A Short Story of On Board Diagnostics

Volker Lantzsch, Volkswagen AG
Robert Gruszczynski, Audi of America
Agenda

- Diagnostics – Why ?

- Progress and Milestones of OBD (US & EU)

- Contents of OBD
  - monitors for gasoline and diesel
  - standardized test procedures

- Standardization (SAE & ISO)

- Emissions
  - LEV, ULEV, SULEV, EU5, EU6, etc.

- Monitoring Programs
  - I/M
  - HU and AU

- Complexity of OBD
  - IUMPR versus False Failure Detection
  - Standardization as Reference
Diagnostics – Why?

- **Environmental Protection**
  - Legislative Requirements
    - For Vehicle Registration
    - For Vehicle Lifecycle
    - For Legislated Documentation

- **Quality Control**
  - Series Production / End of Line
  - Service

- **Vehicle/Driver safety**
- ...
## Diagnostics – Why?

**When is a component considered defective?**

<table>
<thead>
<tr>
<th>Category</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legislated</td>
<td>Electrical Problem, Exceeding emissions limits</td>
</tr>
<tr>
<td></td>
<td>- or -</td>
</tr>
<tr>
<td></td>
<td>Disabling other Diagnostic Monitors</td>
</tr>
<tr>
<td>Safety</td>
<td>If a dangerous condition exists for the driver, vehicle, etc.</td>
</tr>
<tr>
<td>Customer</td>
<td>Performance degradation</td>
</tr>
<tr>
<td>Production</td>
<td>End of Line control</td>
</tr>
<tr>
<td></td>
<td>- and -</td>
</tr>
<tr>
<td></td>
<td>Quality control</td>
</tr>
<tr>
<td>Service</td>
<td>Customers’ satisfaction</td>
</tr>
<tr>
<td></td>
<td>- and -</td>
</tr>
<tr>
<td></td>
<td>Repair improvement</td>
</tr>
</tbody>
</table>

**Emissions/safety issues cannot be directly measured.**

**→ mapping of these characteristics on measurable ones.**
Progress & Milestones of OBD

USA
- Beginning in MY ‘88 OBD I in California (CARB)
- Defective Sensors/Actuators
- Environmental Protection Agency (EPA) takes over in 1994 for all USA
- 1994 CARB introduces OBD II
- OBD II Update in 2005
- Two-year legislation revision

Europe
- Introduction starting 2000 for new gasoline vehicles, 2003 for diesels
- Last update – 2003 for CNG and BiFuel vehicles
- Complete revision for EU5/6 in 2008/2009

Rest of the World
- Japan since 2002 for imported vehicles (2000 inland vehicles), beginning in 2010 - JOBD
- Mexico introduction - 2002
- Korea
- China - first in densely populated areas (Peking, Shanghai...)
## Progress & Milestones of OBD

<table>
<thead>
<tr>
<th>Country</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>OBD</td>
</tr>
<tr>
<td>California (+ Opt-In States(^1))</td>
<td>OBD II</td>
</tr>
<tr>
<td>Europe</td>
<td>EOBD</td>
</tr>
<tr>
<td>Japan</td>
<td>JOB (OBD II / EOBD)</td>
</tr>
<tr>
<td>(South-) Korea</td>
<td>Gasoline: OBD II(^2)</td>
</tr>
<tr>
<td></td>
<td>Diesel: EOBD</td>
</tr>
<tr>
<td>China</td>
<td>EOBD / Own Legislation</td>
</tr>
<tr>
<td>Brazil</td>
<td>OBD II / EOBD</td>
</tr>
<tr>
<td>Taiwan</td>
<td>EOBD</td>
</tr>
<tr>
<td>Mexico</td>
<td>EOBD</td>
</tr>
</tbody>
</table>

\(^1\) Opt-In-States
- Massachusetts
- New York
- Vermont
- New Jersey
- Maine
- Connecticut (MY 08)
- Rhode Island (announced)

\(^2\) South Korea
- EU5 partially, EU6 fully accepted for gasoline
## Contents of OBD : OBD II

### Gasoline

<table>
<thead>
<tr>
<th>(e) MONITORING REQUIREMENTS FOR GASOLINE/SPARK-IGNITED ENGINES.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) CATALYST MONITORING</td>
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<tr>
<td>(2) HEATED CATALYST MONITORING</td>
</tr>
<tr>
<td>(3) MISFIRE MONITORING</td>
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<tr>
<td>(4) EVAPORATIVE SYSTEM MONITORING</td>
</tr>
<tr>
<td>(5) SECONDARY AIR SYSTEM MONITORING</td>
</tr>
<tr>
<td>(6) FUEL SYSTEM MONITORING</td>
</tr>
<tr>
<td>(7) EXHAUST GAS SENSOR MONITORING</td>
</tr>
<tr>
<td>(8) EXHAUST GAS RECIRCULATION (EGR) SYSTEM MONITORING</td>
</tr>
<tr>
<td>(9) POSITIVE CRANKCASE VENTILATION (PCV) SYSTEM MONITORING</td>
</tr>
<tr>
<td>(10) ENGINE COOLING SYSTEM MONITORING</td>
</tr>
<tr>
<td>(11) COLD START EMISSION REDUCTION STRATEGY MONITORING</td>
</tr>
<tr>
<td>(12) AIR CONDITIONING (A/C) SYSTEM COMPONENT MONITORING</td>
</tr>
<tr>
<td>(13) VARIABLE VALVE TIMING AND/OR CONTROL (VVT) SYSTEM MONITORING</td>
</tr>
<tr>
<td>(14) DIRECT OZONE REDUCTION (DOR) SYSTEM MONITORING</td>
</tr>
<tr>
<td>(15) COMPREHENSIVE COMPONENT MONITORING</td>
</tr>
<tr>
<td>(16) OTHER EMISSION CONTROL OR SOURCE SYSTEM MONITORING</td>
</tr>
<tr>
<td>(17) EXCEPTIONS TO MONITORING REQUIREMENTS</td>
</tr>
</tbody>
</table>

### Diesel

<table>
<thead>
<tr>
<th>(f) MONITORING REQUIREMENTS FOR DIESEL/COMPRESSION-IGNITION ENGINES.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) NON-METHANE HYDROCARBON (NMHC) CONVERTING CATALYST MONITORING</td>
</tr>
<tr>
<td>(2) OXIDES OF NITROGEN (NOx) CONVERTING CATALYST MONITORING</td>
</tr>
<tr>
<td>(3) MISFIRE MONITORING</td>
</tr>
<tr>
<td>(4) FUEL SYSTEM MONITORING</td>
</tr>
<tr>
<td>(5) EXHAUST GAS SENSOR MONITORING</td>
</tr>
<tr>
<td>(6) EXHAUST GAS RECIRCULATION (EGR) SYSTEM MONITORING</td>
</tr>
<tr>
<td>(7) BOOST PRESSURE CONTROL SYSTEM MONITORING</td>
</tr>
<tr>
<td>(8) NOx ADSORBER MONITORING</td>
</tr>
<tr>
<td>(9) PARTICULATE MATTER (PM) FILTER MONITORING</td>
</tr>
<tr>
<td>(10) CRANKCASE VENTILATION (CV) SYSTEM MONITORING</td>
</tr>
<tr>
<td>(11) ENGINE COOLING SYSTEM MONITORING</td>
</tr>
<tr>
<td>(12) COLD START EMISSION REDUCTION STRATEGY MONITORING</td>
</tr>
<tr>
<td>(13) VARIABLE VALVE TIMING AND/OR CONTROL (VVT) SYSTEM MONITORING</td>
</tr>
<tr>
<td>(14) [RESERVED]</td>
</tr>
<tr>
<td>(15) COMPREHENSIVE COMPONENT MONITORING</td>
</tr>
<tr>
<td>(16) OTHER EMISSION CONTROL OR SOURCE SYSTEM MONITORING</td>
</tr>
<tr>
<td>(17) EXCEPTIONS TO MONITORING REQUIREMENTS</td>
</tr>
</tbody>
</table>
Content of OBD : Comprehensive Components

Except as provided in sections (e)(15.1.3), (e)(15.1.4), and (e)(16), the OBD II system shall monitor for malfunction any electronic powertrain component/system not otherwise described in sections (e)(1) through (e)(14) that either provides input to (directly or indirectly) or receives commands from the on-board computer(s), and: (1) can affect emissions during any reasonable in-use driving condition, or (2) is used as part of the diagnostic strategy for any other monitored system or component.

CCR Title 13, Section 1968.2

→ All components and systems, which can influence emissions, or other diagnostics, must also be monitored.
Contents of OBD: FTP75 Driving Cycle

- Distance: 11.04 mi
- Duration: 1874 sec (without hot soak)
- Velocity: max 56.7 mph; average 21.2 mph

Graph showing time (t [s]) against distance on the x-axis and velocity on the y-axis.
distance 10.93 km
duration 1180 sec
velocity max 120 km/h; average 33.35 km/h
Standardization: The connection between OBD and Standards

- **SAE J2012** (P-Codes)
- **ISO 11898** (CAN-Physical)
- **ISO 15765** (OBD-CAN)
- **ISO 15765** (OBD-Physical)
- **SAE J 1979** (OBD Data)
- **SAE J1978** (Flash / Scantool)
- **SAE J1699** (OBD Compliance Tests)
- **SAE J 1962** (OBD-Connector)

VOLKSWAGEN GROUP OF AMERICA
Standardization : Scantool output

Sensor values and Status: Mode $01
- MIL-Status, Number of DTC's,
- Readiness
- Measured Values (e.g. RPM, Vbat,...)

Freeze Frame\(^1\): Mode $02
- Stored Mode $01 Data

Fault Code Memory:
- **Mode $07**: Pending Fault Codes
- **Mode $03**: Confirmed Faults (still present 40 WUPs after MIL OFF)
- **Mode $0A**: Permanent DTC's (Only cleared by self-healing, if necessary – "standard trip")
- **Mode $04**: Erase and reset appropriate Mode $01 values

\(^1\) FreezeFrame = Environmental Conditions at the time of the Fault Code
Standardization : Testing for compliance to the standards

Production Vehicle Evaluation (PVE)¹)

Tests run at OEM and reported to ARB :

- Communications test (in sequence with SAE J1699-3)
  - Check of correct data communication, contents and behavior, of the OBD system
  - Performed on production vehicles of each model year

- Complete testing of the OBD system
  - Demonstration of all cases of a legislated DTC
  - Check the MIL Status (Acknowledged fault after the second drive cycle)
  - ARB can require testing of up to 6 vehicles in a model range

- Monitoring in the field (representative of California)
  - Investigation of IUMPR data

¹) Legally required in Title 13 CCR Section 1968.2 (j)(1) through (j)(3)
### Emissions Limits: CARB/EPA

<table>
<thead>
<tr>
<th>Exhaust Emission Standard</th>
<th>HC (g/mi)</th>
<th>CO (g/mi)</th>
<th>NOx (g/mi)</th>
<th>PM (g/mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>California</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tier 1</td>
<td>0,250</td>
<td>3,4</td>
<td>0,4</td>
<td>0,08</td>
</tr>
<tr>
<td>TLEV</td>
<td>0,125</td>
<td>3,4</td>
<td>0,4</td>
<td>0,08</td>
</tr>
<tr>
<td>LEV I</td>
<td>0,075</td>
<td>3,4</td>
<td>0,2</td>
<td>0,08</td>
</tr>
<tr>
<td>ULEV I</td>
<td>0,040</td>
<td>1,7</td>
<td>0,2</td>
<td>0,08</td>
</tr>
<tr>
<td>LEV II</td>
<td>0,075</td>
<td>3,4</td>
<td>0,05</td>
<td>0,01</td>
</tr>
<tr>
<td>ULEV II</td>
<td>0,040</td>
<td>1,7</td>
<td>0,05</td>
<td>0,01</td>
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<tr>
<td>SULEV</td>
<td>0,010</td>
<td>1,0</td>
<td>0,02</td>
<td>0,01</td>
</tr>
<tr>
<td>ZEV</td>
<td>0,000</td>
<td>0,0</td>
<td>0,0</td>
<td>0,0</td>
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<tr>
<td><strong>US-Bund</strong></td>
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<td></td>
</tr>
<tr>
<td>Bin 10</td>
<td>0,156</td>
<td>4,2</td>
<td>0,60</td>
<td>0,08</td>
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<td>Bin 9</td>
<td>0,090</td>
<td>4,2</td>
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<td>0,06</td>
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<tr>
<td>Bin 8</td>
<td>0,125</td>
<td>4,2</td>
<td>0,20</td>
<td>0,02</td>
</tr>
<tr>
<td>BIN 7</td>
<td>0,090</td>
<td>4,2</td>
<td>0,15</td>
<td>0,02</td>
</tr>
<tr>
<td>BIN 6</td>
<td>0,090</td>
<td>4,2</td>
<td>0,10</td>
<td>0,01</td>
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<tr>
<td>BIN 5</td>
<td>0,090</td>
<td>4,2</td>
<td>0,07</td>
<td>0,01</td>
</tr>
<tr>
<td>BIN 4</td>
<td>0,070</td>
<td>2,1</td>
<td>0,04</td>
<td>0,01</td>
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<tr>
<td>BIN 3</td>
<td>0,055</td>
<td>2,1</td>
<td>0,03</td>
<td>0,01</td>
</tr>
<tr>
<td>BIN 2</td>
<td>0,010</td>
<td>2,1</td>
<td>0,02</td>
<td>0,01</td>
</tr>
<tr>
<td>Bin 1</td>
<td>0,000</td>
<td>0,0</td>
<td>0,00</td>
<td>0,0</td>
</tr>
</tbody>
</table>
Emissions Limits: CARB

![LEV II Emissions standards California](image)

- **NOx, PM (g/mi)**
  - LEV II: 0.00
  - ULEV II: 0.00
  - SULEV: 0.00
  - ZEV: 0.00

- **CO (g/mi)**
  - LEV II: 0.00
  - ULEV II: 0.00
  - SULEV: 0.00
  - ZEV: 0.00

- **HC (g/mi)**
  - LEV II: 0.00
  - ULEV II: 0.00
  - SULEV: 0.00
  - ZEV: 0.00

- **CO (g/mi)**
  - LEV II: 0.00
  - ULEV II: 0.00
  - SULEV: 0.00
  - ZEV: 0.00
Gasoline Emission Standards in Europe (mg/km)
Euro 3/4 @ 80,000 km, Euro 5/6 @ 160,000 km

Euro 5/6 retains the THC standard of 100 mg/km and introduces an NMHC standard of 68 mg/km, which is equivalent to 75 mg/km THC for gasoline engines.

Euro 3/4 has no PM standard for gasoline engines. Euro 5/6 introduces PM for gasoline engines with direct injection.

THC = Total Hydro Carbons   NMHC = non Methyl Hydro Carbons   PM = Particulate Matter
Diesel Emission Standards in Europe (mg/km)
Euro 3/4 @ 80,000 km, Euro 5/6 @ 160,000 km
Emissions : Requirements

The OBD II systems, through the use of an onboard computer(s), shall monitor emission systems in-use for the actual life of the vehicle and shall be capable of detecting malfunctions of the monitored emission systems, illuminating a malfunction indicator light (MIL) to notify the vehicle operator of detected malfunctions, and storing fault codes identifying the detected malfunctions.

CCR 1968.2 (a) Purpose

- Fault threshold normally 150% and for Catalyst Monitor 175% of the “FTP full useful life standard” (SULEV 250%).

- “full useful life" corresponds to 10 years / 120,000 Miles (PZEV 15 years /150,000 Miles).

- Manufacturer has to ensure vehicles comply with emission thresholds within "full useful life“
Emissions: Inspection/Maintenance Program in 33 States

1) required in 33 US-States (yellow in chart)
Emissions: Inspection/Maintenance Program in 33 States

I/M Program (Smog Check) introduced in CA in 1982¹)

Vehicles starting MY1976²) all 2 years and upon selling³)

Diesels, motorcycles, Electro- and Hybrid vehicles currently exempt

💡 **NEW:** Diesel starting 1st January 2010 reactive since MY1998 (CA)

**test requirements:** tail pipe⁴) + visual inspection +

- functional MIL check
- check for active DTC (incl. perm. fault codes)
- readiness requirements

⭐ premise: communication with generic scantool

¹) required in 33 US-States (yellow in chart) ²) if older than 6 years ³) if older than 4 years ⁴) depending on the US-State
Emissions: HU and AU (in Germany)

HU\(^1\) check introduced in Germany in 1951
AU\(^2\) check required since 1993 (ASU\(^2a\)) since 1985 for gasoline only

Passenger cars all 2 years, after selling three years exempt
Caravans (~ medium duty) required each year.

Diesels, motorcycles, Electro- and Hybrid vehicles currently not exempt

tested by TÜV\(^3\) or DEKRA\(^4\):
HU requires technical inspection (including safety) visually and on test bay

AU requires tail pipe (by MY2006 only) +
- functional MIL check
- check for stored DTC
- readiness requirements

premise: communication with generic scantool

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\(^1\) HU = Hauptuntersuchung \(^2\) AU = Abgasuntersuchung \(^2a\) ASU=Abgas-Sonder-Untersuchung
\(^3\) TÜV = technischer Überwachungsverein (est. 1866) \(^4\) DEKRA = Deutscher Kraftfahrzeug Überwachungsverein (est. 1925)
Complexity: In Use Monitor Performance Ratios (IUMPR)

**Numerator**
counts driving cycles (DCY) with the diagnostic monitor being able to find a hypothetical fault

**Denominator**
counts DCY including conditions of General Denominator and special requirements if necessary

**IUMPR**
\[
\text{Ratio} = \frac{\text{Numerator}}{\text{Denominator}}
\]

- minimum required ratios (fleet average) ((10%) 33% - 52%)
- report of minimum ratios pooled in diagnostic groups via generic scan tool
- report of „ignition cycle counter“ and „general denominator“ as reference

**General Denominator (reference, CARB cycle)**
- (min.) 10 minutes drive cycle
- 30 secs continuous idling
- 5 minutes greater than 25 mph (cumulative)
- height / temperature
Complexity: IUMPR versus False Failure Detection

**tighter OBD-emission thresholds**

- narrow monitor enable conditions
  - necessary to avoid false failure detection
  - i.e. too low Ratios

**higher Ratio values**

- wide monitor enable conditions
  - necessary to achieve sufficient ratios
  - i.e. higher risk of false failure detection
Complexity: IUMPR versus Emission Thresholds

1. To prevent a diagnostic monitor being calibrated close to the test cycles and therefore not able to run in the field

   Europe (EU 5 – OBD-emission thresholds):

2. Enforcement of higher frequency of diagnostic monitors in the field, in spite of very low OBD emission thresholds

   Europe (proposed EU 6 – OBD-emission thresholds):

   USA (California – OBD-emission thresholds):
Complexity: Influences in OBD

requirements regulations politics
new technology vehicle network
road condition driving behavior traffic
geographical conditions
weather humidity fuel quality

condition not foreseeable

developing testing
- effort/ costs
- ECU resources
Complexity: Standardization as Reference

Requirements for new technologies (e.g. Hybrid)

Requirements for demonstrating that a component/technology has no influence on emissions needs to define

the worst thinkable scenario or conditions (outside of standard cycles)

For a

- fair competition and
- reproducible results and
- comparable results,

standardized procedures are necessary (FTP, US06, …).