Data Modelling

Automotive Engine Fault Detection

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Plan

- Background – Legislation & Fault detection
- Data Collection – SI Automotive Engine
- Model Structure
- Model Training
- Results 1 - Fault Detection
- Conclusions

Onboard Diagnostic Regulation

- California Air Resources Board implemented OBD I 1988
- OBD II implemented 1994 with several revisions to date (latest 2003)
- European equivalent EURO III phased in from 2002
- Next stage EURO IV
- Other countries phasing in OBD include – Korea, Mexico, China.

Diagnostic Monitoring Requirements

- Positive Crankcase Ventilation System
- Engine Cooling System
- Cold Start Emission Reduction System
- Air Conditioning System
- Variable Valve Timing
- Direct Ozone Reduction System
- Particulate Matter Trap
- Comprehensive Components
- Other Emission Control or Source Systems
- Catalyst Systems
- Heated Catalyst Systems
- Misfire
- Misfire for Diesel Engines
- Evaporative System
- Secondary Air Systems
- Fuel System
- Oxygen Sensor
- Exhaust Gas

Types of Faults

Sensor Faults

- Open or closed circuit, value out of range

Actuator Faults

- Variable Valve Timing actuator seized/inactive

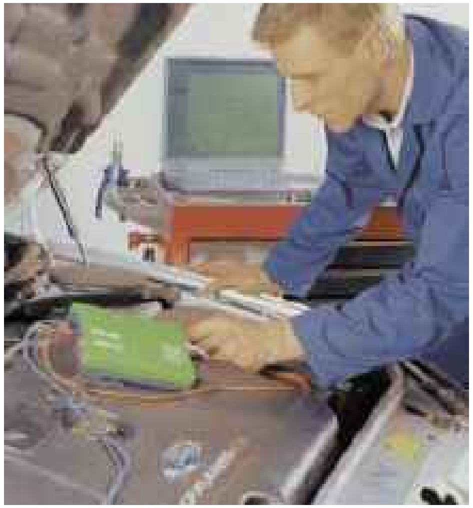
Process Faults

- Catalyst

Control Loop or Controller Faults

- Fuel injection control

Current Technology



- Fault detected by Malfunction Indictor Light (MIL)
- Garage report Diagnostic Trouble Codes (DTC’s)
- Mechanic corrects fault

Current Technology

ODB legislation:

M.I.L.

- "Any fault which causes the tailpipe emissions to rise must be brought to the attention of the driver"
- Fault must be specifically identified
- Detection must be accurate
- Strict thresholds - major challenge to the automotive industry
- As emissions limits are progressively reduced, the OBD challenge increases

Fines

20th Feb 2002 - The CARB announced today that Toyota has agreed to a $7.9 million settlement from a 1998 recall order for potential defects in evaporative emission system monitors.

"Toyota sold vehicles in California with diagnostic systems that were unable to routinely detect fuel system vapour leaks".

Fault Monitors

Currently two common approaches:

- Individual component monitors

  eg cold start strategy:

  - spark timing (commanded)
  - variable valve timing setting
  - high idle speed

- Overall system monitor

  eg cold start strategy:

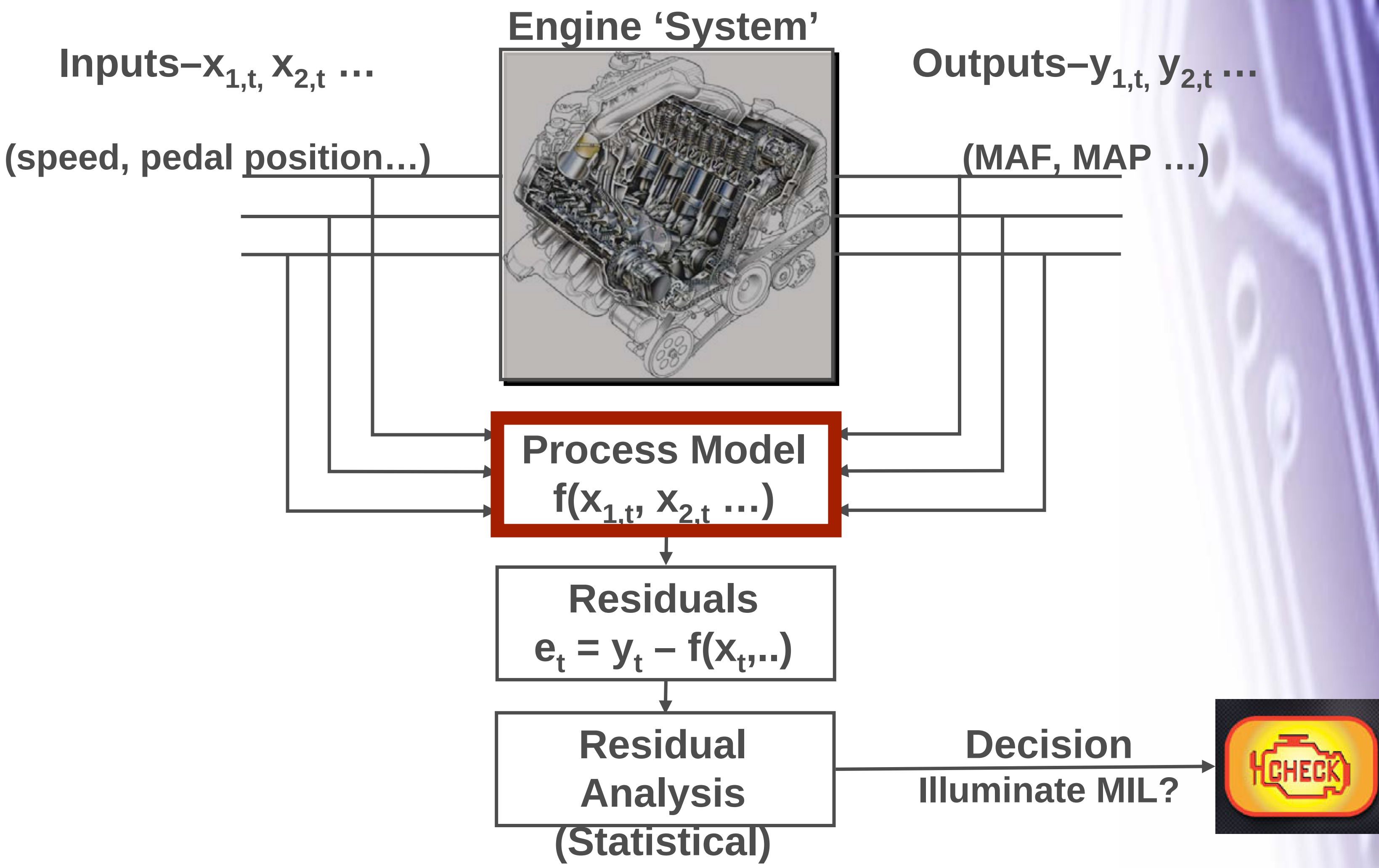
  - Verify exhaust temperature

Fault Monitors

Both approaches are required:

- Individual component monitors
  - allow faulty components to be readily identified
  - required by OBD legislation
  - but, don’t verify operation of overall system
- System monitor
  - confirms correct operation of overall system
  - but, more complex to implement
  - requires a system model

Engine Monitoring



Engine Monitoring

- Most model-based fault detection systems use physical models e.g. of air flow through intake manifold.
- Trade-off between model accuracy and complexity
- Complexity of aftertreatment systems increasing
- Transient engine operation
- OBD systems require >50% of ECU processing time
- Data modelling offers a possible alternative
  - high accuracy possible
  - once trained, final model is easy to implement

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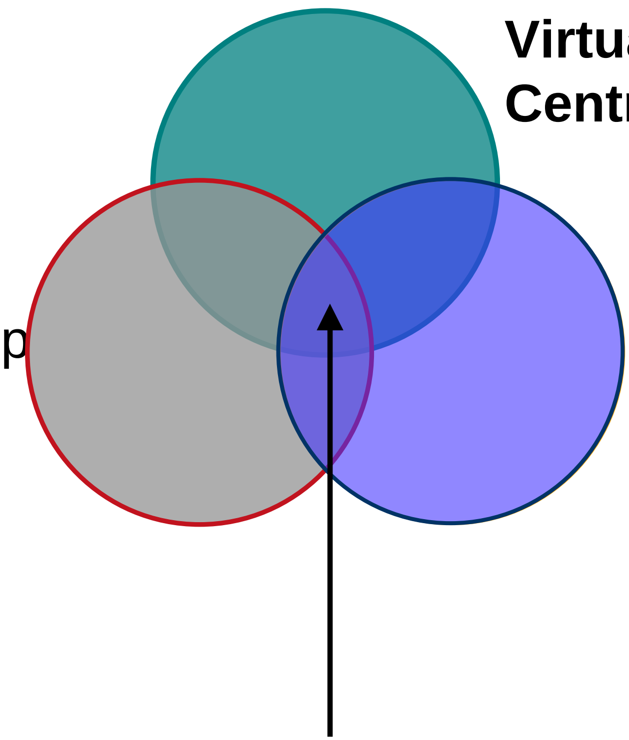
Project Structure

<u>Multidisciplinary</u> project involving two departments:

Virtual Engineering Centre

IC Engines
Research Group
Mech. & Aero.
Engineering



Control
Research Group
Elect. Engineering

Engine Fault Detection Project

Faults

Process

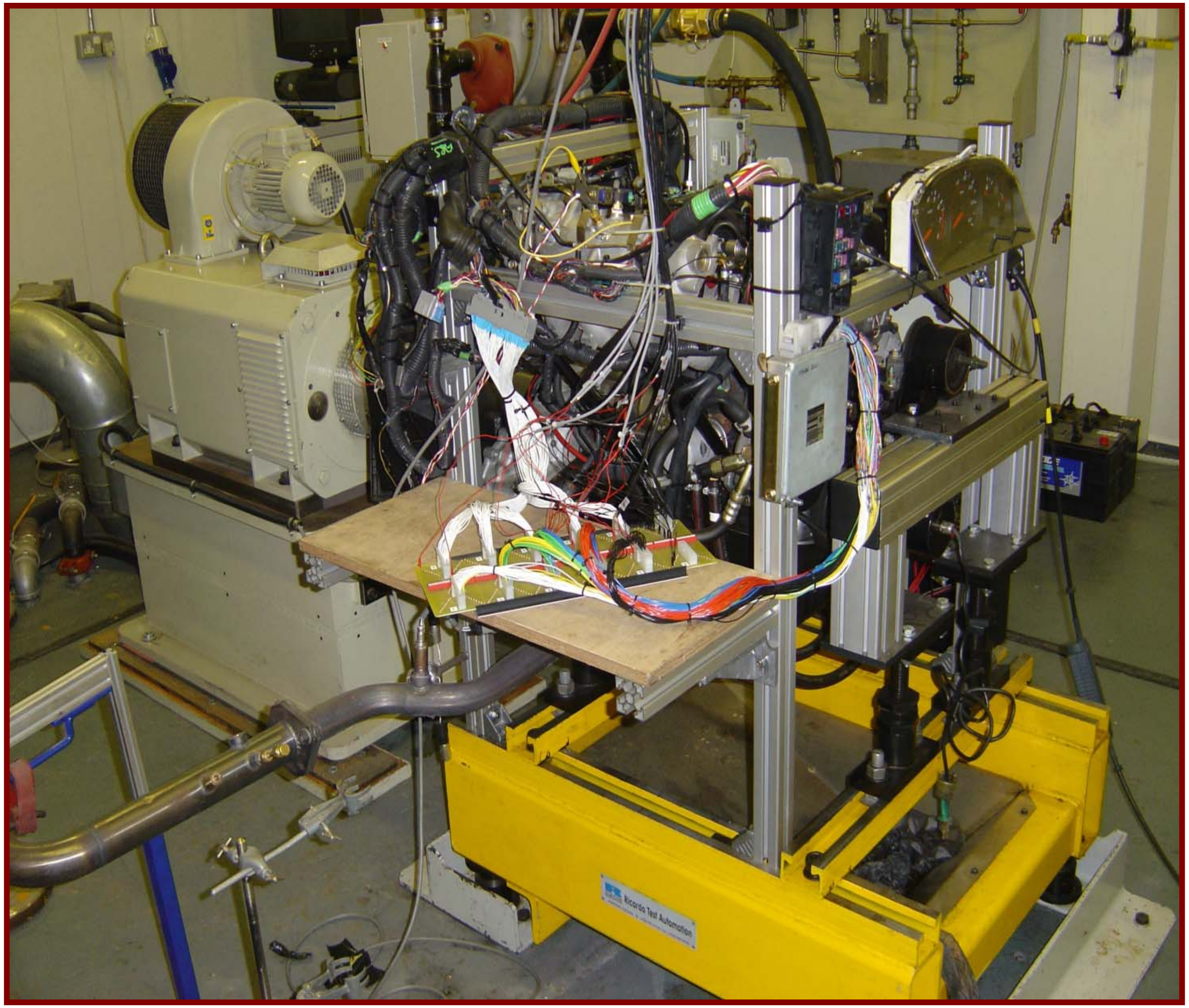
- **Air Leak**
- Catalyst Performance
- Lambda sensor deterioration
- EGR valve

Sensor

- Inlet Pressure Sensor
- Mass Flow Meter
- Throttle Position Sensor
- Coolant Temperature

Data Collection

Data Collection

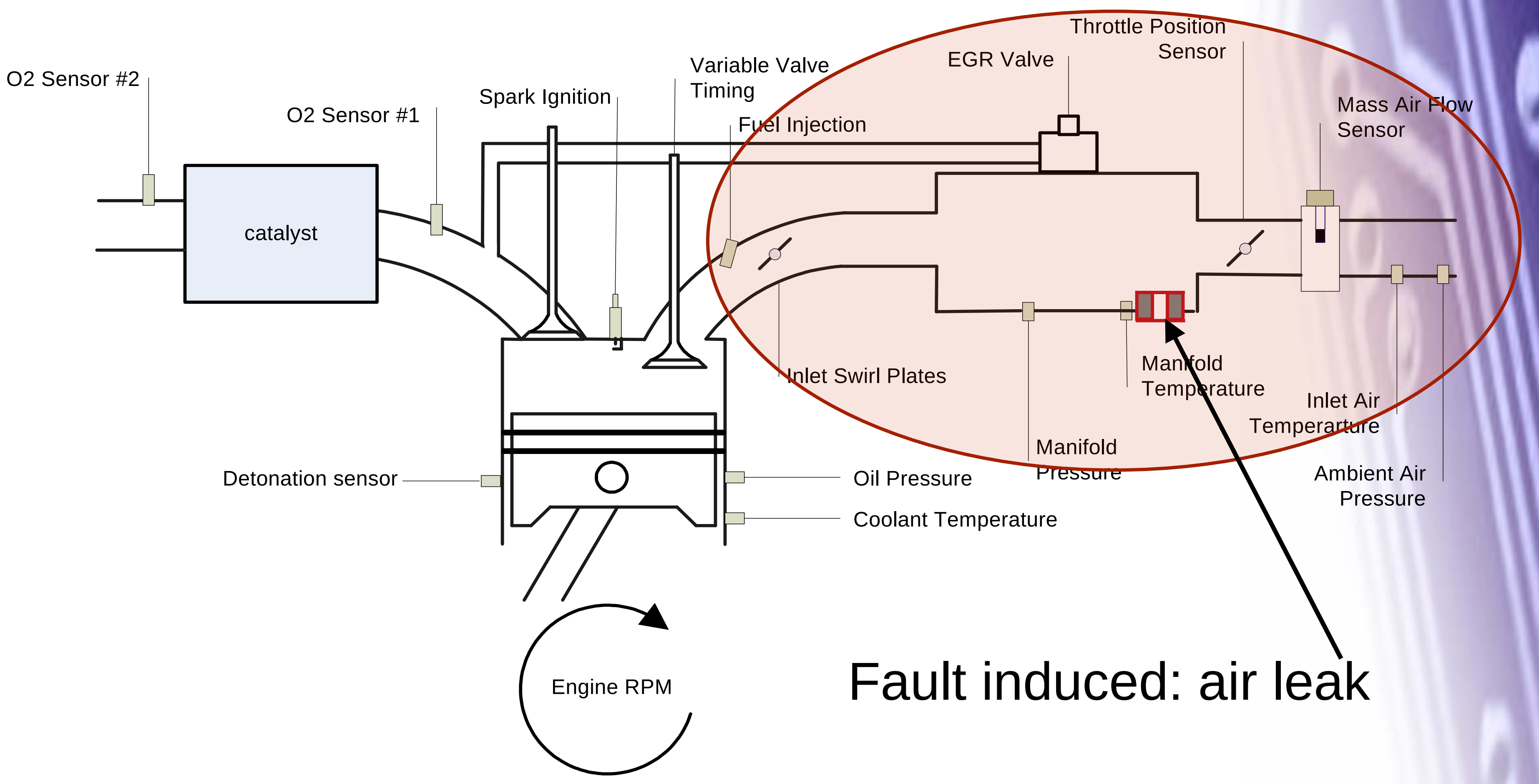


Transient Dyno:
145kW AC

Wiring:
Standard ECU.
Standard harness.

Engine:
Nissan 1.8L. SI.
4 cylinder.
~87kW.

Data Collection



Data Collection

Variables measured:

Inputs	Outputs
Engine speed (rpm)	**Manifold Air Pressure (bar)**
Pedal Position (%)	**Mass Air Flow (g/sec)**
	Manifold Air Temp (^{o}C)

- Available on production engine
- Fault-free data used to build model of intake system
- Inputs identical during fault and fault-free tests

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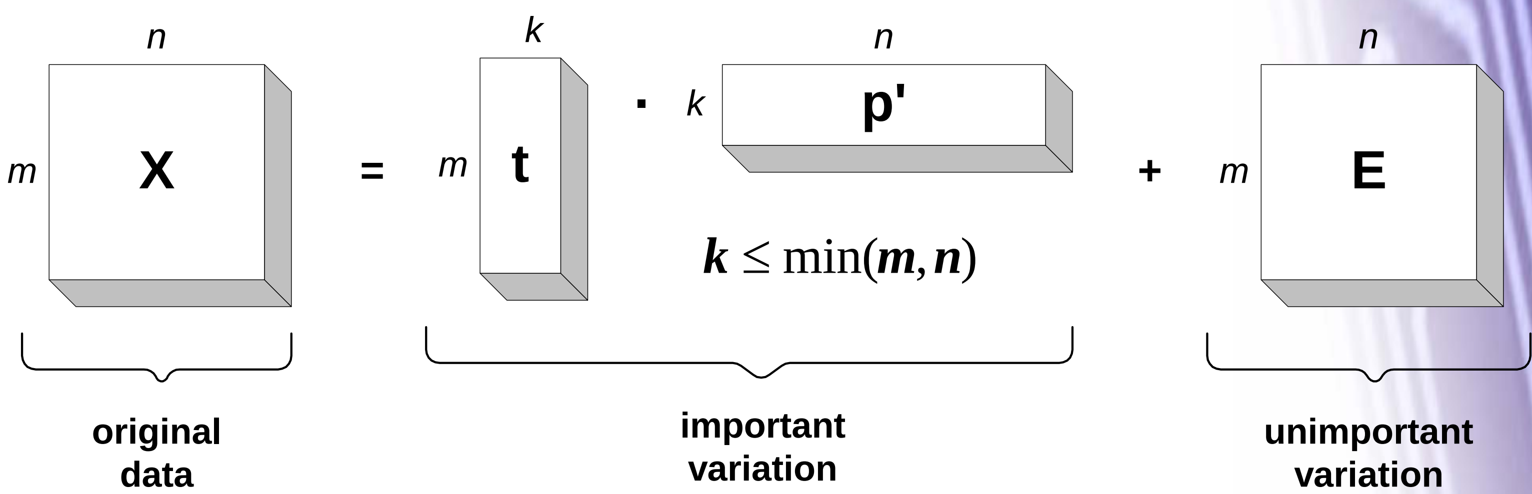
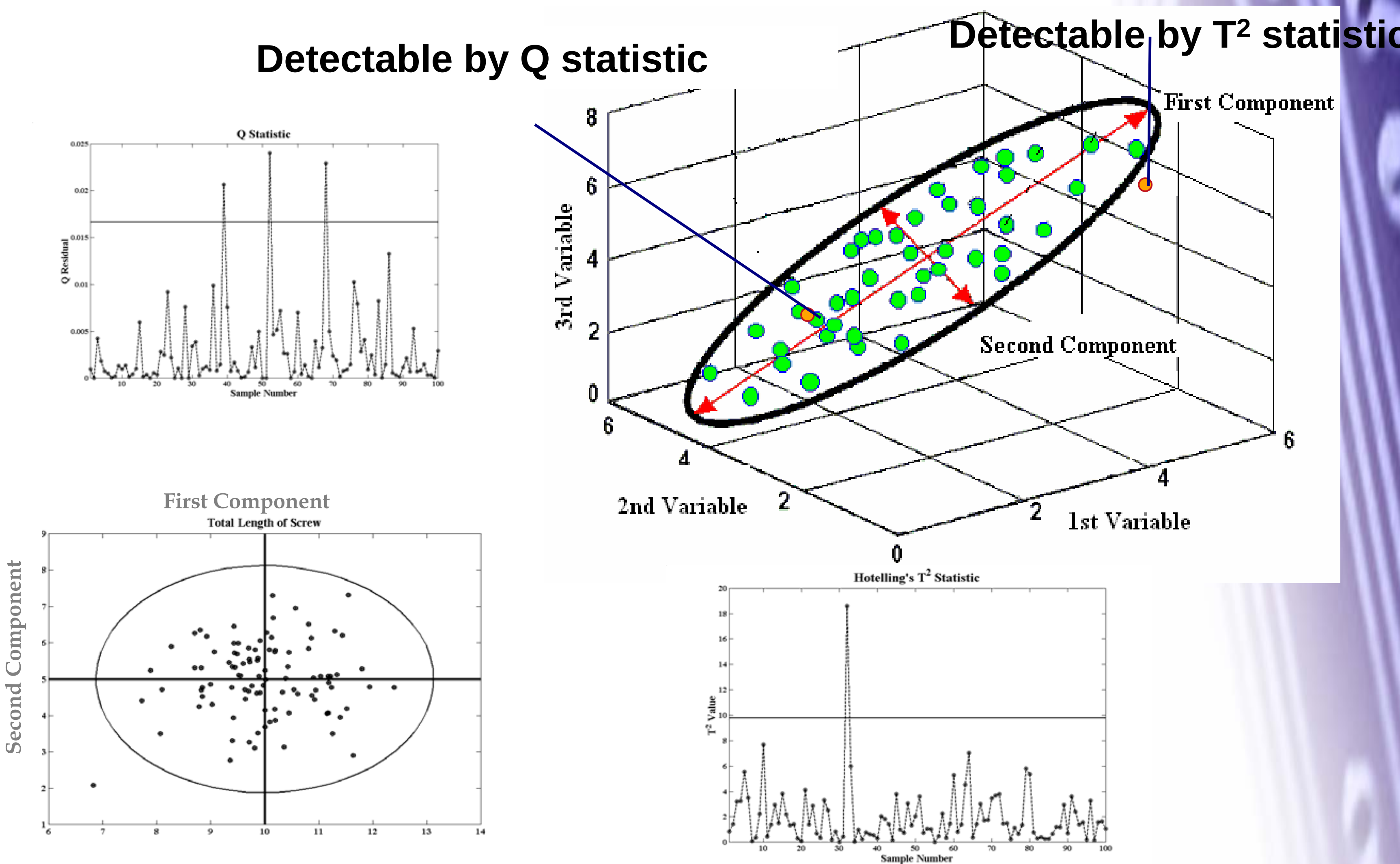
Principal Component Analysis

Why PCA?

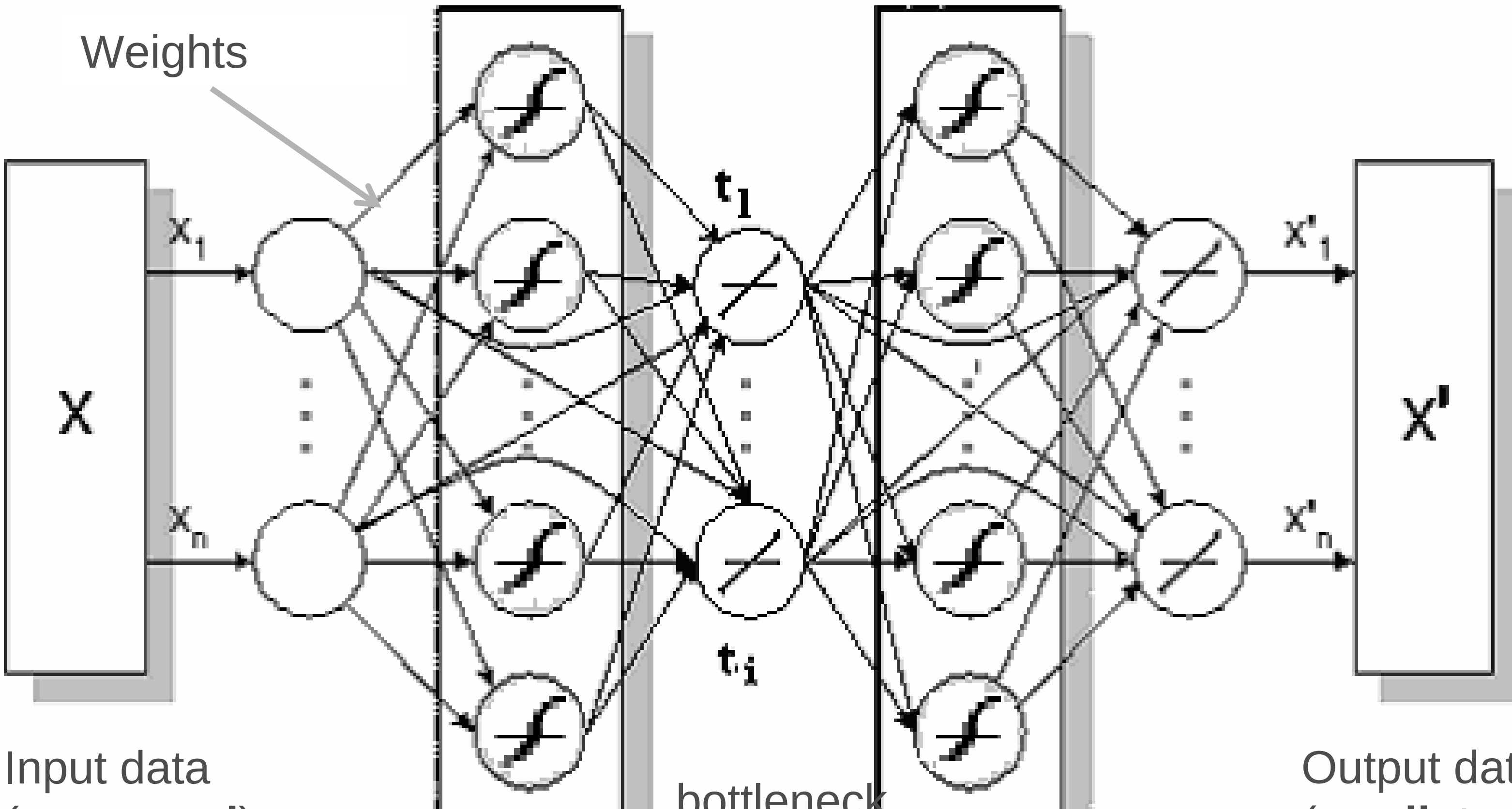


$$X = t_1 p_1^T + t_2 p_2^T + \ldots + t_k p_k^T + E$$

Principal Component Analysis



Model Structure (Nonlinear PCA)



Input data (**measured**)

Output data (**predicted**)

Input layer **5**

mapping layer **15**

bottleneck layer **3**

De-mapping layer **15**

Output layer **5**

Model Structure

Final model equations

$$\hat{x}_1 = W4 \cdot a + W6 \cdot b - 0.0264$$

$$a = \varphi(W3 \cdot b + b3)$$

$$b = W2 \cdot c + W5 \cdot x$$

$$c = \varphi(W1 \cdot x + b1)$$

$$\varphi(\cdot) = \frac{2}{1 + \exp(-2(\cdot))} - 1$$

Engine Control Unit

Current Production Technology

- 32 bit Processor
- Speed – 40 to 75 MHz, 200MHz in development, 1-2 GHz next generation
- On Board Memory – up to 512 kB
- Flash Memory – up to 2 MB
- Typical Microprocessors - Motorola MPC533 or Philips ARM7TDMIS

50% ECU software dedicated to on-board diagnostics (OBD)

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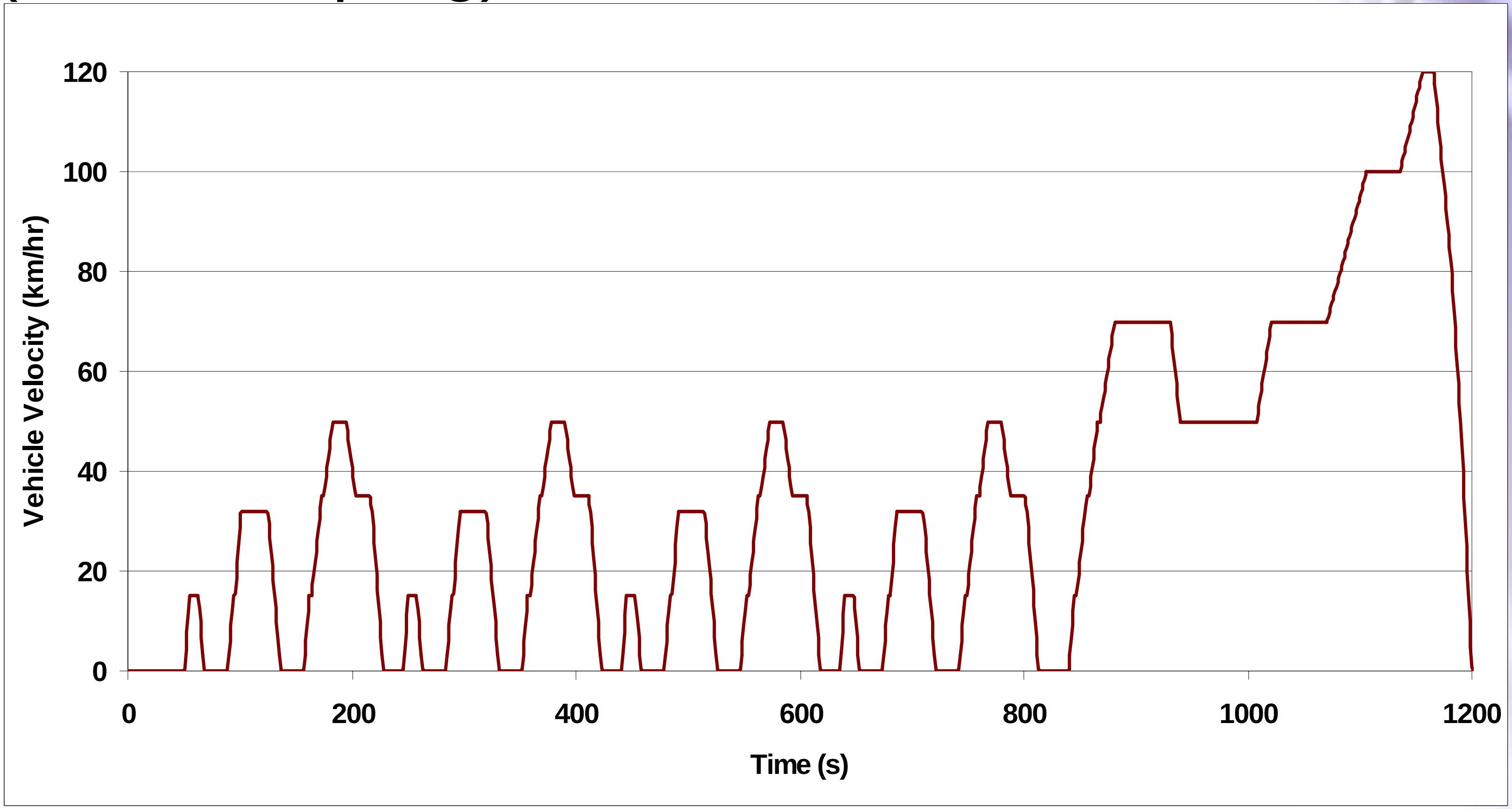
Training Data

- Careful training is crucial to the success of a neural network model.
- Weights are adjusted by training with ‘fault-free’ data.

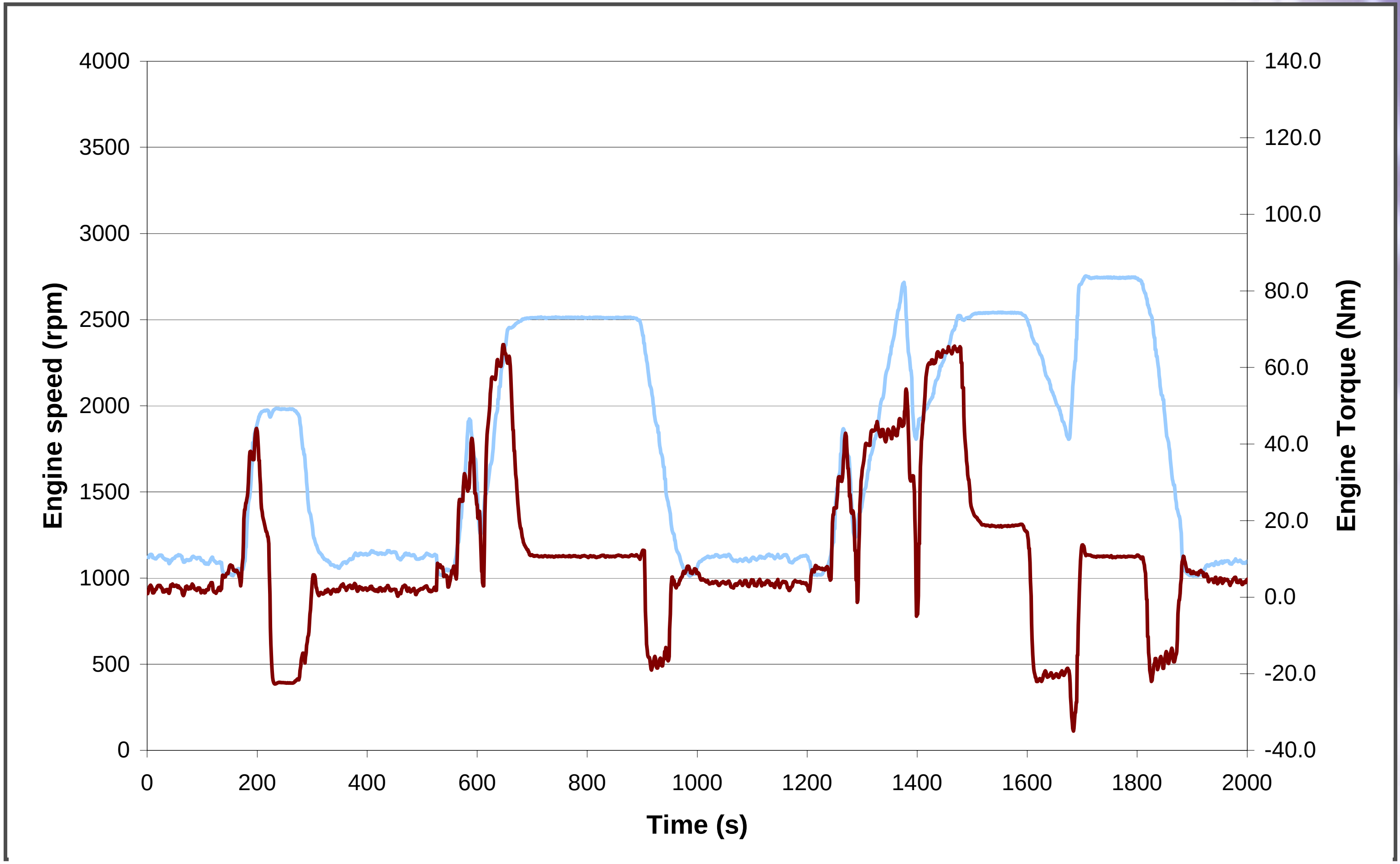
  Aim: predicted variables = measured variables
- Ideally, the training data should cover the whole operating range.
- Options:
  - Steady state (Matrix of speed / load points)?
  - Transient – Government Drive Cycle?

Training Data

New European Drive Cycle (NEDC) initially considered (10Hz sampling)

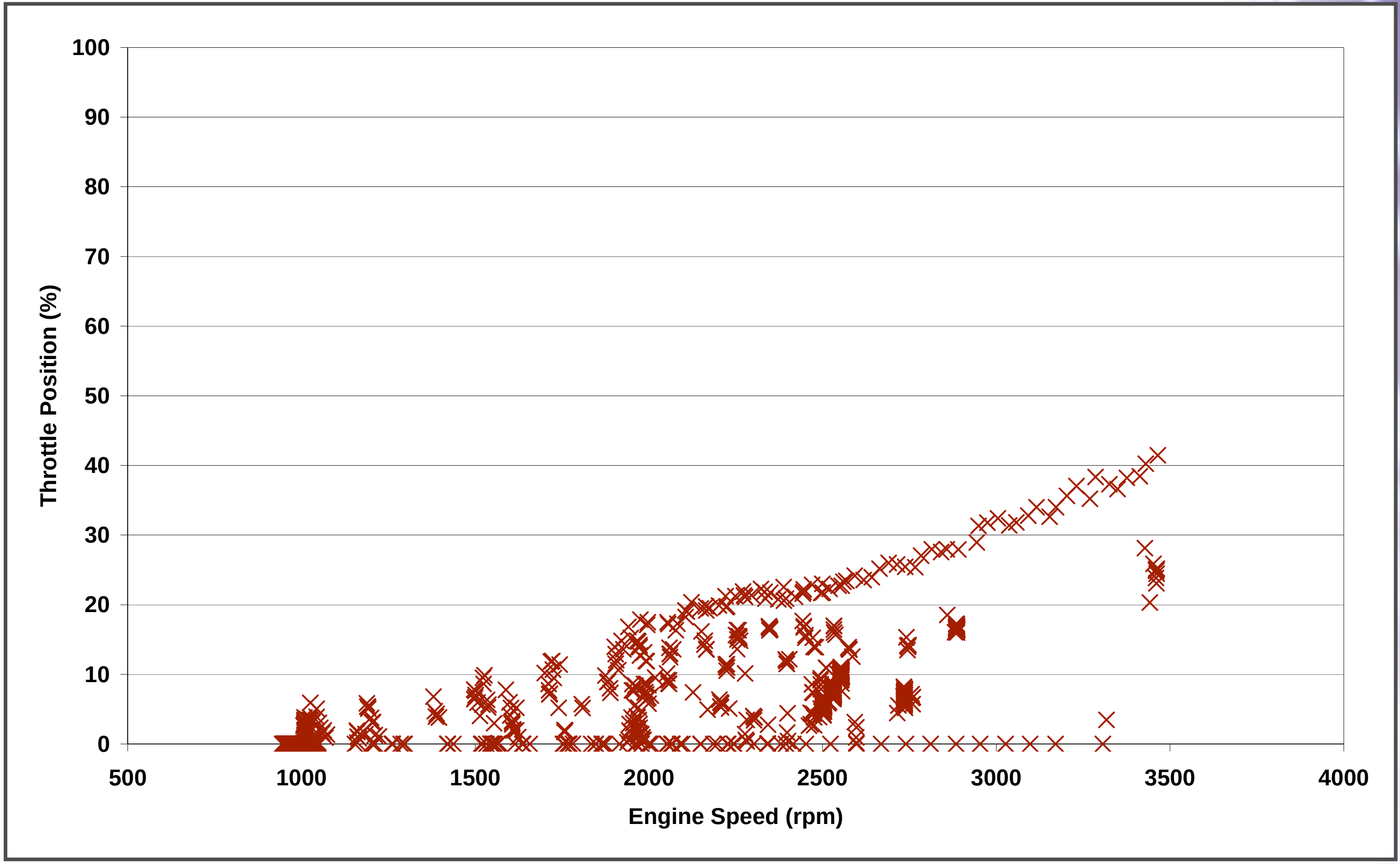


Training Data



Transient inputs (engine speed & pedal position) ∴**Realistic**

Training Data



NEDC covers relatively small area of operating map

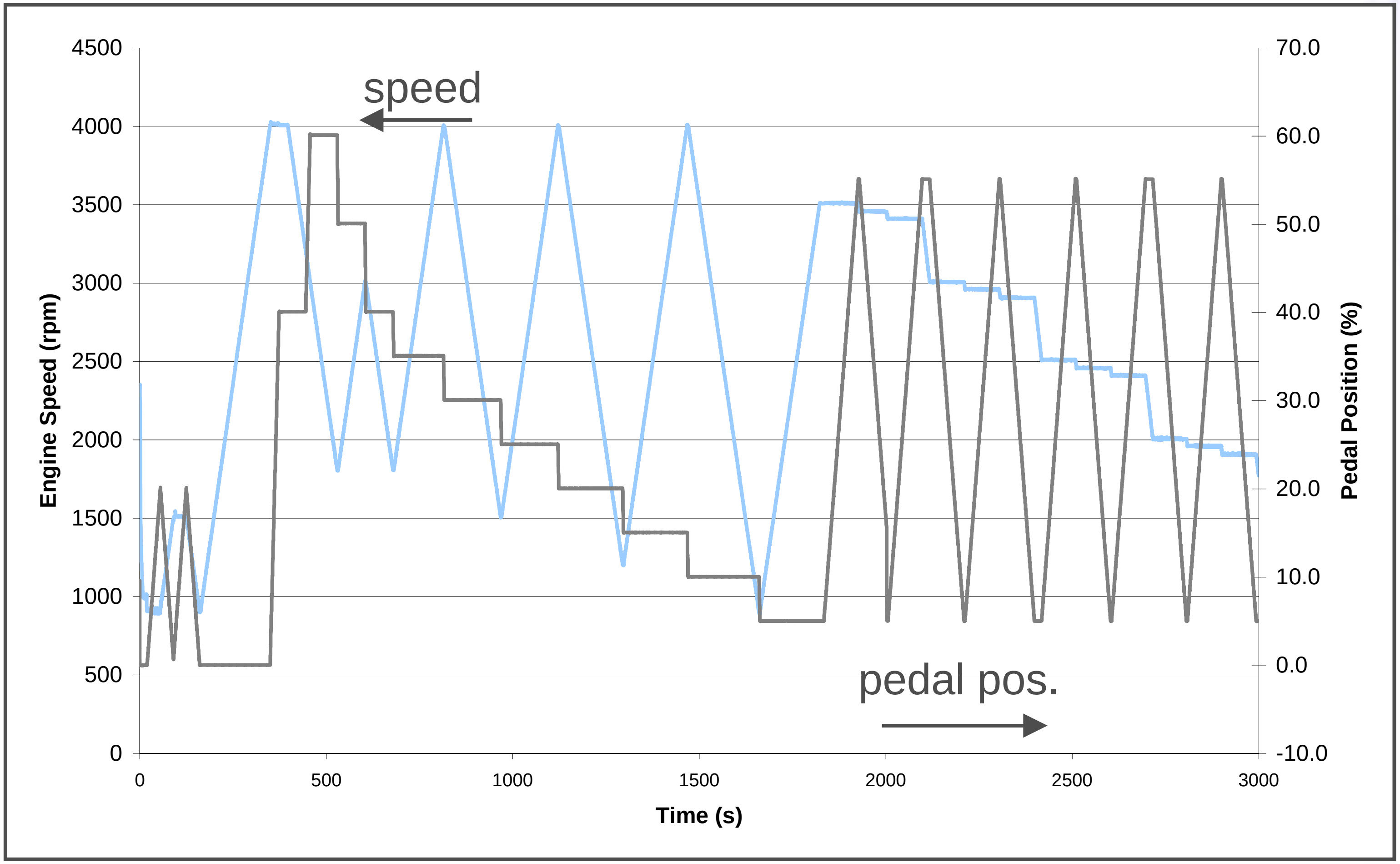
Training Data

- Alternative cycle proposed by Kimmich, Schwarte, Isermann (2005)

'Fault detection for modern diesel engines using signal- and model-based methods', Control Engineering Practice, Vol.13, pp189-203

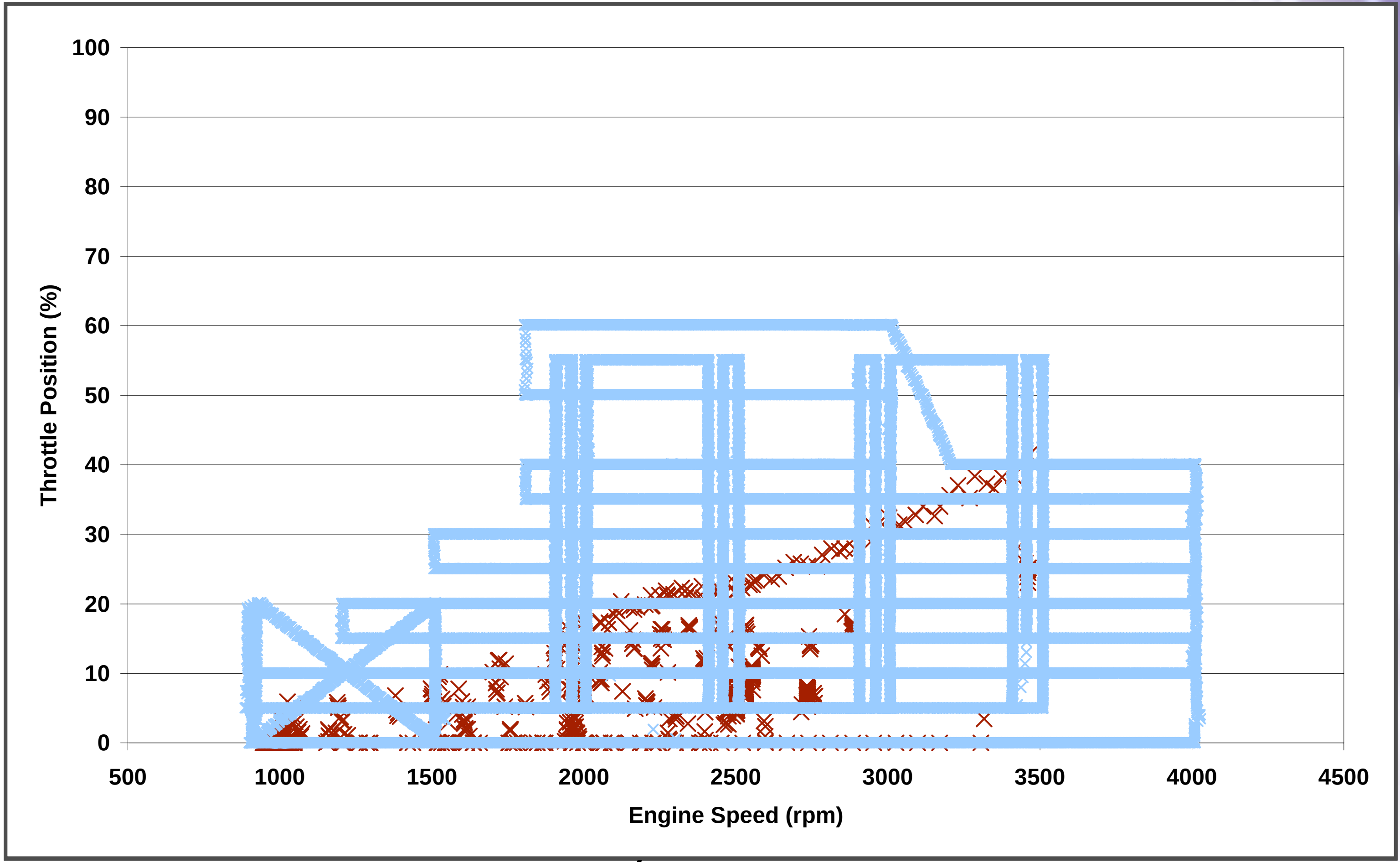
- Dynamic - stimulates low frequencies
- Evenly distributes data points over the complete input space

Training Data



‘Kimmich’ cycle – Covers a broader range of operating conditions

Training Data



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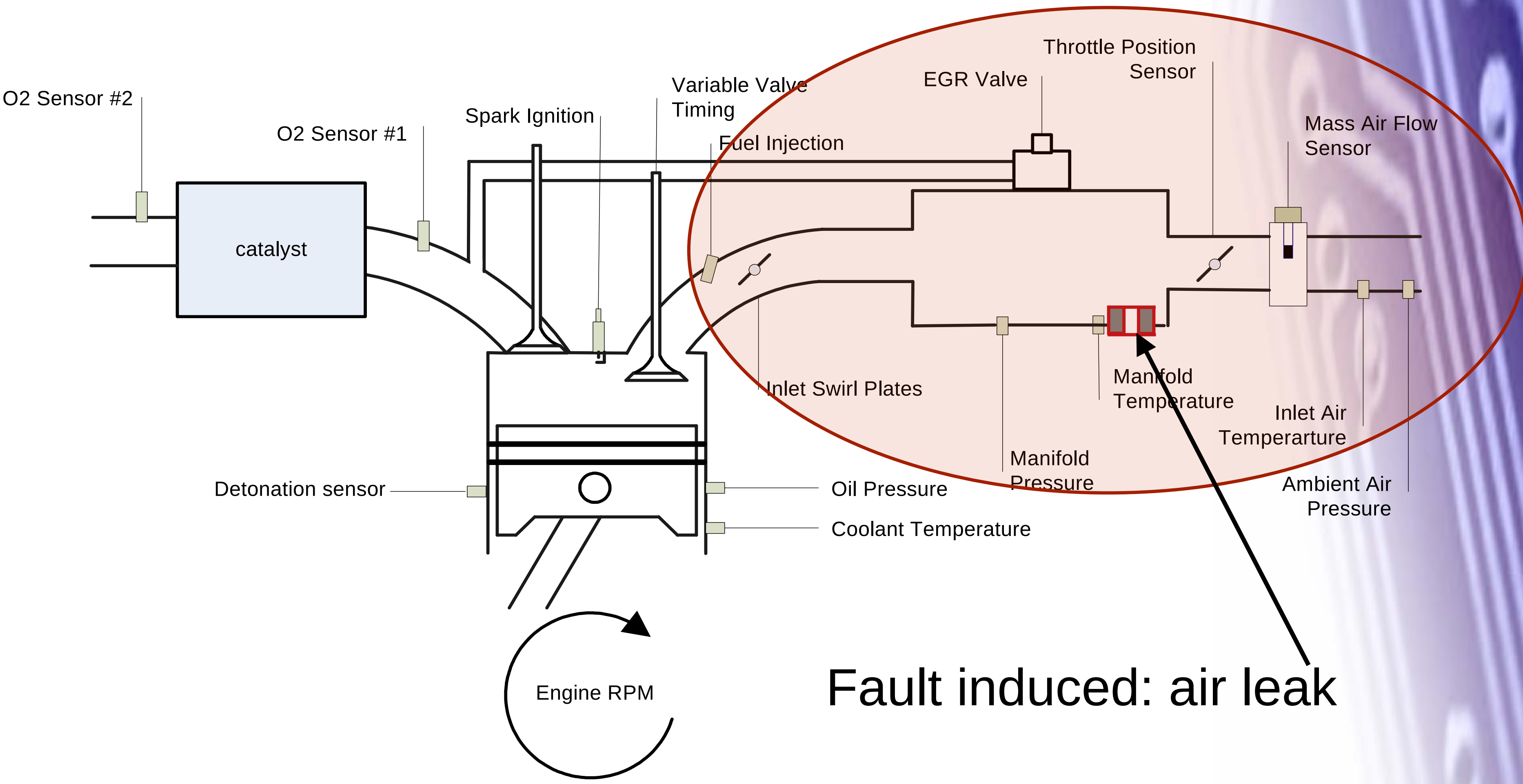
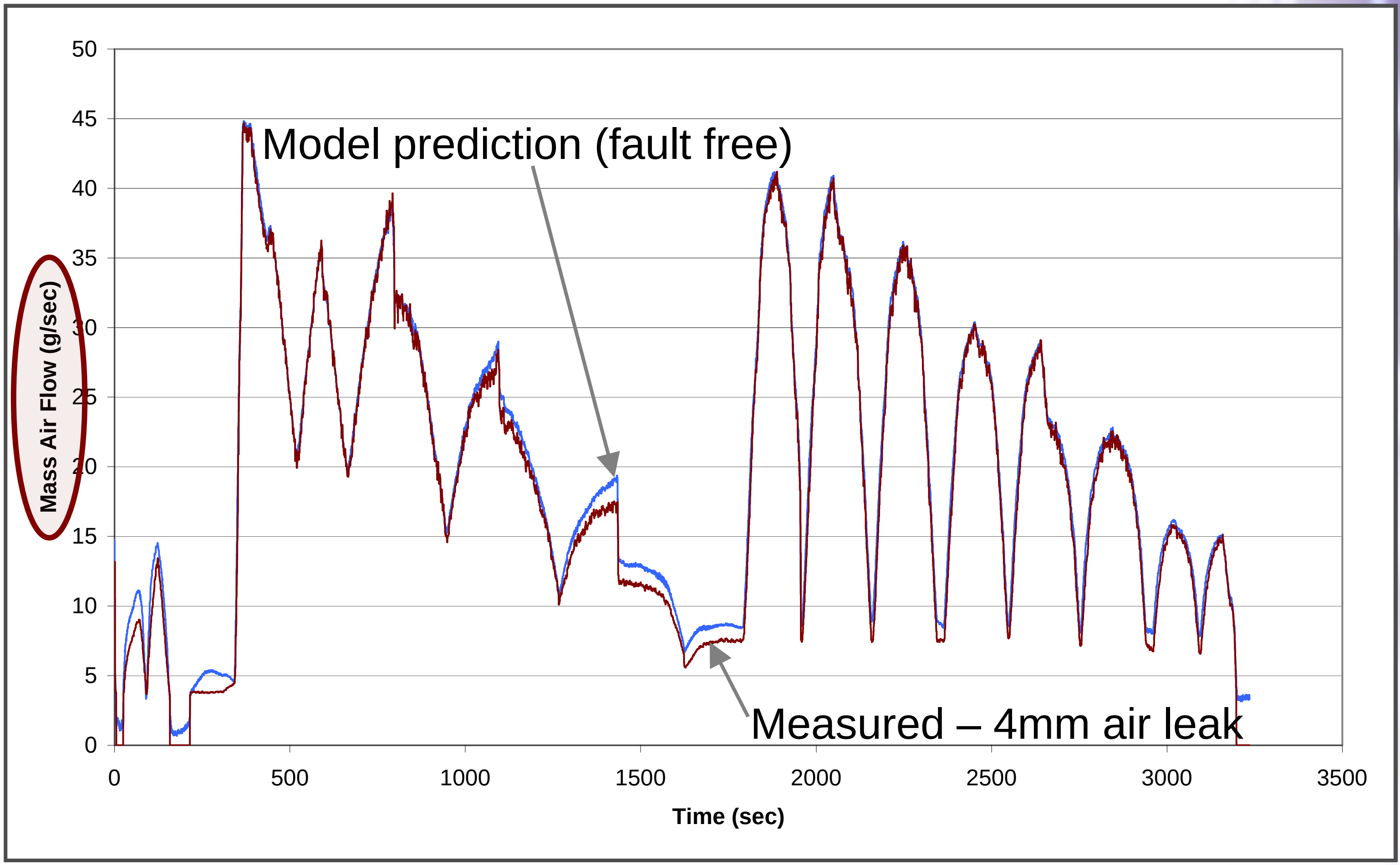
Air Leak Fault

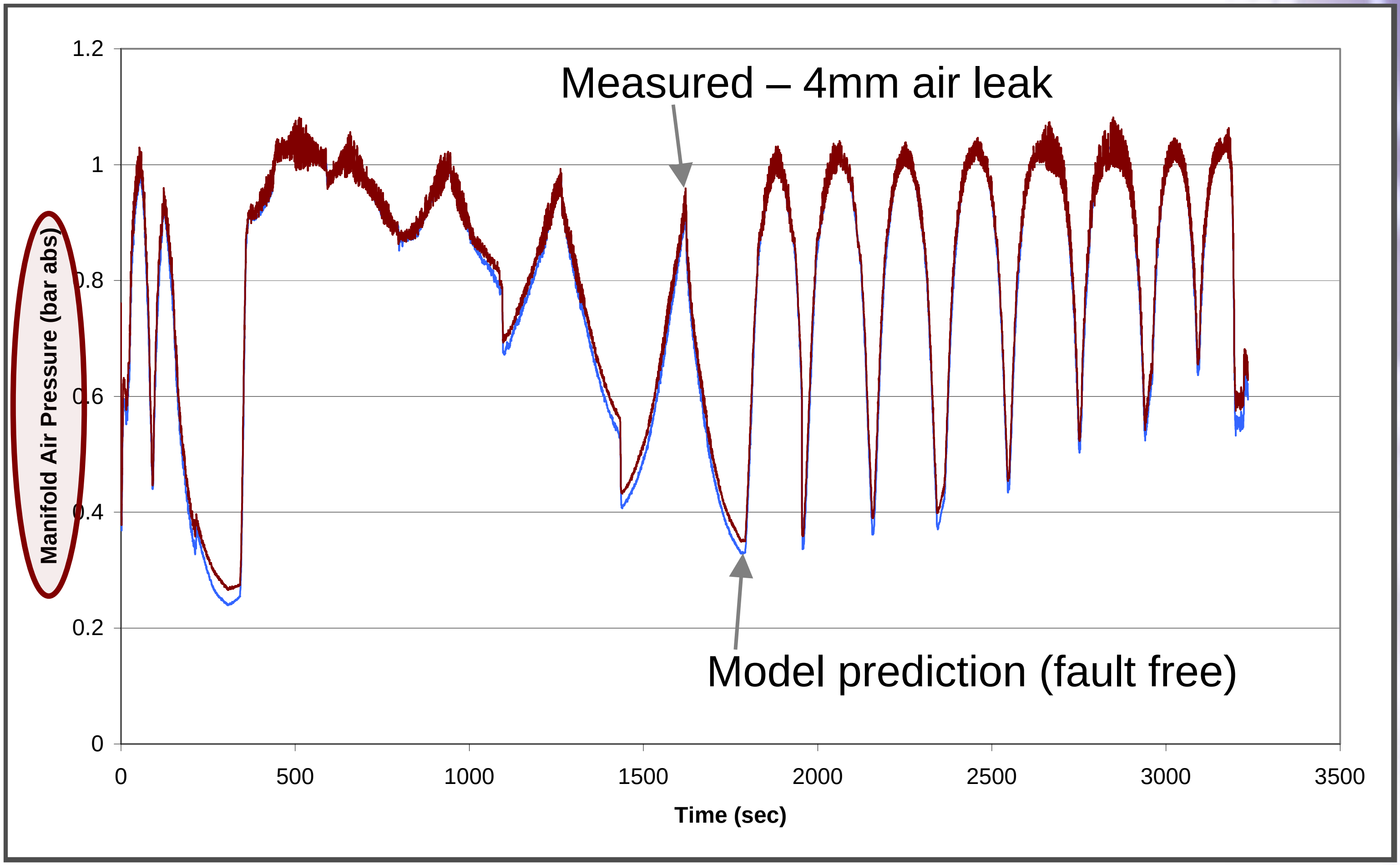


Fault induced: air leak

Results 1 – Mass Air Flow



Results 1 – Manifold Pressure

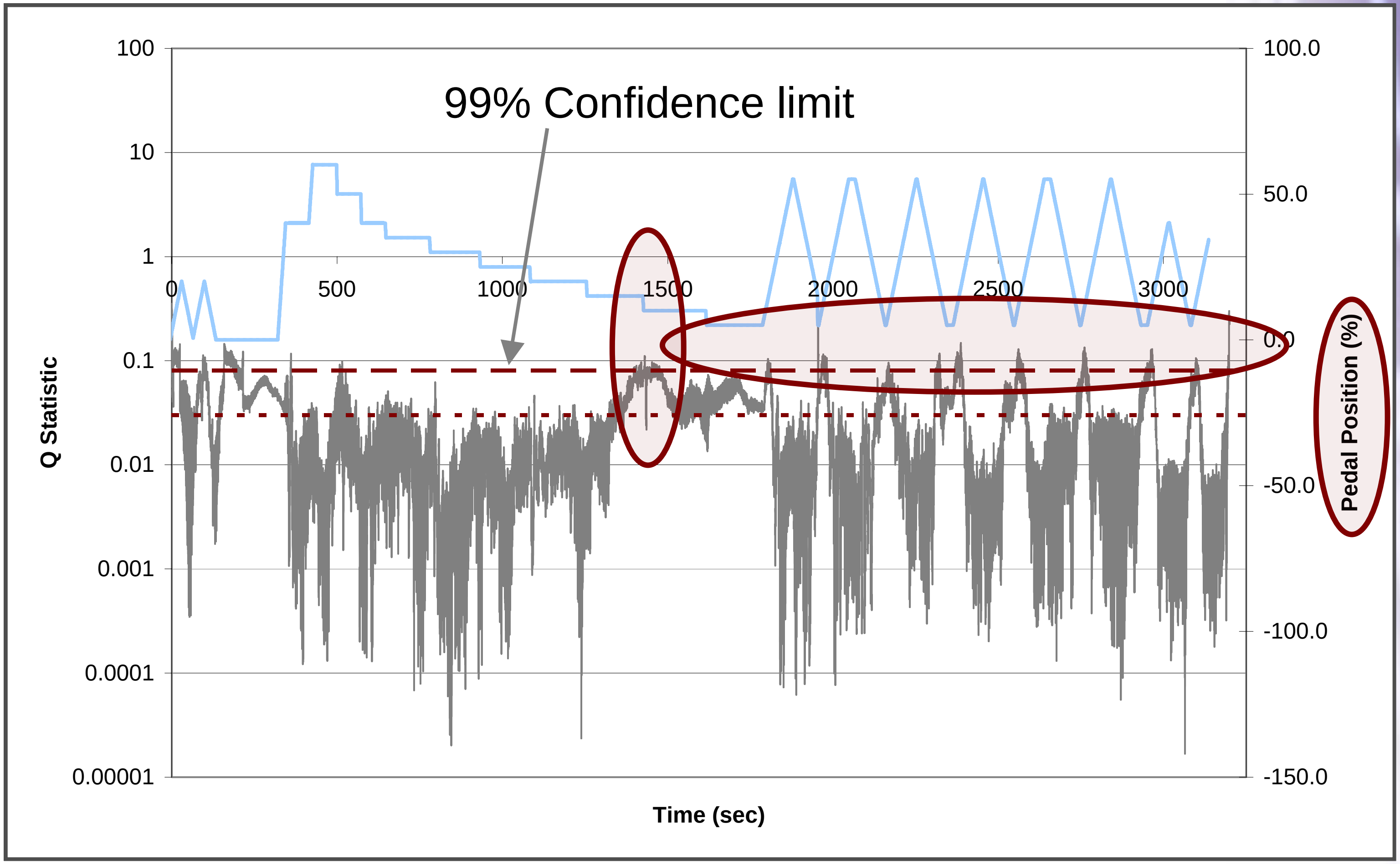


Residual Analysis

- Once trained, the model can be tested with ‘faulty’ data.
- The fault will appear in the form of residuals.
- These residuals are analyzed using the ‘Q statistic’
- This is defined as a sum of the differences between the measured and predicted variables squared.

$$Q = \sum_{i=1}^{5} \left(x - x'\right)^2$$

Results 1 – Q Statistic



Conclusions

- Nonlinear PCA (AANN) is capable of accurately simulating an engine intake system.
- Can simulate dynamic operation.
- Design of training cycle is crucial.
- Provided the model is accurate, residual analysis can increase the accuracy of the subsequent fault detection.

Data Modelling
for
Automotive Diagnostics

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