OBD Development for Diesel Engines: Experiences and Lessons Learned

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Ricardo

Contents

- Stakeholders in OBD
- Typical process for OBD development
- Example issues
  - Diesel Particulate Filter – Wall flow and through flow
  - EGR system
  - Immature base calibration
- Tools
  - Early IUMPR assessment
  - Fleet logger analysis
  - HiL
- Conclusions and lessons learned

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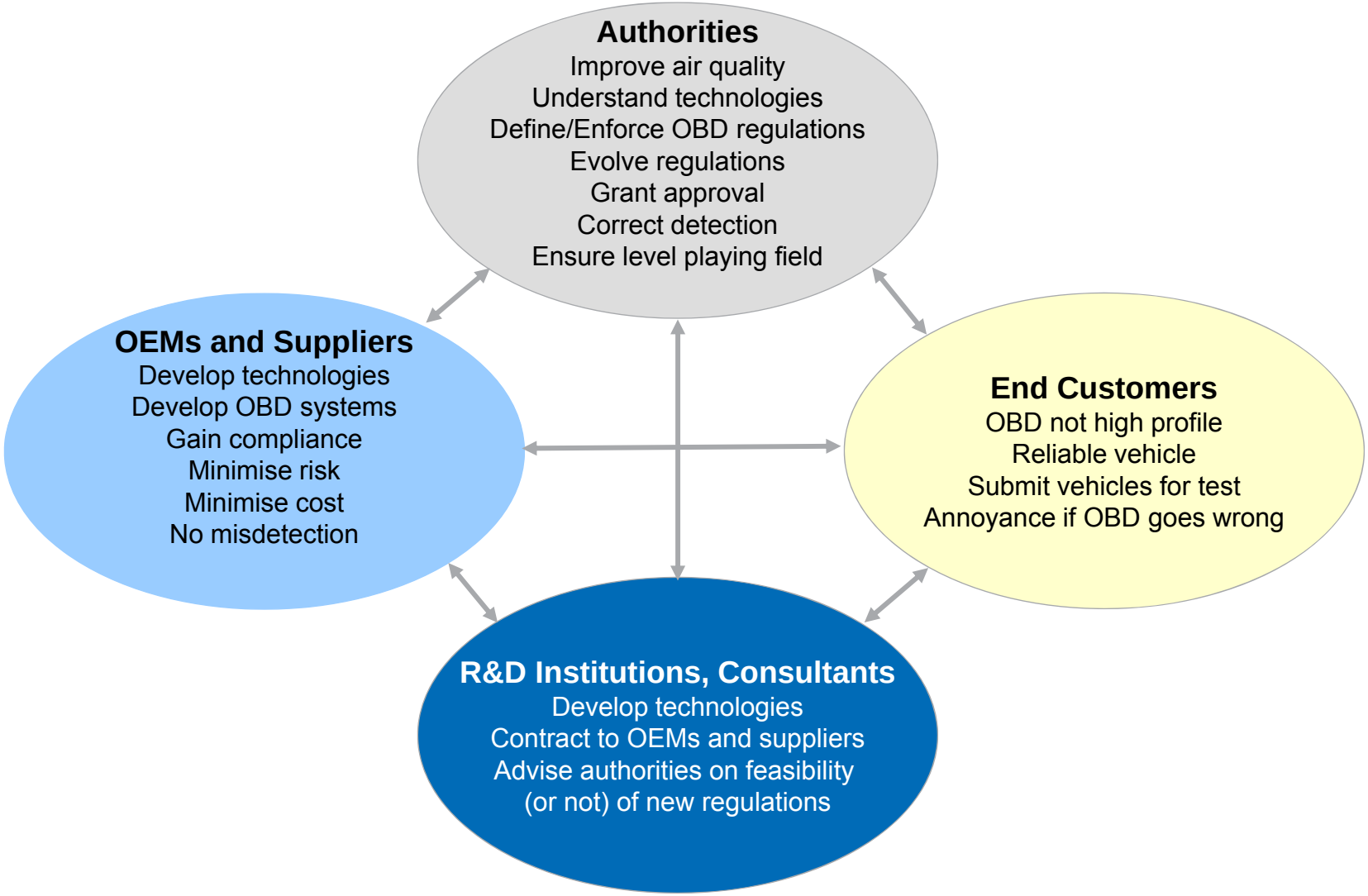
Stakeholders in OBD



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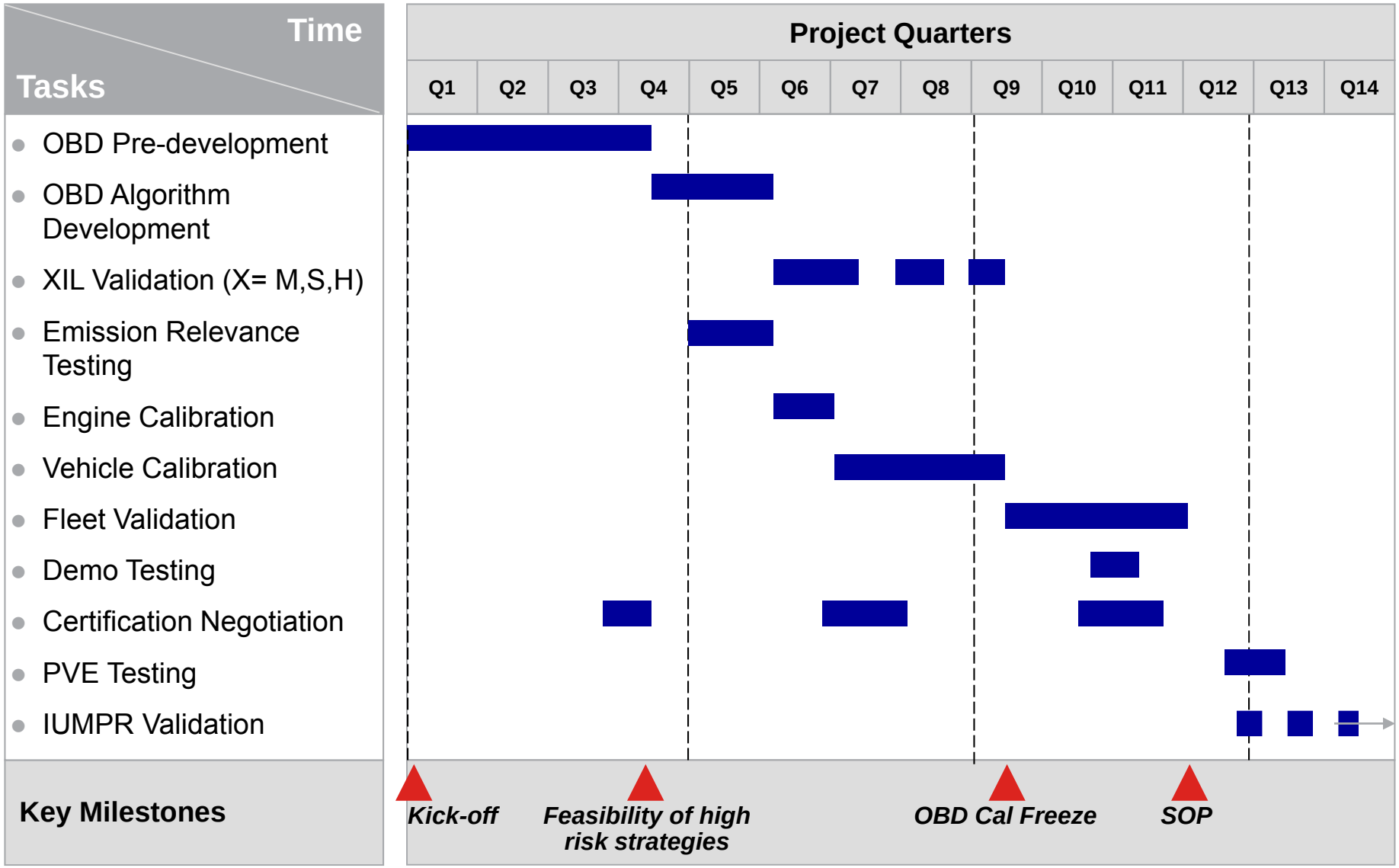
OBD Development – Overview of Typical Process



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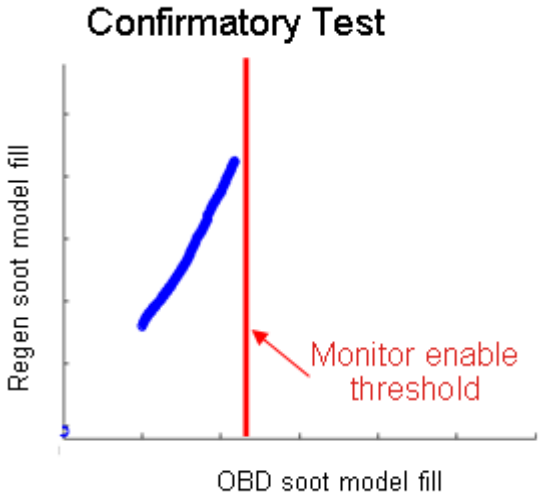
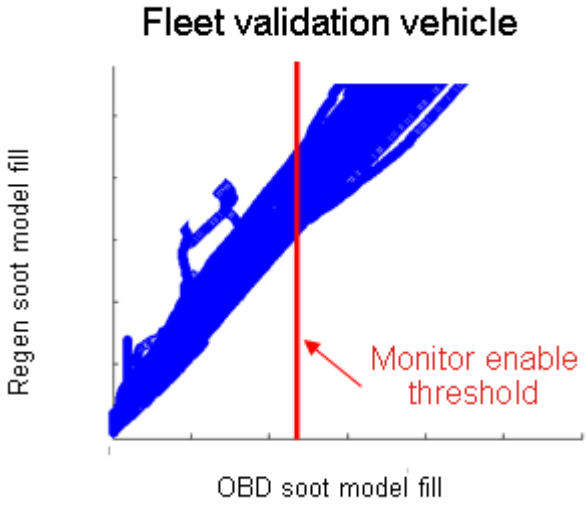
Wall Flow DPF Issue - 1

- Calibrated DPF bypass system used to simulate loss of DPF filtration efficiency
- Threshold failure was correctly detected on the dyno test cycle for development and demonstration
- Threshold failure was correctly identified when tested by Ricardo on development vehicles
- IUMPR data was good during fleet validation
- OBD authority were unable to detect fault during confirmatory testing.
  - No pending code set
  - Numerator was found not to have incremented
  - Investigation found that DPF regeneration was happening before the soot model used by the OBDII monitor reached a sufficiently high fill level to enable the monitor

Wall flow DPF Issue - 2

- 2 separate soot models were used in the ECU
  - A Regeneration soot model and
  - An OBD soot model
- Reasons for having 2 models:
  - Regeneration soot model overestimates fill level to minimise risk of uncontrolled regeneration
  - OBD soot model seeks accurate, if anything underestimation, of fill level model to minimise risk of false detection of leakage in DPF





Wall flow DPF Issue - 3

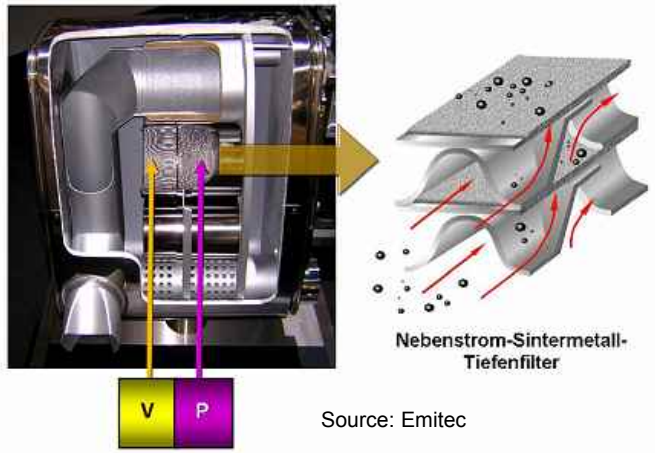
- Root cause
  - Regeneration triggered before OBD system enabled DPF monitor because of difference between 2 models
  - Driving style dependent (worst case was extremely gentle driving)
    - Fleet validation on ‘mixed driving’ routes masked this effect
  - Limited amount of testing by authority meant fault was never enabled

- Resolution
  - Evaluate IUMPR data from field
  - Investigation into possible recalibration with lower enable threshold

- Effort to investigate & rectify issue
  - 1 engineer-month investigation
  - Engineer required to travel to repeat test in territory
  - No rectification required

Through flow DPF Issue

- Issue
  - Blocked DPF was detected OK
  - Missing DPF monitor detected OK but also false MILs found to be generated during fleet testing
- Root cause
  - Through flow DPF has low ΔP vs. flow characteristics
  - Insufficient difference between ΔP's for missing and actual (good) DPF at low exhaust flows
- Resolution
  - Enable missing DPF monitor only at higher exhaust flows
- Effort to investigate & rectify issue
  - Strategy change & validate offline
  - Software implement & check in ECU
  - Re-validate on vehicle
  - Total effort ~3 man-months



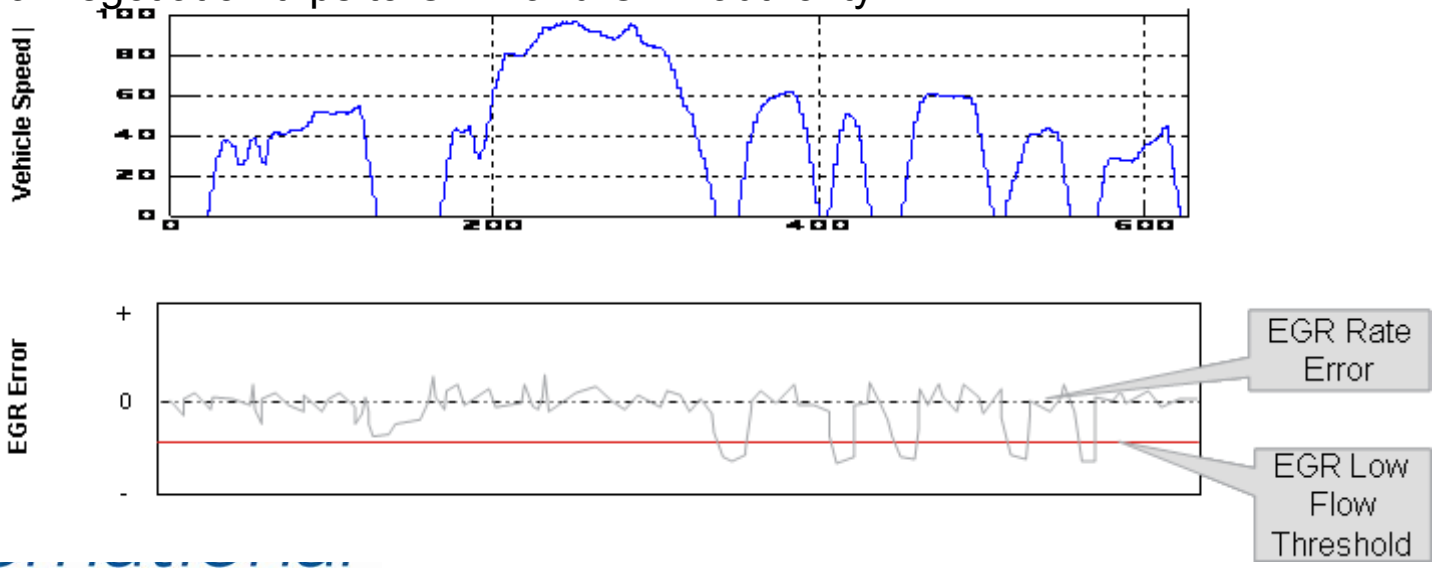
Source: Emitec

EGR Low Flow Issue - 1

- Development testing identified the level of EGR circuit restriction which caused NOx emissions to be at the OBD threshold
- The restriction was correctly detected on the FTP test
- The restriction was correctly detected by the OBD authority during confirmatory testing
- Issue:
  1. Although the threshold EGR flow restrictor can be detected, it is only detected when at idle with the transmission shifted into Park or Neutral
     - Many drivers may not shift into Park when stationary except just before switching off the engine (10 seconds required to detect the fault)
     - Pending codes may easily be cleared on a subsequent drive cycle
  2. The monitor is enabled outside the no-load idle area in-use performance ratio numerator increments with transmission outside P or N
     - Monitor makes a full judgement that the system is ok without having been operated at the most sensitive point required to detect the threshold fault
- Opinion of authority was that the system was not valid *despite passing all the tests* due to risk of false passes

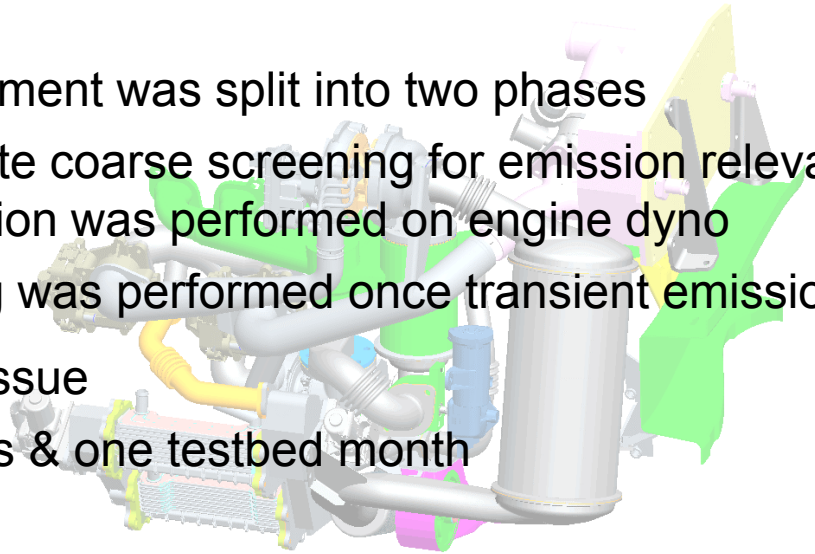
EGR Low Flow Issue - 2

- Root cause
  - During development, EGR low flow monitor had to be de-sensitized outside no-load idle region due to false MIL risk
  - Although detectable on newer vehicles over wider enable region, on higher mileage vehicles threshold EGR restrictor not distinguishable from good system
  - Calibration of base EGR control strategy limited operating regions where reliable, robust monitoring possible
- Resolution
  - Reduce enable region to area where sensitivity to fault is reasonable
  - Re-calibrate monitor so that EGR restrictor distinguishable from good system on higher mileage vehicles
- Effort to investigate & rectify issue
  - Approx 6 man-months
  - Several negotiation trips to OEM and OBD authority



Immature Base Calibration

- Issue
  - Compressed program timescales led to overlap between emissions development and OBD
  - Emissions were not inside target type approval box with engineering margins at start of OBD development over transient cycles
- Root cause
  - Steady-state emissions calibration was OK, transient emissions status not sufficiently mature
- Resolution
  - OBD development was split into two phases
    - Steady-state coarse screening for emission relevance and threshold determination was performed on engine dyno
    - Fine tuning was performed once transient emissions complete on vehicle
- Effort to rectify issue
  - 3 man months & one testbed month



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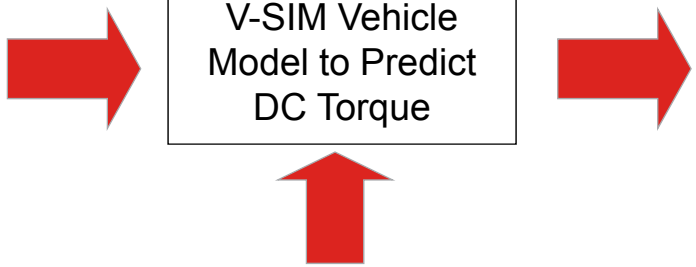
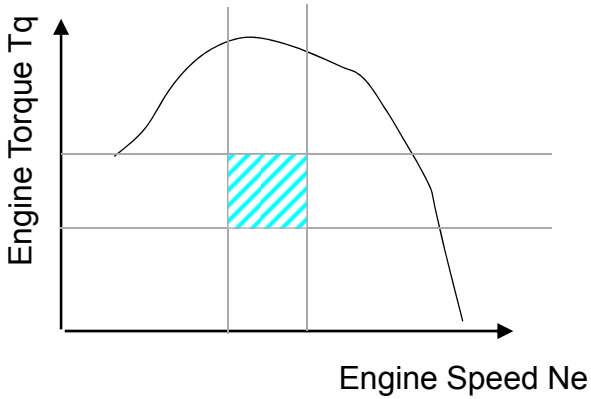
Early Assessment of IUMPR

- Tool to assess IUMPR issues at early stage of OBD algorithm development and calibration:

Vehicle Parameters
Engine Parameters



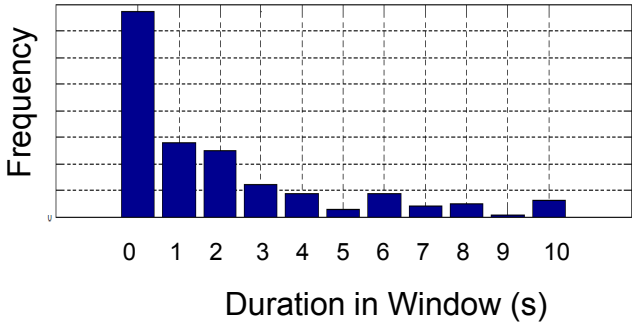


Driving Cycle
- Typical “average”
- Typical F, UK, De, I etc
- Special

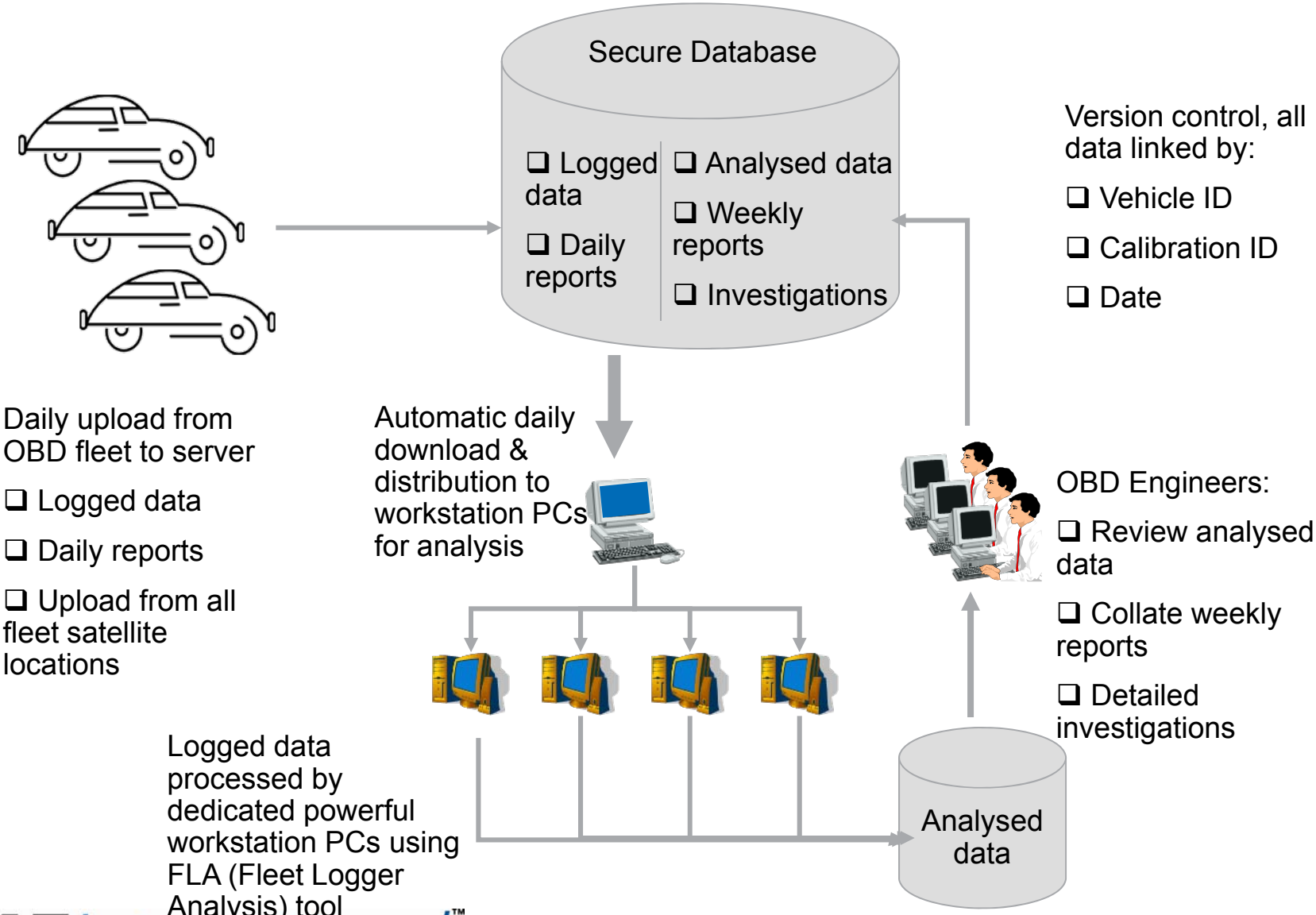
Driving Style
- Gentle
- Aggressive
- Gear shift early/normal/late

Enable Window in terms of
- Engine rpm
- Engine torque, fuel or throttle
- Coolant Temp

Output
(for specified Enable Window)

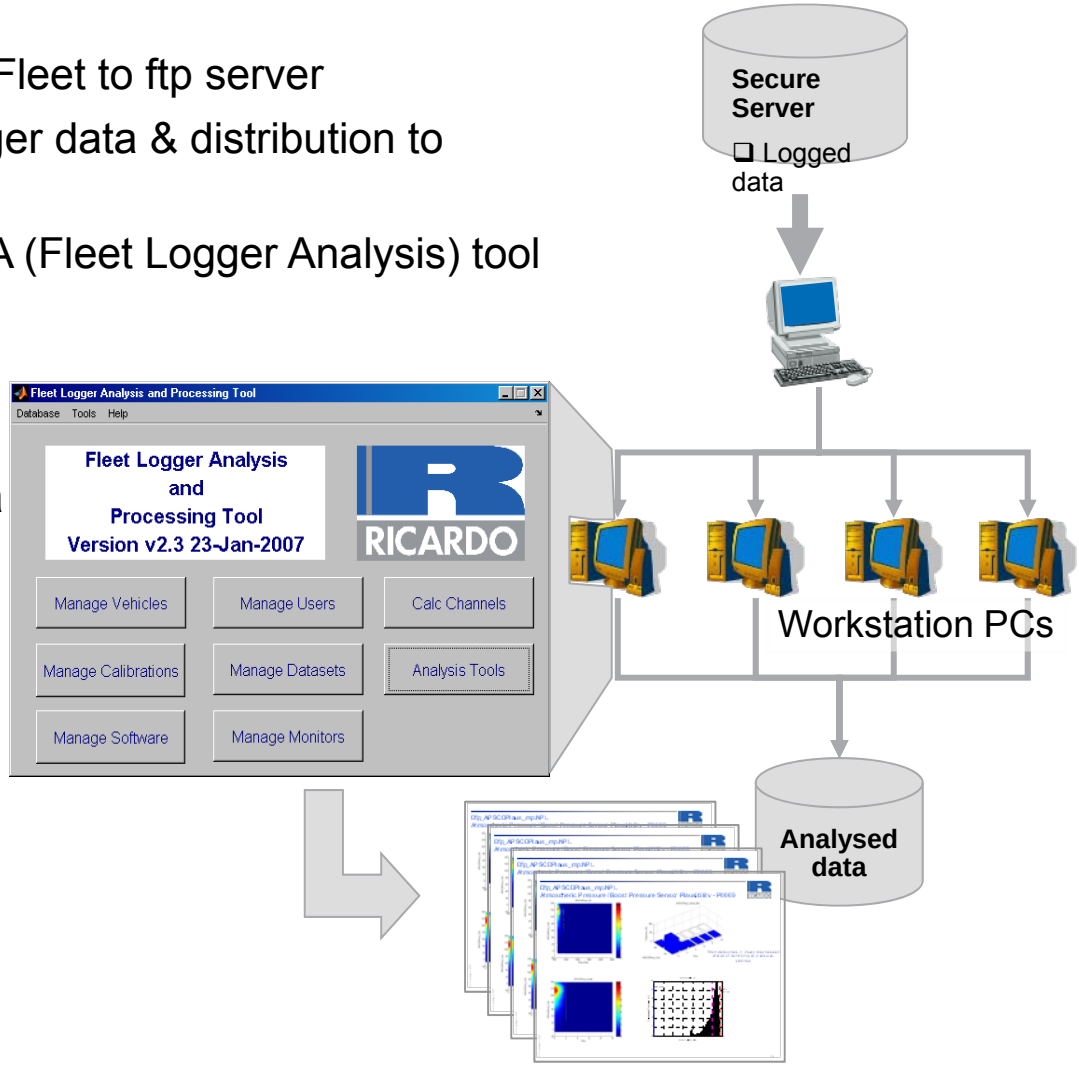


Data management – a significant task requiring thorough planning



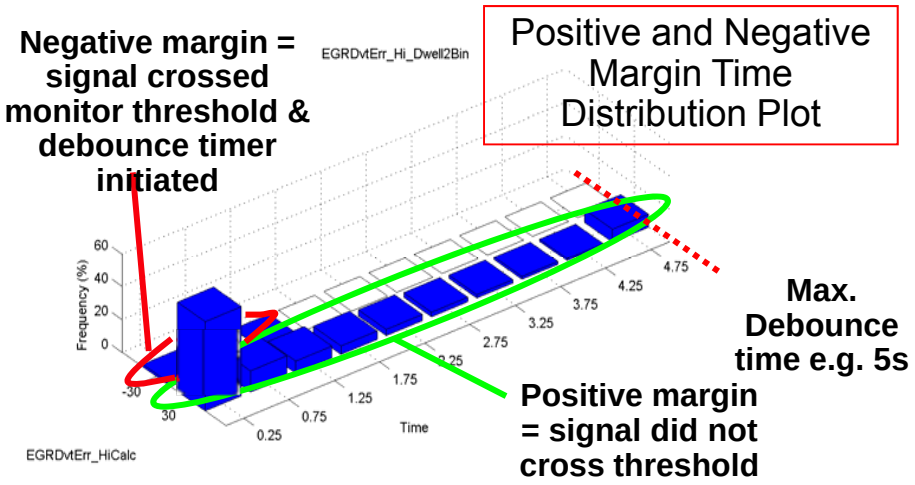
Data distribution & processing - data analysis using FLA (fleet logger analysis) tool

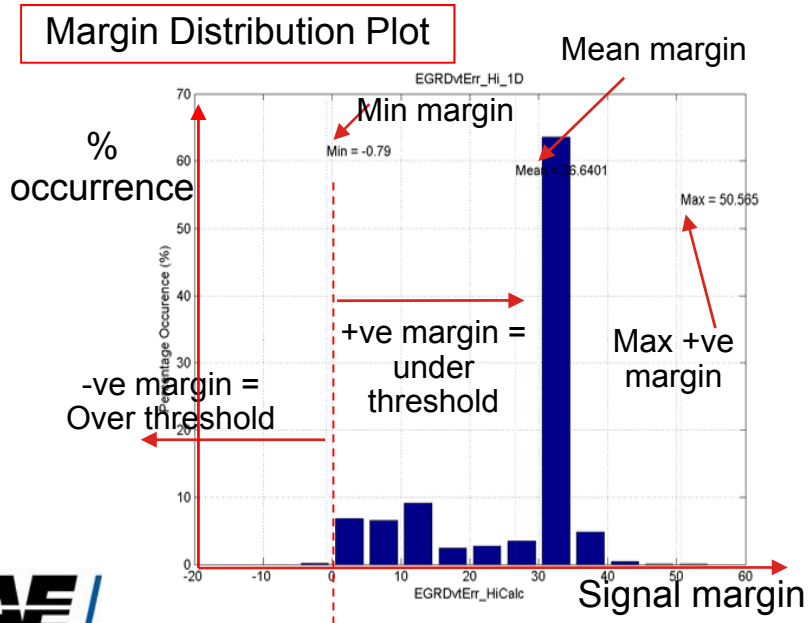
- Automated Fleet Data Analysis
  - Daily uploads of logged data from Fleet to ftp server
  - Automated daily downloads of logger data & distribution to powerful workstation PCs
  - Automated data analysis using FLA (Fleet Logger Analysis) tool developed in-house by Ricardo
- FLA tool:
  - Used to automate and analyse the huge amount of OBD fleet data
  - Generates statistical reports which can be used to validate the OBD calibration, and to identify problem areas
  - Displays statistical distributions or time series data
  - Automated report generation to Excel/PowerPoint formats
  - Matlab based software tool

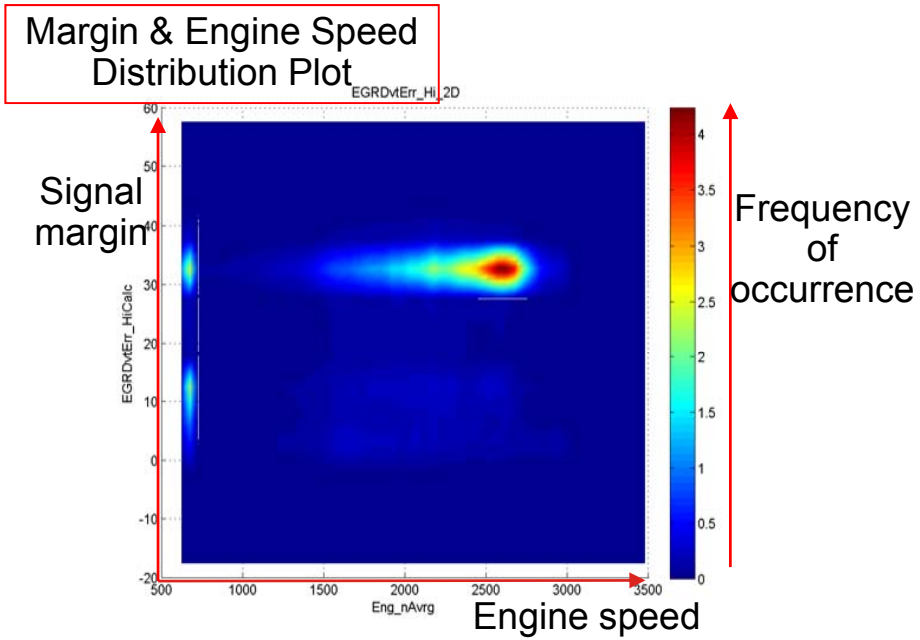


Data analysis using Ricardo FLA – example report plots

- Results can be presented in different formats
- Shown on this slide are:
  - Margin distribution
  - Margin and Engine speed distribution
  - Positive and Negative margin time distribution

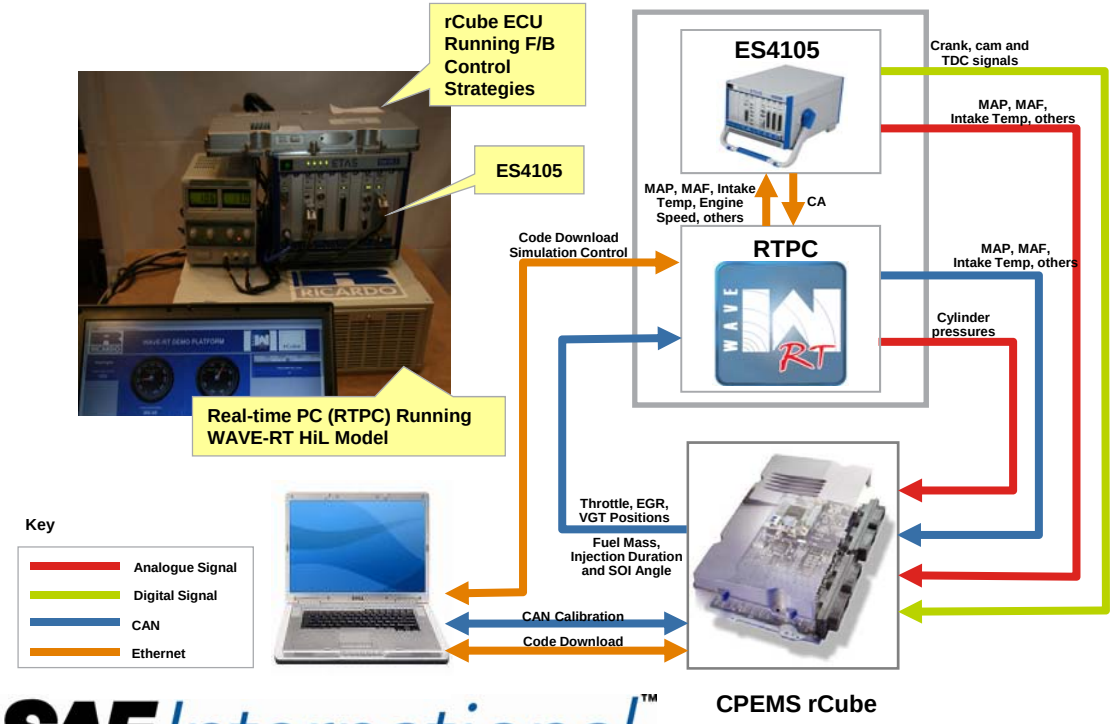


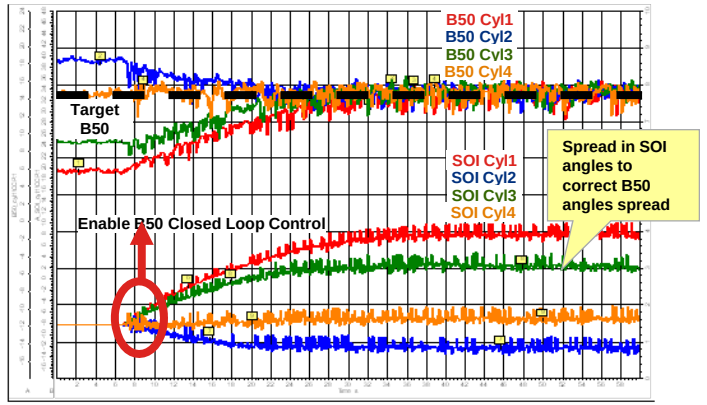




Hardware in the Loop #1

- Problem
  - Inserting faults on sophisticated engine architectures (twin turbo, multi route EGR) can cause possible engine failures
- Solution
  - Use a real-time, crank-resolved, physically-based simulation model to allow faults to be inserted without risking engine hardware
- Benefits
  - No risk to engine hardware
  - Runs on PC and so more engineers can have access and use in parallel
  - Reduced testbed time hence reduced cost





WAVE-RT Results for B50 Control

Hardware in the Loop #2

- Problem
  - Late or no availability of development vehicles for OBD development team
    - Debugging of OBD manager and basic operation is carried out on testbed
    - Proves very costly
- Solution
  - Use a HiL system with simple mean value engine model
- Benefits
  - Reduces project cost (configuration of a simple HiL is cheaper than testbed usage)
  - allows debug of OBD logic operation in a lab environment with easy access to all parameters and signals
  - Allows automated fault injection

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Conclusions and Lessons Learned

- Development Process
  - Be aware of stakeholders different requirements
  - Carry out analysis/testing to identify/confirm:
    - What can affect emissions?
    - How will the control system respond to faults?
    - What could stop a monitor running?
    - Is everything covered by OBD strategy that should be?
  - OBD engineers need input early in base control algorithms development & calibration as this will strongly impact OBD
    - Example: EGR OBD depends strongly on calibration of EGR (& boost) control system. Poor base control system calibration will limit OBD effectiveness
  - Carry out emissions relevance testing after a steady state and transient calibration are fixed and frozen. If this is not possible, be aware of the risks and make contingency plans
  - Determine at an early stage how components will be aged and time/test cycles involved
  - For certification on a dynamometer cycle, testing for correct detection of fault in-vehicle is important
    - A range of drivers not familiar with the monitoring strategies is a benefit
  - Fleet testing must cover a wide range of different driving conditions, but also cover continued operation in the same driving conditions (e.g. only city or only highway driving, extreme driving styles)

Conclusions and Lessons Learned

- Regulations
  - The devil is in the detail
  - Make sure your interpretation is same as other stakeholders
  - Watch for changes
- Monitors
  - Consider all component tolerances (mechanical, electrical, ageing, environment) when calibrating OBD monitors or else false MILs will occur
  - Avoiding ‘false pass’ conditions needs to be as given as much effort as ensuring correct detection/no misdetection
- Tools
  - Having a tool that can give an IUMPR assessment at an early stage in development mitigates risk of algorithm re-design late in the project
  - HiL can help OBD development during early stages when vehicles are unavailable
  - Fleet testing can result in large amounts of data. A data analysis tool needs to be utilised so that the data can be analysed quickly and anomalies identified

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