- Design of experiments.
- Statistical modelling.
- Response model trade-offs and optimisation.
- Implementation.

Cold Engine Emissions

- “Cold Engine” refers to operation **after** engine start up.
- 20°C emissions tests.
- Catalytic converter has not achieved light-off.
- Engine operation is referred to as “Catalyst Heating.”

Challenges before light-off

- Minimise exhaust pollutants.
- Achieve acceptable combustion stability.
- Maximise fuel economy.
- Minimise piece costs, e.g. catalytic converter, engine hardware.

Engine Control Options

- Ignition timing, and fuelling.
- Continuously, variable valve timing for both intake and exhaust.
- Split injection, semi-stratified charge combustion.

Increased complexity means more degrees of freedom !

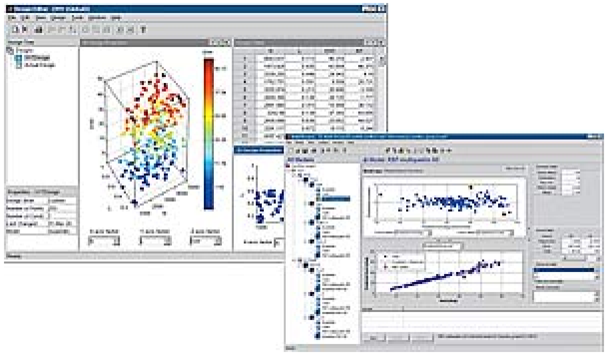
PFI	-	3-4 variables.
DI	-	7-8 variables.

Our brains struggle to visualise 2 or 3 variables at a time !

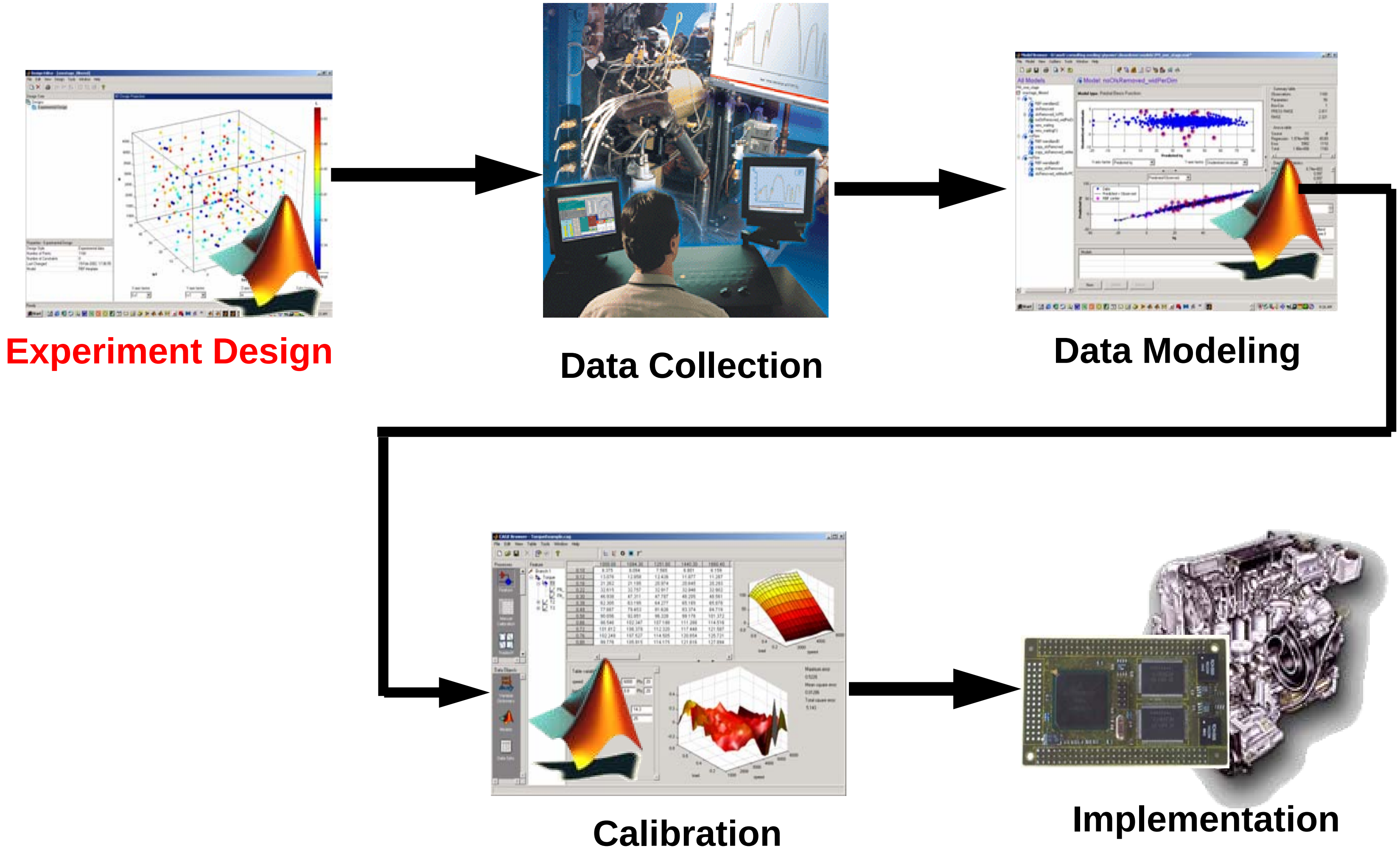
Model-Based Calibration Toolbox

- An add-on toolbox for MATLAB®
- Specifically developed for engine calibration
- Has been commercially available for approximately 5 years

Model-Based Calibration Toolbox provides design tools for calibrating powertrain systems. The toolbox is built on the high-performance technical computing environment of MATLAB® and the modeling capabilities of Simulink®. Model-Based Calibration Toolbox enables the development of optimized calibrations for complex high-degree-of-freedom engines that are difficult to calibrate using traditional methods. Using the toolbox, you can develop a process for systematically generating calibrations that find an optimal balance of engine performance, emissions, and fuel economy.



Model Based Calibration Concept



Design of Experiments

- Design of experiments is a technique used to select the most statistical useful data.
- Essential for high degree of freedom systems.
- # of points influenced by degrees of freedom and model.

Benefits

- Significant reduction in test points compared with ‘one parameter at a time’ or factorial test methods.
- Data collected randomly minimising influence of ‘noise’ parameters.

Examples of DOE

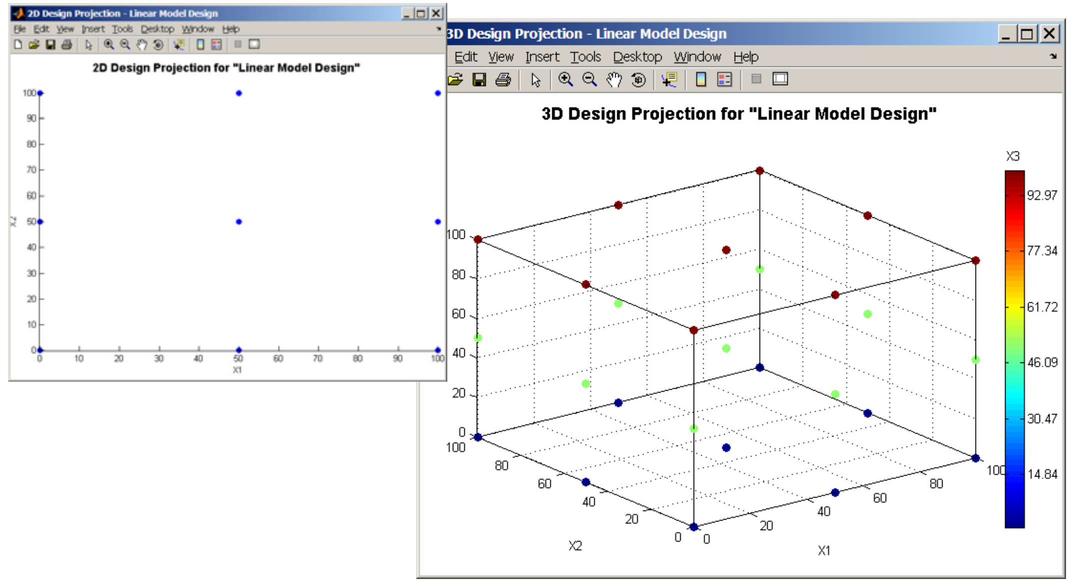
Factorial designs

L^V = # of points

L = Levels.

V = Variables.

3 levels and 3 variables = 27 points.

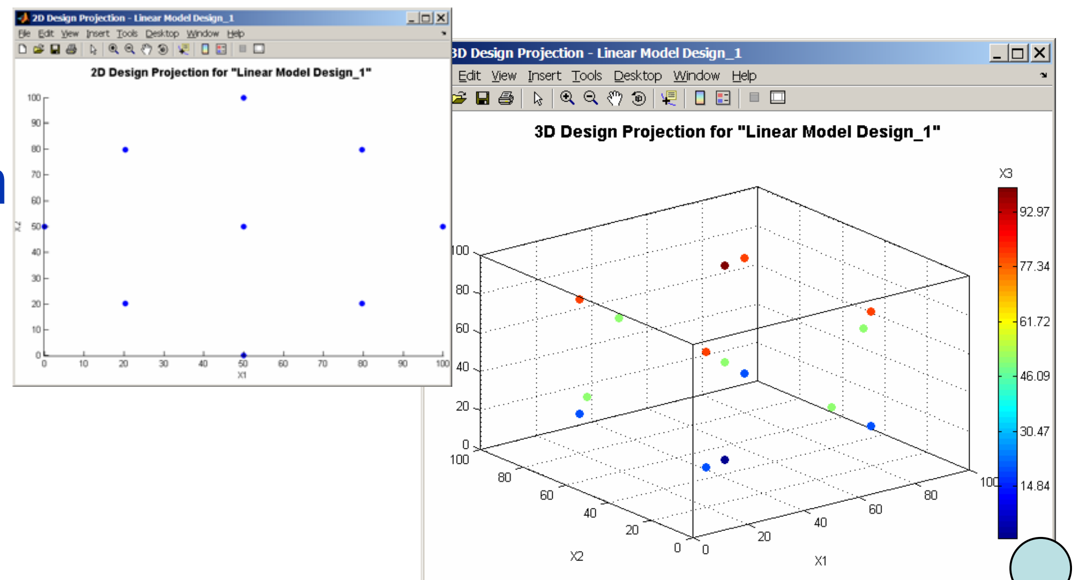


Central Composite Design (CCD)

A classical DOE.

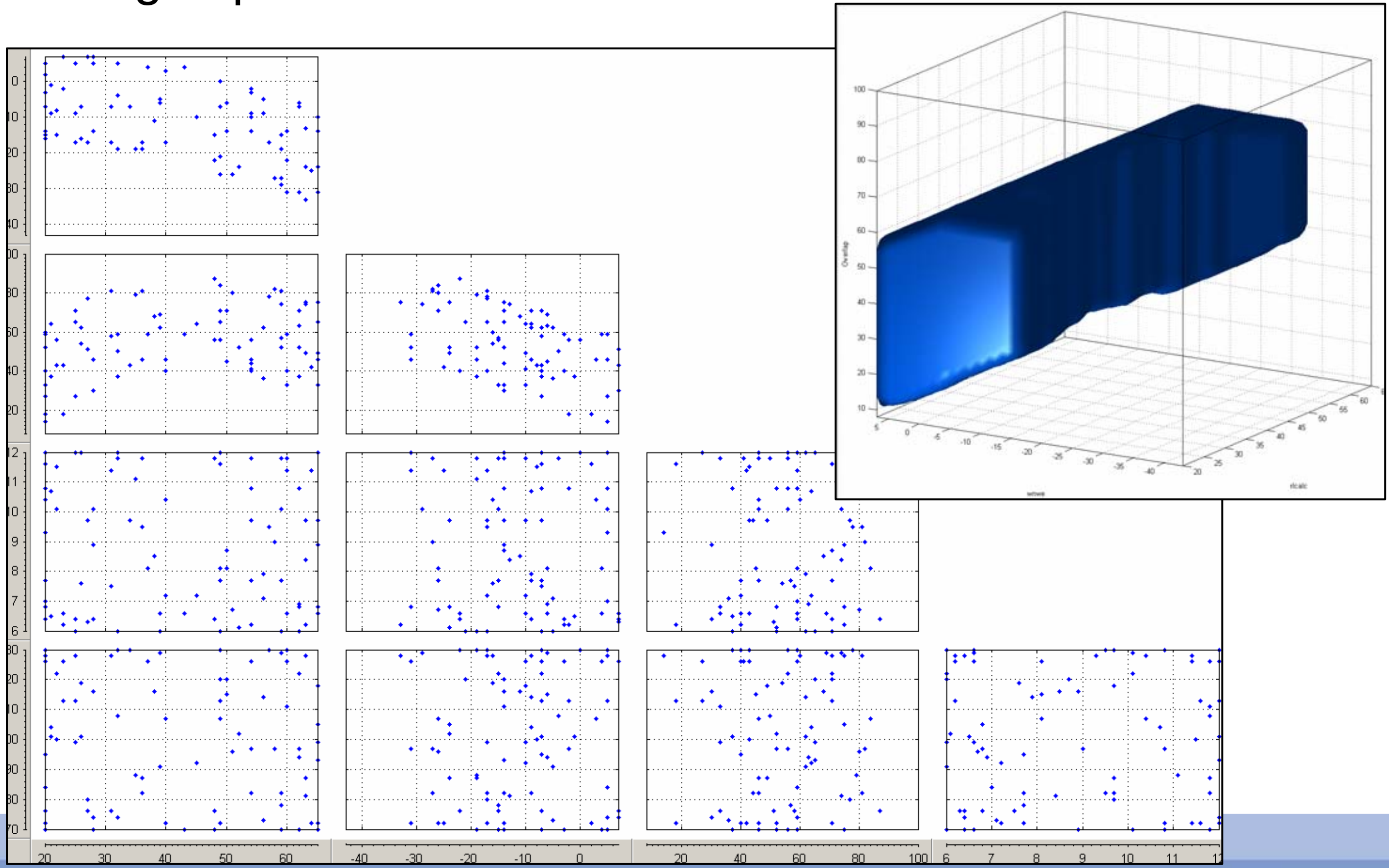
Minimum of 15 points.

Almost 50 % reduction in test points.

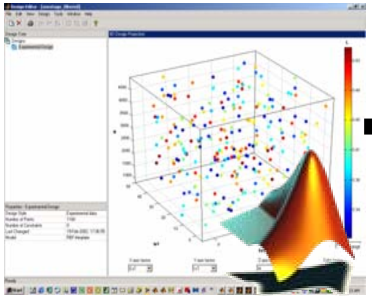


Optimal designs and augmented space fills

- Computer based design, flexible and useful for constrained design spaces.

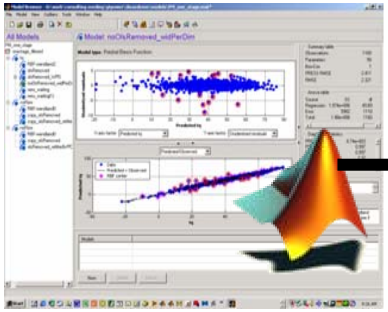


Model Based Calibration

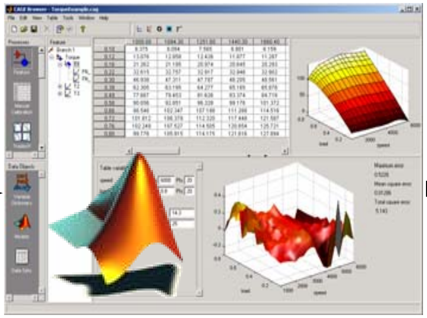


Experiment Design

Data Collection



Data Modeling



Calibration

Implementation

Statistical Modelling

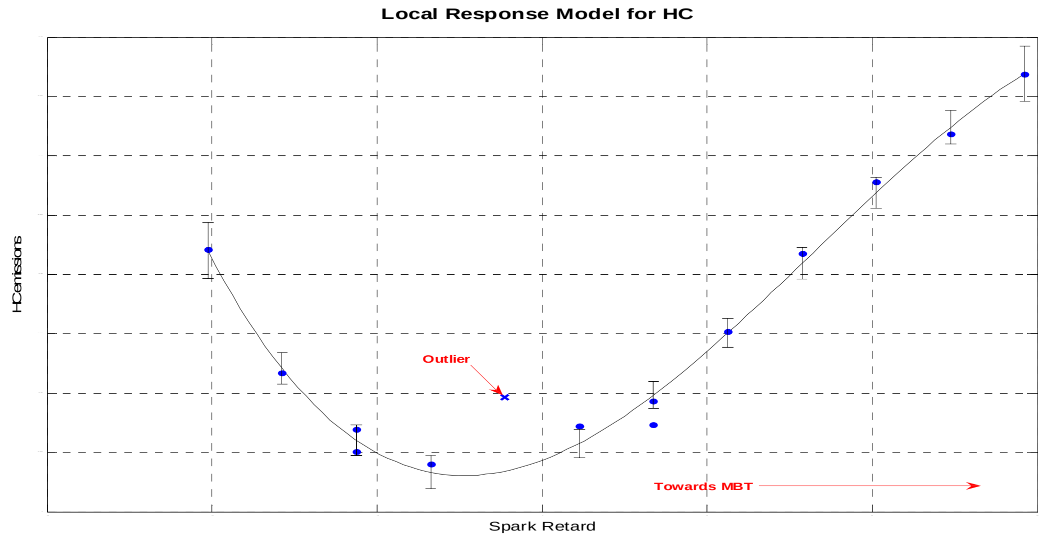
- The choice of variables (factors and responses) should be selected based on physical knowledge.
- Models capture the shape of the response and confidence intervals.
- Modelling is split into two parts;
  - Local model.
  - Global model.

Typical Models are;

- Polynomials.
- Radial Basis Functions (RBF).

Local Model

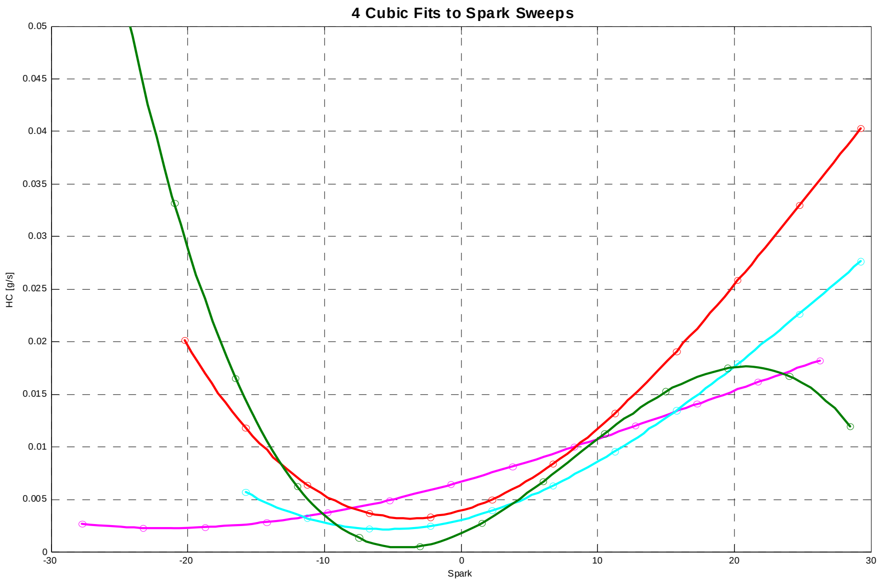
- Local model refers to spark sweep data. Spark is the variable on the x-axis, all other variables are held constant.
- Fitting local models help identify bad data and ‘expected’ trends.



$$HC = b_0 + b_1 SPARK + b_2 SPARK^2 + b_3 SPARK^3$$

Global Model

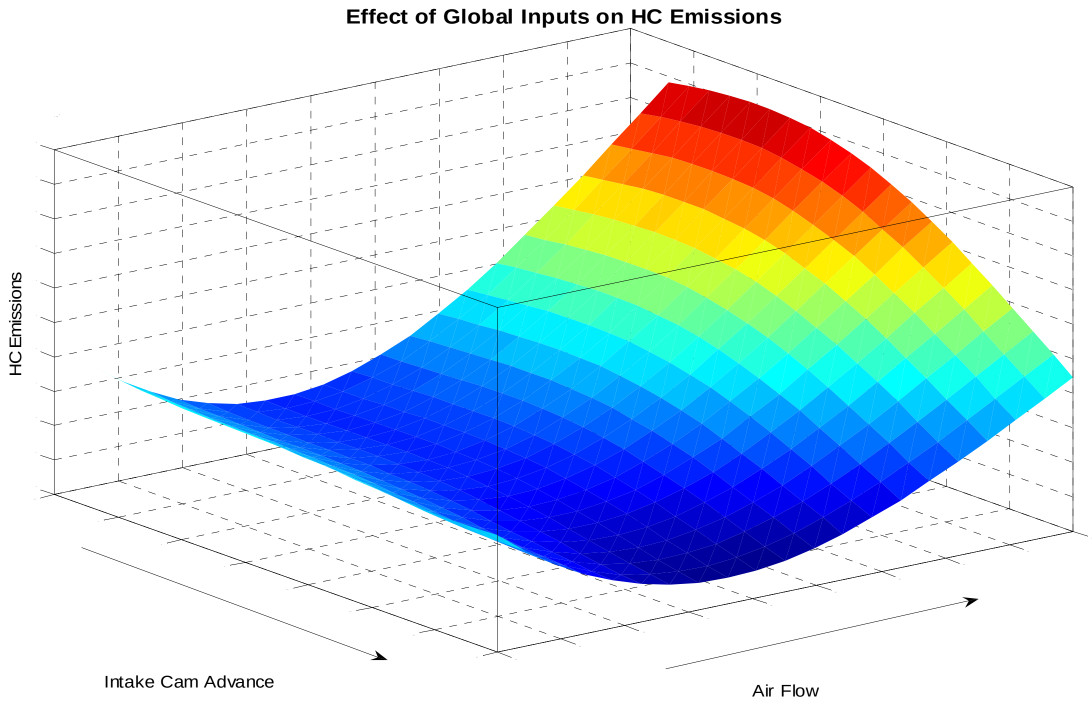
- Coefficients from the local model are fed into the global model.



- A model now represents the local coefficients, enabling reproduction of the spark sweep at any combination of global conditions.

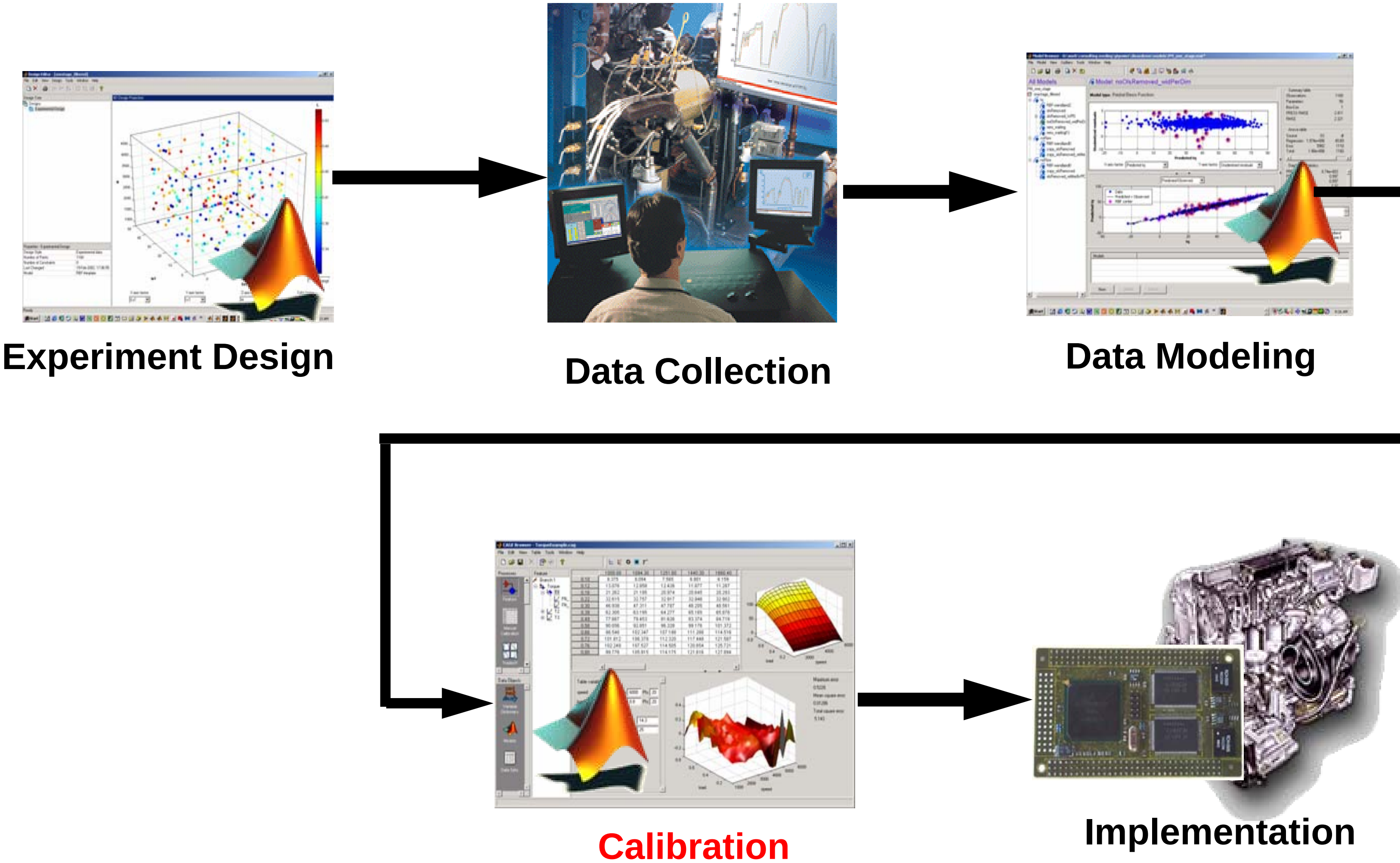
Response Surface

- The response surface can be calculated from the local and global model coefficients.



- Interrogation increases understanding of trends.

Model Based Calibration

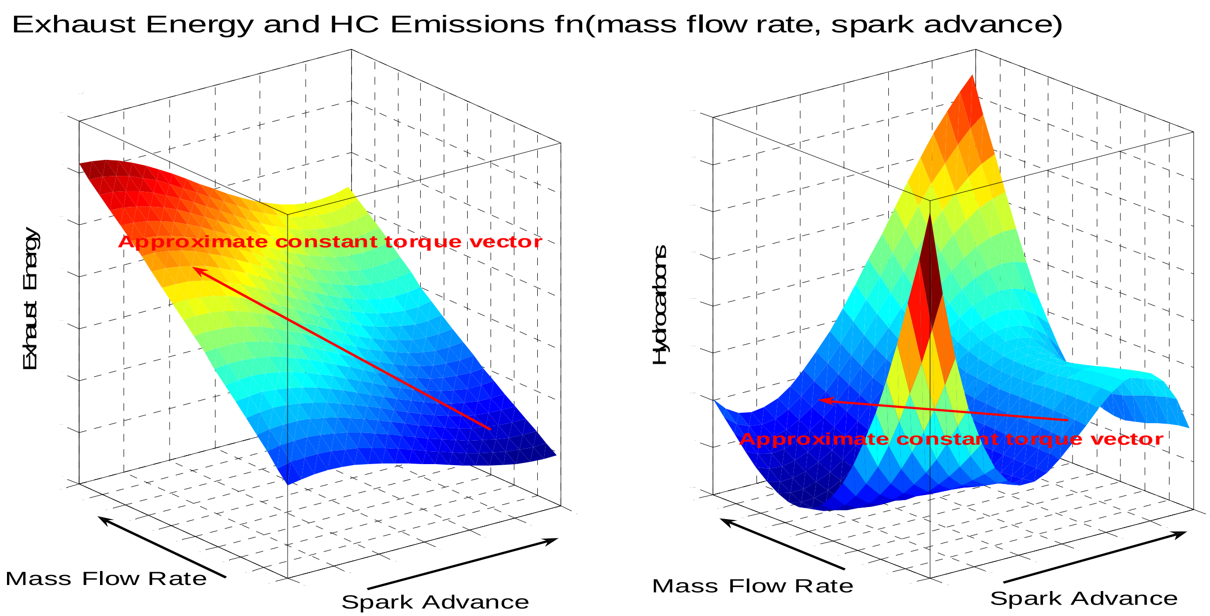


Optimisation and Trade-offs

- Optimise controlled variables to meet emissions targets and satisfy customer expectations.
- Optimisation can focus on one response or consist of trade-offs.
- Input variables can be optimised manually considering all responses.
- Optimization Toolbox algorithms can be used for automatic optimisation.

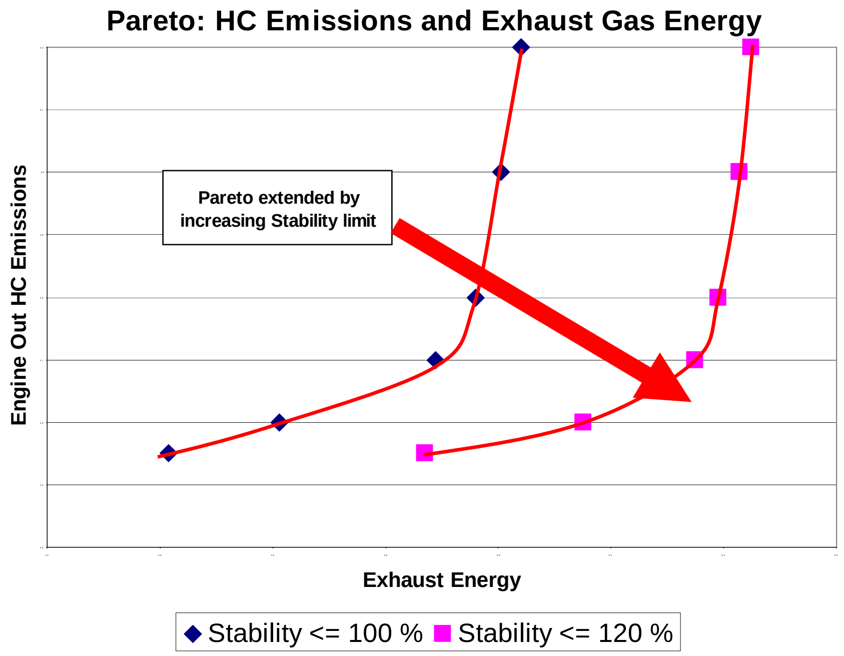
Single Objective Optimisation

- Appropriate when no trade-off exists or is necessary.
- Constraints are used to limit other responses, e.g. combustion stability.



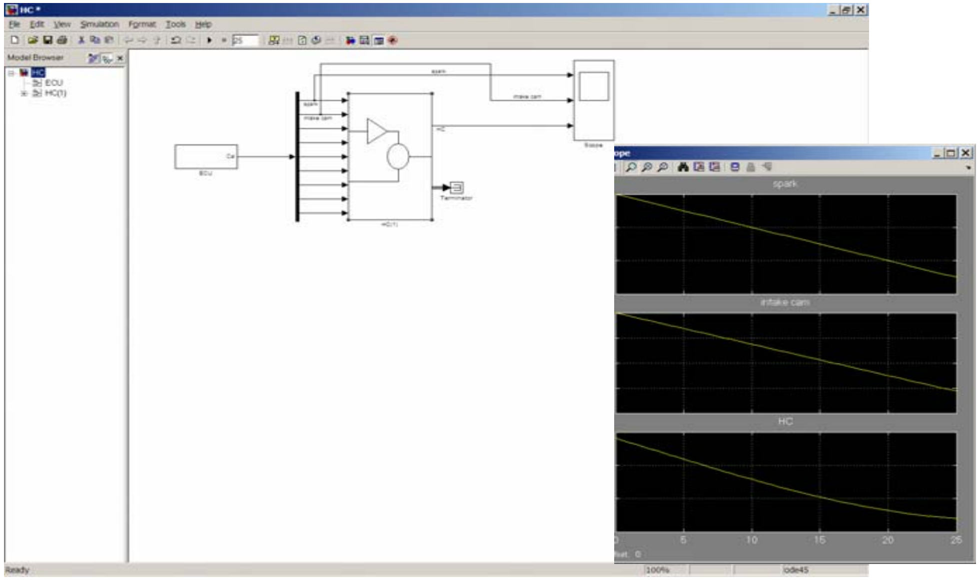
Multi-Objective Optimisation

- Necessary when optimising one response, results in the deterioration of another.
- Generates a Pareto, more time consuming to select optimum calibration.

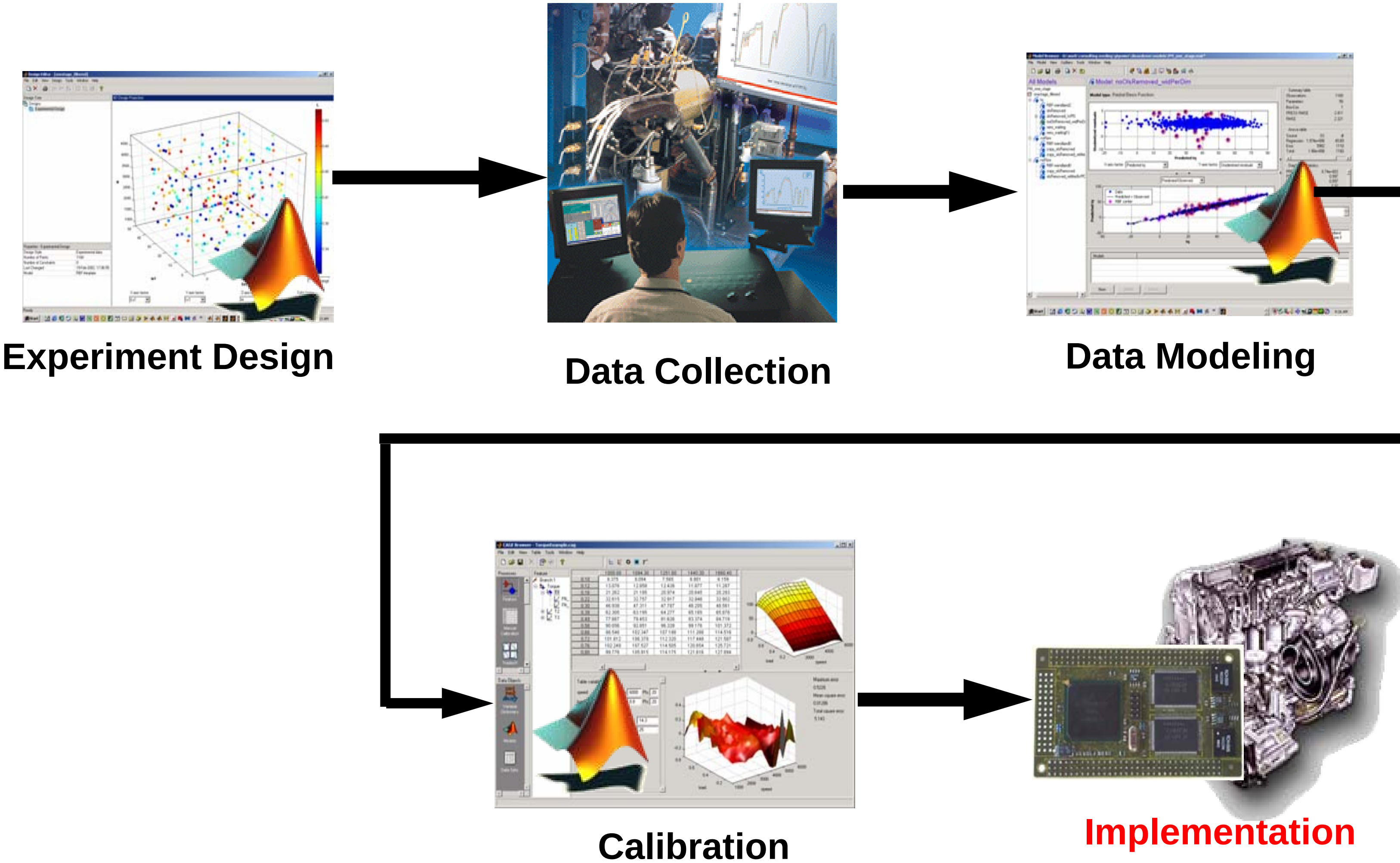


Re-use of Models

- Collect data once.
- Re-use models as many times as required.
- Constraints can be changed.
- Models are an **engine test bed simulator**.

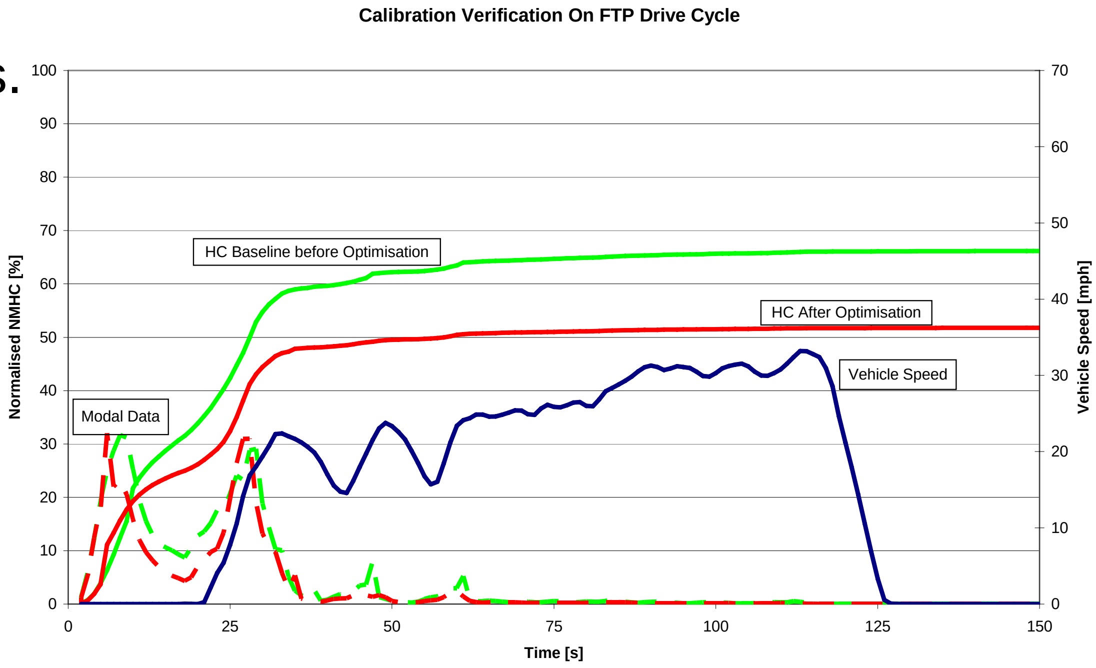


Model Based Calibration



Implementation

- Optimum values must translate into ECU maps.
- Take into account strategy deficiencies.
- Can be limited by engine hardware and other calibration areas.
- Cycle analysis.



Conclusions

- Model-based calibration and design of experiments is a key tool in developing high-technology engines with demanding emissions targets and driveability constraints.
- Use of models allows careful scrutiny of multiple responses and increases understanding of engine operation across all degrees of freedom.
- Use of models as **engine test bed simulator** reduces expensive retesting.
- Experience is a key factor in successful application of this process.

Acknowledgements

Thanks to Kevin Yardley (Manager – Powertrain Calibration) for making it possible for me to present this material at this conference.

The author would like to acknowledge the assistance of the following people at General Motors Holden Ltd. Greg Horn, Martin Jansz, Richard Hurley, Kevin Yardley, Joshua Wood, and Julian Banfield.

Thanks also to David Sampson at The MathWorks for his continuing support of Model-Based Calibration Toolbox.

Questions?