SAE 2009 On-Board Diagnostics Symposium
Update on Light and Heavy Duty Vehicle
September 22-24, 2009 • Indianapolis Marriott Downtown • Indianapolis, IN
Model-Based Diagnostics
A real opportunity for efficient vehicles management

S.A.T.E. S.r.l. – Venezia (Italy)
Meaning of OBD

• **Restrictive notion** - diagnosis only on emissions related components
• **Broader notion** - diagnosis on all the vehicle components

*Why not go further?*
OBD (restrictive notion)

• Goal → Identify components in need of repair before emission standards are exceeded

What does “before” mean?

• OBD now is based on:
  – Static thresholds (Threshold Based Diagnostics)
  – Rationality: checking inconsistent readings
  – Standardized formats

Is it enough?
OBD (broader notion)

• Today’s ECU computing power would allow:
  – Improving the quality of service by applying diagnostics also to subsystems un-related to emissions, but equally important (e.g. the cooling system)
  – Considering emission related subsystems which may not yet be in the OBD II list (e.g. mass air flow sensor)
  – Using new approaches to emission related information (e.g. exploiting information coming from the CAN network)
OBD (broader notion)

- Communication with additional devices ...

Pocket PC

Infotainment system

Ultra Mobile PC
OBD (broader notion)

- Communication with additional devices
  - Download vehicle data
  - Display contextual information by user-friendly interface
  - Development of specific applications based on vehicle data (e.g., monitoring of driving style, fuel consumption)
  - UMTS/HSDPA connection (e.g., send failure information to roadside assistance or fleet management systems)
Enhancing OBD functionalities

- OBD performance could be improved by using a model-based approach
Model-Based Diagnostics

- Model-based approach provides redundancy which cannot be achieved through hardware especially in the automotive context (cost + space)

- Dynamic equations + behavior prediction

- Driver behavior can be part of the diagnostic equation and predictive maintenance scheme
PROs of Model-Based Approach

• Model-based approach is equivalent to using dynamic thresholds:
  - Decrease in false alarms
  - Decrease in missed alarms
  - Increase in diagnostic quality (with a small code footprint)
**Model-Based Diagnostics (1)**

Stats. distribution of coolant temperature (2001)
(residual = estimated by model – actual)

1°C

**Normal working conditions**

**Abnormal working conditions**
Model-Based Diagnostics (2)

Prognosis of engine failures by poor lubrication (2001: M138 prototypes)

Test session
Trend
(-3 $\sigma$)
(+ 3 $\sigma$)

Car Number: M138-2497

Normal
Alarm
Faulty
Failure

5000 ±10000 km
Model-Based Diagnostics (3)

Oil pressure of a vehicle hydraulic system (2005: Ferrari FXX; 2006: F430 Scuderia)

TBD considers only static or zone based limits

MBD looks at this difference
Model-Based Diagnostics (4)

Gearshift classification
(2005: Ferrari FXX)
Model-Based Diagnostics (4)

Gearshift classification

Gearshift classes
Model-Based Diagnostics (4)

Gearshift classification
Model-Based Diagnostics (4)

Gearshift classification
Model-Based Diagnostics (5)

Sensorless tire tread temperature estimation

(2009: Ferrari 458 Italia)
Model-Based Diagnostics (5)

Sensorless tire tread temperature estimation

---

**Model 03 - Opt # 19: DX Front Wheel Temperature**

- CTHW = 150
- KCONV1 = 0.325
- KCONV2 = 15.3379
- NCONV = 0.8
- MHT = 0.7
- MAss = 1600
- KSILIPx = 0.85098
- K1SLIPyFi = 4.4949e-14
- K1SLIPyFe = 0.011201
- K1SLIPyRi = 9.6712e-005
- K1SLIPyRe = 0.01076
- K2SLIPyFi = 0.01645
- K2SLIPyFe = 0.0062633
- K2SLIPyRi = 0.023059
- CTHWi = 13268.8792
- KINT = 216.4651

---

**File:** Opt_19_Mod03_FrontDX_T_00rp080731

**Data:** TT_test01_LAPS_TST04_00rp080717.mat
Model-Based Diagnostics (5)

Sensorless tire tread temperature estimation

Model 03 - Opt # 19: DX Front Wheel Temperature

Model-Based Diagnostics (5)

Sensorless tire tread temperature estimation
Model-Based Diagnostics (6)

Sensor less tire deflation estimation
(2009: tests on Alfa Romeo ALFA159)
Model-Based Diagnostics (6)

Sensorless tire deflation estimation

Normal inflation pressure

Right Rear Deflated Wheel
-0.3 bar
Model-Based Diagnostics (6)

Sensorless tire deflation estimation

![Graph showing normal inflation pressure and right rear deflated wheel pressure]
Model-Based Diagnostics (6)

Sensorless tire deflation estimation

Normal inflation pressure

Right Rear Deflated Wheel -0.5 bar
Model-Based Diagnostics (7)

Sensorless tire deflation estimation

Normal inflation pressure

Undeflated wheel: Left Rear @ -0.5 bar deflation Right Rear
Model-Based Diagnostics (7)

Sensorless tire deflation estimation

- Normal inflation pressure
- Undeflated wheel: Right Front @ -0.5 bar deflation Right Rear
Model-Based Diagnostics (7)

Sensorless tire deflation estimation

![Graph showing normal inflation pressure and undeflated wheel deflation at -0.5 bar]
Emission related models (1)

Mass Air Flow (MAF) sensor diagnostic

- Increments of lambda control signal can be a symptom of MAF sensor anomalies

[Diagram showing wire element contamination, measurement drift, and lambda closed-loop control system compensation with lambda control signal increment]
Emission related models (2)

- The lambda control system also compensates for other effects (e.g. dirty fuel injectors)
- Isolation of MAF sensor anomalies also requires consideration of the air mass flow rate

- torque
- engine rpm
- throttle valve angle
- MAF sensor air temp.

- expected lambda control signal
- expected air mass flow rate

MIMO model
Emission related models (3)

Diagnostic strategy (by exclusion)

• Correlation between residuals of actual and expected values of controllers output:
  – MAF sensor anomalies have effects on both the lambda control signal and on air mass flow rate
  – Injectors or other anomalies have effects only on the lambda control signal
Emission related models can exploit other CAN-bus signals, e.g.:

- Longitudinal acceleration
- Vehicle speed
- Engine torque
- Fuel consumption

Fuel consumption efficiency index
Trends?

• Will threshold based diagnostics disappear?
  No. Not in 20 years. There is too much invested in legislation standardization and infrastructure

• Will threshold based diagnostics be the base for true perceived customer and machine owner value?
  No. The coverage is already too big and rigid to be used to create something that will appeal to the customer

• Will model based diagnostic replace threshold based diagnostics?
  No. They will live concurrent lives, with different purposes
Conclusions (1)

• Models help understanding real systems
• Diagnostics or prognoses are useful if they are providing information before damage occurs
• Today diagnostic systems are limited by their static threshold scope
• Model-Based Diagnostic is the complementary solution, to enhance vehicle reliability, safety and pollution.
Conclusions (2)

• Why limit this only to the vehicle system? Driving activity also involves the human driver, whose behavior can be analyzed by the information contained in the vehicle dynamics and driving command patterns.

• Diagnostic moves from the vehicle to the driver. Making driving ever safer and ever more pleasant.
Driver behaviour detection

Integration of:
- car signals
- GPS
- biosensors

RoundAbout_movie_5Turns_jb090213