Independent Automotive Emissions Services

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REPORT

An In-Service Emissions Test for Spark Ignition (SI) Petrol Engines – PPAD 9/107/09

Phase 2a Report

Evaluation of the significance of OBD/OBM

A report produced for DfT

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Executive Summary

This report is part of a phased project commissioned by the UK Department for Transport (DfT). The focus of the project as a whole is the in-service testing of petrol engined cars fitted with three-way catalytic converters. Within this, the aspect addressed in this report is that of on-board emissions diagnostics (OBD).

The report reviews the objectives, legislative framework and the technical details of the European on-board diagnostics (EOBD) concept. It also reviews the reports on E(OBD) studies undertaken within Europe and the US. The principal objective of the report is to consider the options for using EOBD as part of the in-service test. Key conclusions from this, and their consequences are as follows.

- The original regulatory purpose of an On Board Diagnostic (OBD) system is to ensure correct operation of the emissions control system of a vehicle, in use, during its lifetime. This is achieved by proxy, by monitoring emissions related components for deterioration and malfunction. An important consequence of this definition is the fact that EOBD was not primarily intended for roadworthiness testing.
- In practice EOBD is a development/extension of manufacturers engine diagnostics (extended to cover emissions). A consequence of this is that there is a range of levels of EOBD sophistication above and beyond the minimum requirements laid down within the EC directive.
- The experience of other European studies on EOBD indicate that there are some difficulties to be overcome both in detection of excess emitters (i.e. error of omission) and in the success rate of ECU/EOBD (on-board) to scan tool (off-board) computer communications. The US experience, and that from the introduction of other new technologies, suggests this is partially caused by a current lack of maturity of EOBD technology and should be expected to improve with time.
- A further consequence of the newness of the technology is currently a poor level of quantification of its rate of detection of faulty vehicles, and hence the emissions savings that this rate of detection affords (a key element required to calculate its cost effectiveness).
- Within the current EOBD systems two technical options for reading the system are either to use the malfunction indication lamp (MIL) or to use a generic scan tool. Both approaches have weaknesses. Inspection of the MIL would currently not detect if the system had been reset. However, this could be overcome by extending the specification of the MIL to include a “system ready” component that is illuminated when the readiness codes are set. The use of a scan tool might be a test of variable severity for variable levels EOBD implementation for different vehicles. If it were found this were the case to an unacceptable degree further data processing could be added into an “MOT specific scan tool” to ignore less severe faults.
- Fundamental tenets of the current in-service test are that it should be a demonstrably cost effective programme that improves air quality, universally applicable and fairly applied. The findings of the report indicate that inspecting EOBD systems using either technical option above as part of the annual roadworthiness test would at present not comply with these tenets.

It is too early for data to be available to quantify the savings potential, and the number of errors of omission and of commission, that an EOBD inspection might provide. However, indicative data exists from a US EPA study which tested 194 vehicles whose MIL was illuminated. 70.1% of these vehicles had emissions **under** their appropriate FTP certification standard (the US equivalent of our type approval standard), i.e. 29.9% of these OBD failures were over their type approval emissions standard.

In the context of in-service testing, EU Directive 2001/09/EC allows for the use of EOBD inspection to replace the low idle CO test as part of a member state's roadworthiness testing programme. (The requirement to measure λ and CO at high idle remains unchanged.)

Overall whilst it is agreed that EOBD has the potential to improve the effectiveness of in-service testing, the authors recommend that currently it is premature to propose augmenting the current UK in-service test with an EOBD system inspection. There is a body of evidence that indicates that many of the real problems that currently exist are principally caused by technical immaturity rather than more generic issues regarding concept or consistency of implementation. The technology requires time to mature. A corollary to this is the authors' view that to replace the current tailpipe emissions test with an EOBD system inspection would also be inappropriate at present.

Looking to the future, it is recognised that EOBD seems reasonably well formulated given the concept of monitoring in-use emissions through diagnostics and comparing these with emissions standards, as opposed to the direct measurement of exhaust gas composition. However, in comparison with other emissions regulations it is, in essence, a compromise necessitated by the technology available. If on-board emissions measurement (OBM) (the direct measurement of exhaust gas composition during use) were to advance to a stage of being a practical likelihood, then this should be considered as the primary technique used to monitor in-service emissions, i.e. superseding EOBD.

A more likely scenario is that it remains appropriate to consider the use of EOBD testing. The report contains recommendations on what further in-depth analytical and practical work is required to make good inadequacies of the currently available information on which to base recommendations on the viability of EOBD based inspection concepts. This comprises programmes of work to quantify the cost effectiveness and practicality of inspecting EOBD systems at the annual in-service test.

The report concludes by estimating a timeframe for the formulation and implementation of possible amendments to the roadworthiness directive to incorporate EOBD-based inspection concepts. On the assumption that it is prudent to wait until some experience from pilot studies is available it is difficult to see how the key data could be available before early 2006. Given the time required for debate and the reaching of a consensus position, it is estimated that the passing EC amending directives would occur not earlier than 2008.

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1 Background

The purpose of an On Board Diagnostic (OBD) system, as specified in the regulations that make its fitting to new vehicles mandatory, is to ensure correct operation of the emissions control system of a vehicle during its lifetime by monitoring emissions related components for deterioration and malfunction.

This simple statement contains some profound messages regarding some strengths and limitations of OBD. A key strength is the day-to-day monitoring of a range of emissions related components such that faults are much more rapidly detected and brought to the driver’s attention than would be the case if inspection and maintenance were solely reliant on either routine servicing or the annual roadworthiness test.

The OBD system does not involve the measurement of emissions directly (this is known as on-board monitoring, OBM, and is a possibility for the future). Indeed, OBD is more an extension of the standard vehicle mechanical diagnostics and has been adapted for its role of monitoring emissions. A further corollary is that OBD is not designed to replace a tailpipe emissions test (as is performed at the annual roadworthiness test).

European On Board Diagnostics (EOBD) were modelled on American OBD systems. These were introduced from 1991 model year in California and are known as OBD I. The USA is now using systems meeting a higher standard, OBD II, which was introduced nation-wide from 1996 model year.

Within Europe EOBD was introduced by European Directive 98/69/EC, with Stage A limit values (also known as Euro III standards) for implementation from 1/1/2000 on new models and by 1/1/2001 for full implementation on gasoline vehicles. (Diesel vehicles will have to comply by 2003 and LPG/CNG by 2003 or 2005.)

The output from the EOBD system is presented to the driver as a warning light, situated in the instrument cluster, with an engine symbol. This is known as the malfunction indicator lamp (MIL). The MIL symbol can illuminate or flash. When this happens the driver should go to the dealership for testing and rectification work, as necessary, to correct any engine/emissions systems faults.

A dealer interrogates the information stored within the EOBD system via a 16 pin diagnostic socket (as specified in ISO 15031-3) located in the passenger compartment of vehicle. (In the US the location of this socket within the vehicle is stipulated as being on the lower edge of fascia next to the steering column. In Europe there is no such specific location stipulated in European standards.) A diagnostic fault code reader (scan tool) is required to obtain and display the diagnostic information stored.

2 The regulatory framework and standards used to specify EOBD

Key issues addressed in Chapter 2

In this chapter the regulations and standards that specify EOBD systems are reviewed. These comprise the principal European directive, amendments to it, and the ISO standards referred to in the European directive. The mechanism for the approval of EOBD systems to comply with these regulations and standards is also reviewed.

2.1 INTRODUCTION

The requirement to fit EOBD systems is specified in European Directive 98/69/EC, an amending directive to 70/220/EC. Because of its pivotal role in the definition of EOBD the portions of this directive describing EOBD are reproduced in Appendix 1.

Since the publication of this directive further amending directives have been issued. These are:

1999/102/EC describing some issues related to the dates of application of EOBD for various classes of vehicle,
2001/01/EC (OJ35 6/2/01 p34) again giving further details regarding application dates,
2001/09/EC describing how EOBD can be used as part of the roadworthiness test. The details within this amending directive are discussed further in Chapter 5 of this report.

The articles of Directive 98/69/EC cover a range of aspects within the heading “Measures to be taken against air pollution by emissions from motor vehicles”. Some aspects were discussed in the Phase 1 report[1], e.g. the type approval emissions limits for 2000 and 2005. Highlighting some aspects pertinent to EOBD:

Article 1 the technical annexes of 70/220/EC should be amended, including the addition of Annex XI describing the functional aspects of EOBD.

Article 3 by 31/12/99 a proposal from the Commission to the European Parliament should be submitted which contains the threshold limits for OBD for 2005/6 for M_1 and N_1 vehicle classes, and
further proposals will consider the requirements for the operation of an on-board measurement system (OBM).

[1] An in-service emissions test for spark ignition petrol engines – Phase 1 report: Definition of an excess emitter and effectiveness of current annual test, J Norris, PPAD/9/107/09, AEA Technology report AEAT/ENV/R/0679, June 2001.

Article 4 in a similar vein this article specifies requirements for:

- a report on the drawing up of a standard electronic format for repair information by 1/1/2000,
- appropriate measures for replacement components, including approval procedures for those emissions control components that are critical to the correct functioning of OBD systems by 30/6/2000 and
- appropriate measures to enable third parties to develop replacement components by the making available of the necessary technical information, by 30/6/2000.

2.2 TECHNICAL DETAILS WITHIN THE DIRECTIVE INCLUDING EMISSIONS STANDARDS

Directive 70/220/EC contains a number of key technical annexes. Article 1 of 98/69/EC amends these, including adding a new annex, Annex XI, which is entitled “On-board diagnostics (OBD) for motor vehicles”. Annex XI is reproduced in Appendix 1 of this report. It comprises three sections:

1 Introduction
2 Definitions – This includes defining the concept of vehicle families. Whilst the emissions performance of individual “vehicle types” will vary the EOBD system characteristics across the “vehicle family” will be similar. This is used when obtaining type approval for EOBD systems and is discussed further in Section 3.3
3 Requirements and tests.

The third section includes the following paragraphs:
3.2.1 covering circumstances when the EOBD system can be temporarily disabled
3.3 the description of the test parameters which includes the EOBD pass/fail emissions limits (in g/km), (paragraph 3.3.2)
3.5 the activation of the MIL
3.6 the storage of fault codes
3.7 extinguishing the MIL
3.8 erasing fault codes.

The functional aspects of OBD systems are described in detail in the five pages of Appendix 1 to Annex XI (also included in Appendix I to this report). This covers:

- description of the test,
- test vehicle and fuel,
- test temperatures and procedures,
- test equipment,
- OBD test procedure, which includes
  - preconditioning,
  - failure modes to be tested,
  - OBD test systems, and
  - diagnostic signals (including the EOBD – scan tool communication protocols).

Paragraph 3.3.2 of Annex XI to Directive 98/69/EC says that EOBD systems must indicate the failure of an emissions related component or system when that failure results in an increase in emissions above the EOBD threshold limits listed in Table 1.

Table 1 E.U. emissions standards for passenger cars.

	CO (g/km)	HC (g/km)	NO_X (g/km)
EOBD threshold limits	3.2	0.4	0.6
Euro III gasoline (98/69/EC Stage A)	2.3	0.2	0.15
Euro IV gasoline (98/69/EC Stage B)	1.0	0.1	0.08

It is noted that the current EOBD threshold limits are higher than the current Type Approval standards, (98/69/EC Stage A).

All the emissions standards above are for when vehicles are tested over the NEDC, Type Approval Type 1 test.

Annex XI of the directive contains within it references to other standards. Specifically:

Para 3.1.1 All emissions related fault codes must be consistent with ISO DIS 15031-6 (SAE J 2012 dated 7/96).

Para 3.5.1 The MIL when activated must display a symbol in conformity with ISO 2575 – 1982E.

Para 6.5.3.1 The on-board to off-board diagnostics link must comply with either ISO 9141-2, ISO 11519-4 or ISO DIS 14230.

Para 6.5.3.2 The test equipment and diagnostic tools which communicate with the EOBD system (i.e. the scan tools) must meet or exceed the functional specification given in ISO DIS 15031-4.

The EU regulations require both the communications protocol and the scan tool to meet ISO standards. Herein lies a detailed technical specification outside the EC directive.

2.3 THE ISO STANDARDS

The EU directive contains references to a number of ISO standards. Whilst it is not appropriate to cover these in detail it is informative to examine an illustrative standard. The one selected is ISO DIS 15031-4, the standard pertaining to scan tools entitled: *Road vehicles – Communications between vehicle and test equipment for emissions-related diagnostics – Part 4 External test equipment*. Its importance to the reading of the information from the EOBD system is evident from Figure 1, which shows, schematically, how the EOBD system described in Figure 2 can be read using the malfunction indication lamp (MIL) or a scan tool.

In the figure many components or aspects are tagged with a reference to the section within Chapter 3 of the report that provides a more detailed explanation.

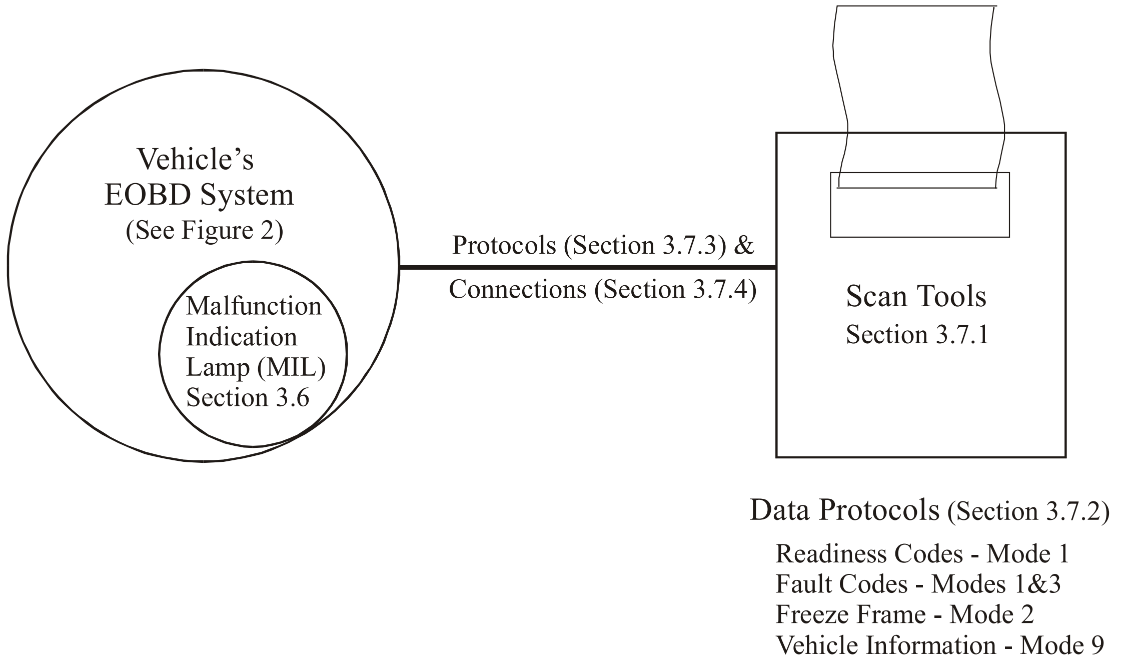

Figure 1 Schematic of options for reading information from an EOBD system

The contents of this standard are
1 Scope
2 Normative reference(s)
3 Term(s) and condition(s)
4 Required functions of the external test equipment
5 Communication protocols
6 Connections to the vehicle
7 Network access
8 User interface
9 Power requirements
10 Electromagnetic compatibility
11 Conformance testing

and these are somewhat typical of ISO standards.

Section 2 of ISO DIS 15031-4 is interesting. It says: "The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 15031. **At the time of publication, the editions indicated were valid. All standards are subject to revision**, and parties to agreements based on this part of ISO 15031 **are encouraged to investigate the possibility of applying the most recent versions of the standards indicated below**." There then follows a list of twelve further ISO standards. (The emphasis in bold type is added by the authors to illustrate the inherent lack of consistency of the ISO standards.)

A key facet of ISO standards, clearly stated within them, is that they are subject to revision. Further, the revised standard generally keeps the same number as its parent. This is a distinct difference from the **unique** numbering scheme used by the EU for its directives.

Another chapter of interest is that on “Conformance testing”. The opening paragraph is:

> “Conformance testing specifies the tests required to be passed in order for external test equipment to be **type approved** as “conforms to ISO 15031-4”. Only external test equipment that passes all of these tests may be so labelled. External test equipment does not need to support all the listed protocols. Equipment that passes all tests but do not support all protocols specified in section 5 shall be labelled…… **Validation of the conformance test is the responsibility of the equipment manufacturer and the equipment manufacturer may elect to self-certify.”**

Again this marks a distinct difference relative to conformance testing with EU directives on vehicle emissions, where an independent certification agency must be involved. The highlighting of this difference is not intended as a criticism, but noting its presence is important. Indeed, given the different purposes of the two groups of documents it could be argued it is entirely reasonable.

The ISO standard is for hardware with a clearly defined purpose which is achieved by it complying to the ISO standard. Failure to comply could well lead to failure to perform, consequent loss of sales and potential claims for recompense etc. Hence self-certification can be viewed as being reasonable because it is in the manufacturers interest that the product does comply.

In contrast vehicle owners require mobility. The emissions standards set within an EU directive are, at best, of secondary concern to the owners. More significantly, failure to meet standards would go unnoticed by the vehicles’ owners in the vast majority of cases. Therefore, to effectively enforce the emissions standards both external verification of the emissions performance of new vehicles and continued checking in-service are required.

2.4 COMPLYING WITH LEGISLATION AND STANDARDS

Meeting the OBD requirements of the EU directive is part of the revised type approval process specified in directive 98/69/EC. However, there is a difference: type approval is required for all “vehicle types” whereas EOBD approval need only be obtained for each “vehicle family”. Paragraph 6.4.1 of Directive 98/69/EC indicates that a vehicle-OBD family can have variations in engine accessories, tyres, equivalent inertia, cooling system, overall gear ratio, transmission type and type of bodywork. Consequently, a sporty three door, 6-speed manual gearbox vehicle and an automatic people carrier fitted with the same engine, OBD system, catalyst configuration and exhaust, could be of the same vehicle-OBD family and require only one generic EOBD system approval. Obviously, each different vehicle type will be subject to the Type I to VI tests.

Directive 98/69/EC describes how the OBD system tests are "to be carried out on the vehicle used for the type V durability test, given in Annex VIII, …… at the conclusion of the Type V durability testing." This involves both paperwork and practical testing.

The manufacturer has to complete a form describing the EOBD system (the form is given in Annex II of the directive) together with a declaration detailing:

- the percentage of misfires that lead to the EOBD emission limits being exceeded,
- the percentage of misfires that could lead to the exhaust catalyst(s) overheating prior to causing irreversible damage,
- the MIL system,
- the measures taken to prevent tampering and
- if applicable, details of the vehicle family.

For the practical work a vehicle that has undergone durability testing is used (presumably with no MIL illumination having occurred). Following appropriate preconditioning, five fault conditions are tested, in turn:

- replacement of the catalyst with a deteriorated or defective catalyst,
- induced misfire at level that causes HC emissions to exceed standard,
- replacement of the oxygen sensor with deteriorated or defective oxygen sensor,
- electrical disconnection of any other emission related component connected to a powertrain management computer,
- electrical disconnection of the electronic evaporative purge control device (if fitted).

In each case a Type 1 test (NEDC) is run. The emissions should not exceed the EOBD threshold limits quoted in Table 1 by more than 20% (otherwise it is not a sufficiently severe test for the EOBD system) and the MIL should **activate before the end of the test.**

2.5 DISCUSSION

The authors' general view is that Annex XI and its associated appendices are comprehensible and well written. However, two areas of weakness are noted.

The first arises from the juxtaposition of highly prescriptive portions of the directive, e.g. regarding the systems to be monitored, and the effect orientated portions, e.g. the requirement that "measures are taken to prevent tampering". Whilst the vehicle manufacturers have opted for a system of readiness codes (Section 3.8.2 – Mode 1), there appears to be quite a range of different approaches adopted.

The second area is the potential weakness noted that arises from the use of ISO standards to define the scan tools and the EOBD system – scan tool communication protocol. These "standards" can evolve quite rapidly in a new technological field such that instruments built to the same standard in different years can be significantly different. In particular the older tool may not communicate with more modern systems. The authors believe this somewhat dilutes the relatively tightly specified aspects of the EOBD system.

In terms of backward compatibility of scan tools, it is believed that the majority of scan tool manufacturers would aim to produce tools that communicate with older systems. Also discussions with a generic scan tool manufacturer showed how they sought to develop ways of modifying their existing scan tools to overcome generic communications difficulties from more modern vehicles. The fixes could generally be classified as:

- hardware, e.g. an additional short connector/adapter to be placed in between the cable from the EOBD system and the scan tool (used especially to reconfigure pins, or to add, for example, an additional earth connection),
- software, e.g. a patch to the original software to take account of changes in the communications protocols used (e.g. the timing characteristics of serial signals).

The general message we received was that whilst the lack of consistency in ISO standards is a facet to be mindful of, in reality it is anticipated not to cause too many practical difficulties.

3 Technical description of EOBD systems

Key issues addressed in Chapter 3

This chapter gives technical details on the EOBD systems describing the terminology used by EOBD engineers and the directive. The purpose and the functionality of key components and sub-systems are also described. So too are scan tools and their associated connection and communication protocols.

3.1 OVERVIEW AND INDEX

This chapter of the report contains a more detailed technical description of the components of the EOBD system and their operation. Much of this, including the associated technical phrases, or jargon, may be new and presents the challenge of finding a convenient format for ordering the information. This is done in the schematic diagrams of Figures 1 and 2.

Figure 2 shows the operation of the EOBD system during normal vehicle operation. (As for Figure 1 many components or aspects are tagged with a reference to the section within this chapter of the report that provides a more detailed explanation.) This comprises the collection of signals from sensors, relating these outputs to the vehicle's emissions performance using algorithms and the comparison of the predicted emissions performance with standards specified in the regulations. This may result in subsequent actions being taken.

Some aspects of EOBD are explicitly defined by directive 98/69/EC, while others are the manufacturer's implementation of a performance requirement specified in the directive. Where possible this report will differentiate between the two.

In addition to the regulations specifying the introduction of EOBD, there have been further advances in automotive engineering. Vehicles contain an increasing number of controlling computers in addition to the ECU (e.g. for braking, stability program, gearbox control and ventilation/heating/air conditioning) and the sensors associated with these systems. Single/ separate wires are no longer practicable because wiring harnesses become unmanageably complex and bulky. The controller area network (CAN) serial bus system has been especially developed to provide solutions to these problems in automotive applications. This serial bus is included in the EOBD – scan tool connector, see Appendix 3. Its importance in this study is that it is a further hardware option for reading EOBD data, and it is increasingly being used. This further technology development is known to be the cause of some communication problems that have been reported.

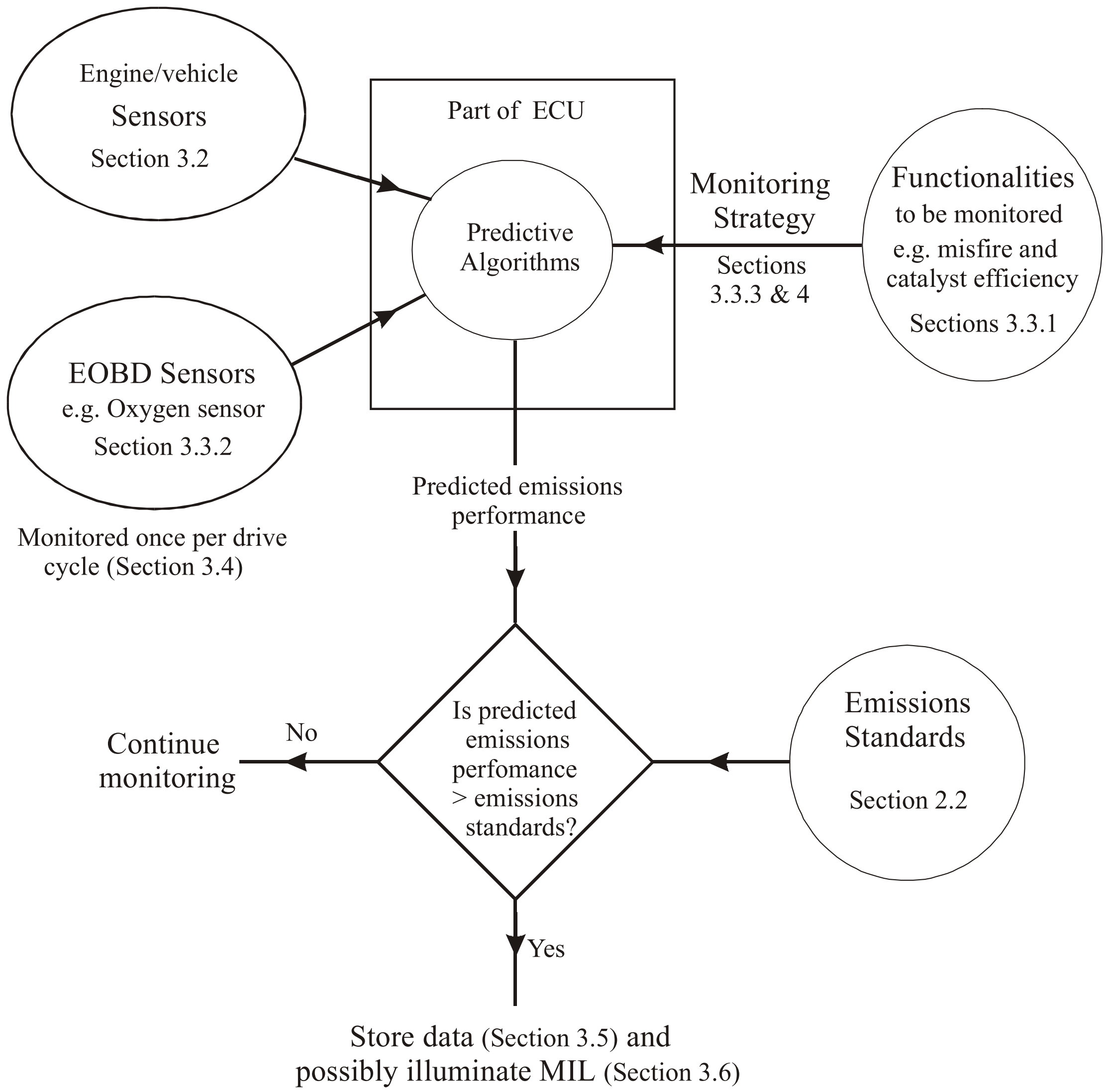

Figure 2 Schematic of EOBD system during normal vehicle operation

3.2 EOBD SYSTEMS WITHIN THE VEHICLE

The controlling processor and memory of the EOBD system is **within** the engine's control unit (ECU). Hence, the EOBD system adds extra emissions-specific inputs to the data collected by the ECU (PCM) from the engine and vehicle control sensors. Malfunctions causing excursions in emissions levels are recorded as fault codes within the EOBD memory in the ECU.

EOBD regulations define the parameters associated with emissions that require monitoring, the data transmission protocols, and the information display requirements for both the vehicle (MIL illumination) and the scan tool (display modes).

The engine management system provides integrated control of the fuel -injection and ignition requirements for the engine. Sensors monitor engine condition at short time intervals (milliseconds). These inputs are filtered to suppress signal interference and converted to digital format for processing within the ECU. Outputs from the ECU are passed to output amplifier circuits to convert them to the levels required by the various actuators.

The primary control variables for engine management systems are engine speed (derived from crank angle sensor inputs) and load factor derived from inlet air mass (which is either measured directly, or is calculated by the ECU using inputs from various sensors - manifold absolute pressure, barometric pressure and inlet air temperature). The sensors used vary depending on the engine management system and vehicle application.

Semiconductor memory chips within the ECU store a series of control maps. The primary control variables determine the position on the control maps to provide optimal parameters for fuel-injection and ignition timing. These control parameters are further modified (trimmed) by inputs from other sensors operating via their control maps. For example the throttle position sensor, which provides information on the rate of change of throttle actuation, modifies the fuel-injection and ignition timing parameters to improve engine response under transient conditions.

If the engine is fitted with exhaust gas re-circulation (EGR) (used to inhibit NO_X formation) its control map will determine when and how much EGR is applied throughout the engine speed /load curve.

There are algorithms within the ECU control strategies dedicated to improving emissions control. These include adaptive input control which helps to maintain stable exhaust emissions for the life of the vehicle. Also, adaptive strategies are applied to the lambda, idle air control and throttle angle maps. They supplement closed-loop control circuits to improve their speed of response and optimise ignition timing performance.

The ECU has integrated self-diagnosis for fault monitoring and can substitute default values for emergency operation, sometimes at reduced performance (limp-home mode) for ECU faults and for many engine sensors. Modern engines cannot run without their electronic systems so that sudden failure can have safety implications.

If deviations of a sensor's output occur that, from the manufacturer's calibration studies, cause the vehicles emissions to exceed the standard set in the regulations, the EOBD system takes a predetermined course of action. The diagnostic functions enable ECU or sensor faults to be recorded and stored (fault codes) to assist repair work. They form the basis of the EOBD diagnostic system. They can be used for protection of sensitive components. For example if an over-fuelling or misfire condition is detected, corrective actions can be implemented to protect the catalytic converter from overheating and becoming irreversibly damaged.

3.3 SENSORS AND SYSTEM MONITORING STRATEGIES

3.3.1 General

The EOBD regulations (paragraph 3.3.3 of Annex XI of Directive 98/69/EC) require that certain systems are monitored. These are for:

- reduction in catalytic converter efficiency,
- the presence of engine misfire,
- oxygen sensor deterioration,
- other emission control system components or systems, or emissions-related powertrain components or systems which are connected to a computer, the failure of which may result in tailpipe emissions exceeding the EOBD threshold limits given in the directive,
- circuit continuity of any other emission-related powertrain component connected to a computer,
- circuit continuity, at a minimum, of the electronic evaporative emission purge control be monitored for.

Deterioration of any of these systems such that the vehicle's emissions over the NEDC (Section 3.4) exceed the EOBD threshold (Section 2.2) should cause the MIL to illuminate and the sensor values to be stored (Section 3.5). The only other stipulation is that monitoring should also occur for misfiring that could lead to exhaust catalysts overheating prior to causing irreversible damage.

To meet the EOBD regulations manufacturers monitor some sensors continuously, and some over a period of time or cyclically. Examples of sensors/systems that might be monitored continuously include misfire detection, the duration of injection of fuel and the continuity of electronic circuits of emissions related components. Examples of sensors that might be monitored more intermittently, or over longer periods of time, are those for the catalytic converter efficiency and the oxygen sensor. Examples of other emissions-related components or systems are oxygen sensor heater (if supported) and secondary air injection (if fitted).

3.3.2 Oxygen sensors

Directive 98/69/EC only uses the term "oxygen sensor" when referring to this generic type of sensor. However, the colloquial trade term within the UK is λ (lambda) sensor, although some manufacturers refer to them as HEGO or UEGO sensors. In this report we use solely the term oxygen sensor.

This sensor (which is based on a zirconia oxygen cell) is used to monitor the oxygen content of the exhaust. It produces a voltage dependent on the oxygen concentration. The ECU uses this voltage as one of the parameters to control fuelling. During operation the ECU compares the voltage produced by the oxygen sensor with stored upper and lower voltage limits (rich and lean switch points). The ECU control strategy will reduce the amount of fuel delivered to the engine by the fuel injectors (forming a lean mixture) until the lean switch point is reached. It will then increase the fuelling (forming a rich mixture) until the rich switch point is achieved, when the cycle is repeated. The voltage output of the oxygen sensor varies cyclically and this can be used for fault diagnosis. The oscillation frequency is dependent on engine speed and air mass flow (load).

Further details about this important sensor are given in Appendix 3.

EOBD systems have two oxygen sensors. The pre-catalyst sensor provides fuelling control inputs during closed loop operation and the post-catalyst sensor provides data from which catalyst buffering capabilities can be derived. The output from this sensor is also used to monitor any drift of the pre-catalyst sensor. This is achieved by the EOBD system dynamically "tuning" the voltage/oxygen concentration calibration curve for the pre-catalyst oxygen sensor as its ages, thereby compensating, to some degree, for ageing effects.

Both sensors are monitored by the EOBD system for open circuit and for deterioration using diagnostic strategies summarised in Appendix 3.

3.3.3 Strategies for monitoring catalytic activity

A three way catalyst is only effective when the air/fuel ratio is carefully controlled to oscillate around the stoichiometric point (a ratio of about 14.6:1 on a weight basis) at a frequency of 0.5 to 1 times a second. When operating in the lean portion of the cycle CO and HC present in the exhaust are oxidised by the oxygen available in the exhaust. At this time the catalyst also stores oxygen. When operating in the rich portion of the cycle CO and HC are oxidised by the oxygen absorbed/stored within the catalyst. The ability of the catalyst to operate efficiently is therefore dependent on it maintaining a sufficient oxygen storage capacity (often known as the OSC) and the engine's control system providing both the correct air/fuel ratio and varying this by a few percent at the right frequency.

The above forms the basis for the most widely used strategy for monitoring catalyst activity. Fluctuations in the feed gas air/fuel ratio downstream of the catalyst will be damped by the catalyst's OSC. Comparison of the pre- and post-catalyst oxygen sensor signals is used to derive the OSC of the catalyst.

Further details on this aspect of the OBD system are given in Appendix 3.

3.3.4 Strategies for monitoring for misfire

Engine misfire describes a lack of combustion in the cylinder of a spark-ignition engine. It can be due to the absence of a spark, poor fuel metering such that the fuel system fails to deliver a combustible mixture, poor compression or other causes. It results in high HC emissions into the exhaust manifold. These can be consumed by the catalyst, generating heat which damages the catalyst both physically (it can melt) and chemically (by reducing activity). It is also likely to result in excess HC emissions from the tail pipe.

Experience has indicated that an engine misfiring for about 2% of firings can raise emissions by up to 50%. If engine misfire occurs in excess of about 17% of the time catalyst damage will occur.

Strategies that are currently used to monitor for misfire include:
- looking for crank shaft velocity fluctuations,
- monitoring the ionising current using the spark plug as an electrode, and
- analysing the exhaust pressure.

Further technologies are being investigated. These include:
- in-cylinder pressure sensing, and
- magnetostrictive sensing analysis in the engine crankshaft.

Further details regarding these strategies are given in Appendix 3.

3.4 EOBD DRIVING CYCLES.

Directive 98/69/EC defines three different types of driving cycle.

1. Type 1 test (the NEDC) defined in Annex III, Appendix 1 of the directive
2. "A warm-up cycle" which involves sufficient vehicle operation so that the coolant temperature rises by at least 22°C from engine starting, and reaches at least 70°C.
3. "A driving cycle" which consists of engine start-up, driving mode where a malfunction would be detected if present and engine shut off.

Within the regulations the last two are only referred to in the context of activation and extinguishing the MIL, and erasing a fault code. It is the responsibility of the manufacturers to tune their EOBD algorithms within this framework.

Further, manufacturers may want to "specify" their own driving cycle for test driving vehicles in order that all the EOBD systems are monitored at least once. An example of this would be the following four phases:

- A cold engine start, vehicle operation (engine exceeding the starting speed, a coolant temperature increase of 23°C with coolant temperature exceeding 71° C), overrun, and engine stop.
- After a cold engine start, if the engine is allowed to idle for long enough (about 3 minutes), the secondary air injection system (if fitted) will be checked.
- During constant driving at 40 -50 kph (lasting about 4 minutes) the oxygen sensors and control frequency will be checked.
- During constant driving at 60 to 100 kph (lasting about 15 minutes) the catalytic converter efficiency, oxygen sensors, and control frequency will be checked.

Within these phases, in order to safeguard against transients or driving outside the manufacturer's vehicle's envelope, the tester is warned that the diagnostic sequence will be interrupted if the engine speed exceeds 3000 rpm, the throttle pedal position changes sharply or the vehicle speed exceeds 100 kph.

3.5 THE STORAGE AND CLEARING OF FAULTS

An emissions fault detected by driving cycle monitoring may occur as an isolated incident. If a fault code is generated too readily this will lead to incorrect alarms and a general loss in confidence with the EOBD system. Therefore some manufacturers use "presumed faults" to track a potential fault prior to its being "confirmed". At first a presumed fault code will be stored, with the appropriate sensor data in the "freeze frame" mode (see Section 3.7.2 mode 2), but the MIL will not be illuminated.

If the system check is completed during the next driving cycle and the fault still persists, the fault goes to a confirmed status and the MIL is illuminated. If the system check was interrupted before the next driving cycle was completed (i.e. vehicle went outside defined parameters for a system check) the presumed fault will be monitored on the subsequent driving cycles until it has been either confirmed or shown to be an isolated incident.

At the same time that a presumed or confirmed fault flag is set some engine and emissions system parameters are also stored. This constitutes a snap-shot of sensor values and is known as a freeze frame (Section 3.8.2 Mode 2). Its purpose is to aid diagnosis, not least by recording the sensor values at the time the EOBD system registered the fault.

A single fault code entry will be cleared from the ECU if the fault fails to re-appear after 40 successive driving cycles in which the same operating conditions are satisfied.

If the same operating conditions as when the fault occurred are not met, 80 successive fault-free driving cycles are required for the system to clear the fault code.

The scan tool can also be used to clear fault codes.

3.6 MALFUNCTION INDICATION LAMP (MIL)

The EOBD regulations require that a vehicle's EOBD system comprises a malfunction indication lamp (MIL) as a key interface between the system and the vehicle's driver. Any emissions fault requiring customer action is notified via the MIL, which can flash or be permanently illuminated depending on the fault.

The regulations require the MIL to illuminate under the following conditions:
- ignition on without the engine running (MIL functionality check),
- self-test routine detects a fault,
- emissions related fault occurs in two successive driving cycles and
- if misfire conditions are detected that could cause damage to the catalytic converter, the MIL will flash as long as the fault is present.

Similarly, the regulations specify that the MIL may be extinguished if an emissions related fault fails to occur in three complete successive driving cycles. However the fault code is still present in the ECU, i.e. considerably beyond this. This is to aid subsequent diagnosis, and if appropriate, rectification. It can also be cleared by a technician with a scan tool.

3.7 SCAN TOOLS AND THEIR ASSOCIATED PROTOCOLS

3.7.1 Scan tools

Scan tools are also referred to as diagnostic fault code readers.

In Section 3.2 it was seen that EOBD is, to a considerable extent, an extension of the computerisation of engine management. Many vehicles controlled by an ECU but not fitted with EOBD have a "break-out" socket for manufacturers and their franchised dealers to interrogate a vehicle. This is a powerful diagnostic tool in their armoury for vehicle maintenance. In principle, however, there was nothing to stop each vehicle manufacturer from developing their own package, comprising the information available, the connections between the on-board and external computers and the communications protocol. In practice a few protocols became dominant.

The introduction of EOBD has required a further harmonisation through its specification of the protocols allowed, the information to be available, etc. This, in turn, has led to the development of generic scan tools, i.e. scan tools designed to read all EOBD systems. However, it remains the situation that manufacturers' scan tools (diagnostic fault code readers) have additional capability over generic scan tools for vehicle systems specific to the manufacturer.

EOBD regulations define the minimum standard of test equipment and diagnostic tools as that it should meet or exceed ISO DIS 15031-4, and the basic diagnostic data and control information should conform with the formats specified in ISO DIS 15031-5.

3.7.2 Modes of operation for scan tools

The structure of the communication messages to be supported by scan tools is specified in ISO 15031-5. This defines nine services, or modes, of operation. The formal title is given first with the more colloquial expression included within brackets.

Mode 1 Request current powertrain diagnostic data (readiness tests and live readings)
Mode 2 Request powertrain freeze frame data (freeze frame readings)
Mode 3 Request emissions related powertrain diagnostic trouble codes (confirmed fault codes)
Mode 4 Clear/reset emission-related diagnostic information (reset stored fault codes)
Mode 5 Request oxygen sensor monitoring test results (test results/ monitoring oxygen sensors)
Mode 6 Request on-board monitoring test results for non-continuously monitored systems (presumed faults/systems not continuously monitored)
Mode 7 Request on-board monitoring test results for continuously monitored systems (presumed faults/systems continuously monitored)
Mode 8 Request control of on-board system, test or component (start test/control system or component test)
Mode 9 Request vehicle information (vehicle information stored in ECU)

When monitoring the EOBD system Modes 1, 3 and 9 are important, whilst for verification, diagnosis and repair Mode 2 is used.

Mode 1 Request current powertrain diagnostic data (readiness tests and live readings)
One aspect written into 98/69/EC, within the section on *Application for EC type approval* is the requirement for "manufacturers to describe the provisions taken to prevent tampering with and modification of the emissions control computer". It has long been recognised that simply setting and storing a flag when a fault is detected is inadequate. This is because it can be reset (either legitimately using for example a scan tool in mode 4, or for example by disconnecting power from the ECU). The strategy adopted by manufacturers is to have two (groups of) flags, both set initially to "off". These are:

- readiness code(s) which only get set when the vehicle has undergone a driving cycle, and
- fault code(s) which get set if a fault is detected.

For a vehicle to be demonstrably compliant the readiness code(s) should be set and no fault code(s) should be set.

This strategy means that a faulty vehicle whose MIL and fault codes are reset by disconnecting the battery also has its readiness code(s) reset. Completing a driving cycle to set the readiness code(s) reveals the fault, sets the fault code(s) and also illuminates the MIL.

Whilst the directive specifies what is to be achieved, it does not prescribe any single method for doing this. Appendix B of ISO DIS 15031-5 specifies that in Mode 1 eleven systems can be monitored (detailing the binary bits to be set for each). These are listed in Appendix 4 of this report. However, as was found in the CITA study, manufacturers can argue that a single readiness code is sufficient to meet the anti-tampering requirements and not implement the monitoring of all eleven.

Consequently, experience has revealed variations in the way the readiness codes are used to meet the regulations.

Notwithstanding, Mode 1 should provide three key sets of information:

- the EOBD system's indication as to whether the MIL is illuminated,
- the number of fault codes stored in the ECU, and
- the status of the readiness codes.

Mode 2 Request powertrain freeze frame data (freeze frame readings)

The purpose of the freeze frame is to aid in fault diagnosis. When a fault occurs a fault code is stored along with a snapshot of sensor values, oxygen sensor data etc. This provides information to the vehicle technician to aid diagnosis and repair.

Directive 98/69EC requires only one freeze frame be stored; that pertaining to the most recently noted fault. However some manufacturers already choose to store up to 20 frames, whilst the EOBD systems' architecture means that most could store up to 255 frames. Also, there is scope for increasing the amount of information stored in each frame.

Mode 3 Request emissions related powertrain diagnostic trouble codes (confirmed fault codes)

Diagnostic trouble codes (DTCs) are more commonly known in Europe as fault codes. In this report these two terms are interchangeable. Accessing this mode is only required if the data exchange in Mode 1 indicated that there are fault codes to be displayed.

Originally developed by the SAE (Society of Automotive Engineers) for US OBD systems, DTC's have been adopted, after being internationally standardised, for EOBD fault reporting. They are listed, with their descriptive text, in ISO DIS 15031-6 and are referenced in paragraph 6.5.3.4 of Appendix 1 to Annex XI of 98/69/EC. The codes are alpha numeric, comprising a letter followed four 4 numbers, e.g. P1260. Further details regarding the encryption used are given in Appendix 4 of this report.

Mode 9 Request vehicle information (vehicle information stored in ECU)
This service is to enable the external test equipment to request vehicle specific information from the ECU, such as the vehicle identification number (VIN) and calibration identifiers. The ISO standard notes that some of this information may be required by regulations.

3.7.3 Protocols between EOBD systems and their readers

Paragraph 6.5.3.1 of Appendix 1 to Annex XI of 98/69/EC restricts the on-board to off-board computer link to being one of three possibilities:
1. ISO 9141-2 Road vehicles – diagnostic systems CARB requirements (J1850 PWM)
2. ISO 11519-4 Road vehicles – low speed serial data communication (class B)
3. ISO DIS 14230 part 4 Road vehicles – diagnostic systems (also known as Keyword protocol 2000)

(Interestingly ISO 15031-4 specifies 5 protocols, the three above plus two further.)

3.7.4 Diagnostic connector between EOBD systems and their readers

The diagnostic connector is a 16 pin socket located within the passenger compartment of the vehicle. The scan tool is connected via a lead and operates from the vehicle power supply. Further details of this, including the standardised pin configuration, are given in Appendix 3.

4 The findings from (E)OBD studies

Key issues addressed in Chapter 4

Previous studies on (E)OBD systems undertaken within Europe and the US are reviewed in this chapter. The emissions standards for the (E)OBD systems in use on either side of the Atlantic are compared to show the relevance of some of the US data. The lessons that can be drawn from these studies and their relevance to the UK debate are discussed.

4.1 SOURCES OF INFORMATION

Sources of practical experience from (E)OBD testing largely derive from studies in the US because OBD legislation was introduced earlier in the US than in Europe.

The US EPA studies have centred on the statistical analysis of data on a large number (116,000) of vehicles passing through the Wisconsin in-service test facilities[2], and on a detailed investigation carried out in 4 test laboratories[3]. This latter investigation involved a sample of 201 vehicles which either reported for testing with their MIL on or were suspected of being high emitters in spite of the MIL being off. The EPA also provided a contact name within the Oregon Department of Environmental Quality who have provided information about their OBD testing programme[4].

European practical experience has been largely based on experimental studies aimed at addressing specific technical questions. Examples include:

- the recent CITA study[5] involving induced system malfunctions in a representative range of current OBD-fitted vehicles, and
- an experimental study on a single vehicle within the DG Entr OBD study[6] that was aimed at validating a model for simulating the performance of aged catalysts.

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[2] Analyses of the OBDII data collected from the Wisconsin I/M Lanes, T Trimble, U.S. Environmental Protection Agency, EPA420-R-00-014, August 2000.

[3] Evaluation of on-board diagnostics for use in detecting malfunctioning and high emitting vehicles, E Gardetto and T Trimble, U.S. Environmental Protection Agency, EPA420-R-00-013, August 2000

[4] OBD summary report for 2001 and Oregon's Overall Summary Report for 2001, Private communication with G Beyer, Oregon Dept of Env Quality, Oct 2002.

[5] 2nd CITA research study programme on emission testing at periodic and other inspections – Study 3 – use of OBD at periodic inspection (Interim report of test phase), Brussels, June 2002

[6] On-Board diagnostic systems to control emissions from motor vehicles – Final report, EC Enterprise DG, Contract ETD/99/502510, MTC, Mercel and LAT AUTh, 1999

The DG Entr study also included a review of the above US experience and re-analysis of some of the US data to address the specific objectives of that study.

There would therefore appear to be a very limited body of data in the public domain compared with that which is presumably in the hands of the individual vehicle manufacturers.

In the US, OBD was introduced US initially in California in 1991 and nation-wide in 1994. OBD II, which includes monitoring of all vehicle systems and processes influencing exhaust emissions as opposed to just electrical components, was introduced on model year 1996 vehicles. In Europe, EOBD was introduced on 1/1/2000 for new models and by 1/1/2001 for full implementation. As shown in Table 2 below, there are similarities between US Tier I and European Stage III type approval and OBD standards, particularly for CO and HC. These similarities support the relevance of the US experience to the European situation and this has been exploited for emissions savings potential analyses in the DG Entr study.

Table 2 European and US emissions standards

Pollutant	Certification standard g/km		OBD threshold g/km		OBD/type approval ratio	
	US Tier 1	Euro III	US Tier 1	Euro III	US Tier 1	Euro III
CO	2.13	2.3	3.2	3.2	1.5	1.4
HC	0.26	0.20	0.38	0.40	1.5	2.0
NO_X	0.25	0.15	0.38	0.60	1.5	4.0

4.2 EVOLUTION OF OBD SYSTEM PERFORMANCE

The EPA data on the scan tool readiness tests[2] showed that the ‘not ready’ reading (i.e. readiness test criteria not yet run during vehicle use prior to inspection) dropped by model year as follows:

1996 = 5.8%,
1997 = 2.3%,
1998 = 1.4%

with the majority of the 1996 events due to the system not being ready for the catalyst monitor and those for 1997 & 8 due to the system not being ready for the evaporative system monitor. The EPA suggested that a likely explanation for this progression was ‘manufacturer learning curve’.

An example from the detailed study[3] that illustrates the learning curve issue was a vehicle which suffered an “unanticipated” oxygen sensor failure and was, consequently, an error of omission. The manufacturer, noting this, has revised the system logic such that had the same fault occurred in a later model year it would have illuminated the MIL.

Further strong support for the EPA’s manufacturer’s learning curve hypothesis comes from the Oregon OBD data. Oregon started a state-wide in-service OBD inspection programme for all vehicles from model year 1996 in December 2000. They have collected, analysed and reported data for the testing undertaken in 2001[4]. Figure 3 shows the number of MIL failures,

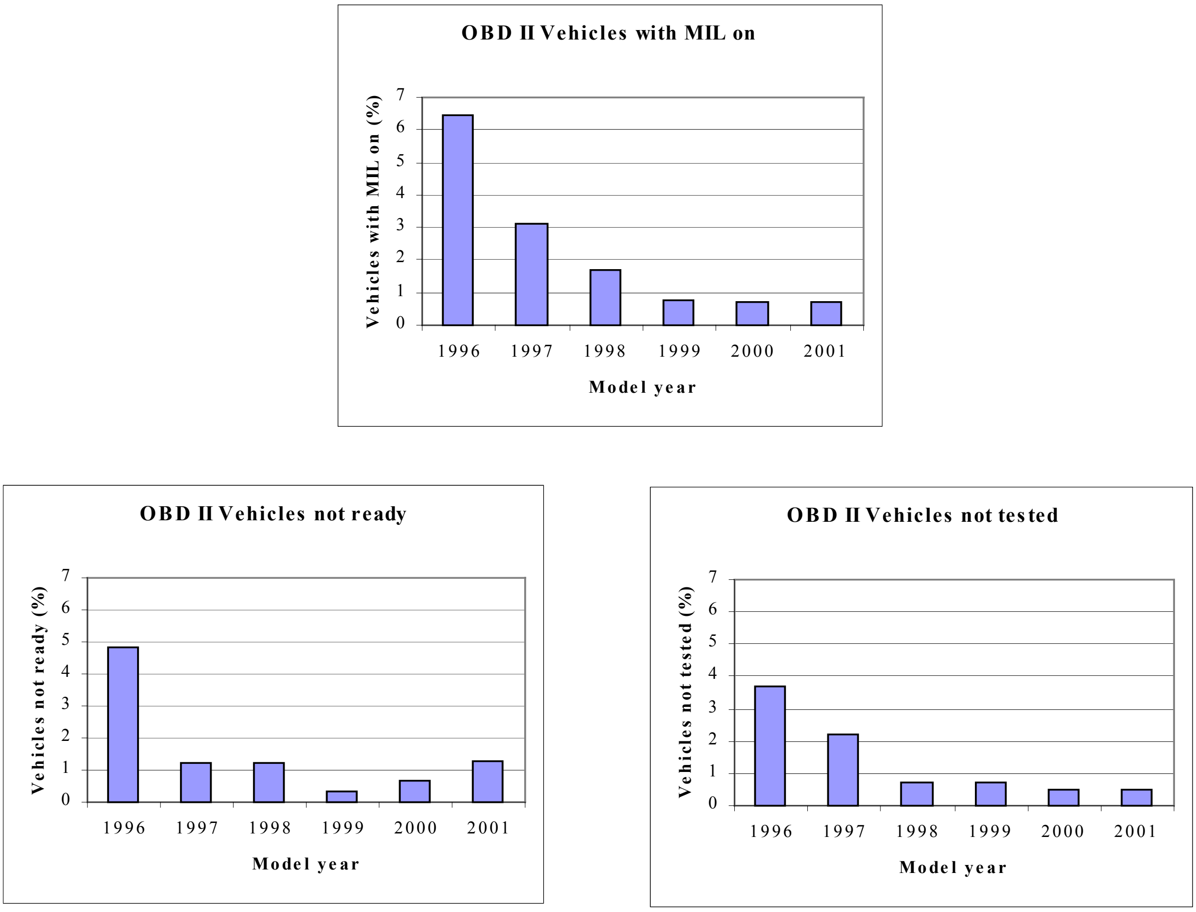

Figure 3 OBD data from Oregon's in-service test programme for 2001

vehicles not ready and vehicles not tested (bypassed) for 2001 broken down by vehicle model year and expressed as a percentage of the total number of vehicles inspected (which was 184,781). In all three graphs there is a trend for fewer faults being observed for newer year models. It is expected that this originates from:

- changes in technical maturity and
- increasing fault/problem frequency with vehicle age.

Unfortunately there are not sufficient data at present to deconvolute these two factors.

The breakdown of the vehicles bypassed (2,708 vehicles, i.e. 1.4% of the whole) is given in Table 3. This reveals that for this period of examination failure of the OBD system to communicate with the scan tool occurred in 0.14% of cases, and, from Figure 3, this already low frequency is probably decreasing with the newer models.

Table 3 Breakdown of reasons for vehicles not tested

No of times	Rank	Percentage	Reason for not testing
1,121	1	0.60%	Could not find vehicle diagnostic connector link
918	2	0.49%	Exempted from OBD test by EPA
356	3	0.19%	Miscellaneous
271	4	0.14%	Scan tool did not communicate
42	5	0.02%	OBD scan tool inoperable

In the CITA study there was a significant variation in the level of sophistication of the EOBD systems of different manufacturers. It had a bearing on the versatility of the system in question to communicate with different models of scan tool. This presumably reflected the comparatively recent introduction of the EOBD legislation and the different degrees of historical involvement of the European vehicle manufacturers in the US market. It also reflected the different degrees to which individual manufacturers have exploited the capabilities of OBD in its original role as an engine management tool rather than as the object of approvals legislation.

This would imply that minimum compliance with the OBD requirements of type approval legislation does not necessarily confer on a specific vehicle model the ability to be well suited to the potential requirements of a generic in-service inspection of the system for the purpose of reducing excess emitters. The effect of a historical learning curve and the technical shake down following the introduction of new or modified legislation should therefore be taken account of when considering either using or changing OBD legislation to meet the objectives of in-service I&M schemes.

4.3 RESULTS OF US STUDIES

Analysis of the data for 1996 model year vehicles[2] showed that about 1.5% of the fleet were presented for testing with the MIL on and that this proportion consistently rose to about 8% at 160,000 miles service after dropping to a minimum of about 0.9% at 40,000 miles.

An important conclusion by the EPA from this work was that there was very poor agreement between the results of the OBD system and IM240 tests with both failing a similar number of vehicles but with very few vehicles failed by both tests. The lack of agreement appeared to be worse the more recent the vehicle model year.

A detailed study[3], which included emissions tests using the FTP and IM240 test protocols and OBD system interrogation, was also carried out on a test sample of 201 vehicles (194 of which had reported for testing with MIL on and 7 with MIL off but suspected as being high emitters). Vehicle sourcing was based primarily on rental fleets, repair facilities and used car fleets rather than individual owners. OBD interrogation was via a variety of SAE 1978-compliant scan tools. (SAE 1978 was the fore-runner upon which ISO 15031-4 is based.)

The main findings on emissions levels were that of the vehicles reporting with MIL on, 136 met the FTP standard, a further 27 were high emitters (i.e. >1.0 times but within 1.5 times the FTP standard) and 31 were very high emitters (i.e. over 1.5 times the FTP standard). Further analysis of the EPA data of Reference 3 reported in Reference 6 revealed that CO and NO_X accounted for 80% of the FTP excedences, NO_X alone for 48% and HC for only 1%.

Technical faults were not identified on 22% of the vehicles presented with their MIL on. Of the 43 vehicles in this category, the MIL became extinguished during emissions testing in 10 cases. Of the remaining 33 cases, 30 passed the FTP test and a further 2 were within 1.5 of the emissions standard. On examination of the fault codes many had intermittent problems.

15 had misfire codes and a further 11 had fuel trim codes registered and the OEM diagnostics were unable to identify specific causes.

The most common aspects of the OBD systems that exhibited faults were oxygen sensors (29%) and ignition and fuel system components. Catalysts, EGR systems and ECUs each comprised only about 7% of the identified faults. There was also a case of electrical shorting preventing MIL illumination when commanded by the OBD.

Vehicles that exceeded the FTP emissions or had faults indicated by the OBD were repaired and re-tested to the FTP protocol. The repair of OBD-indicated faults generally returned the vehicles to normal operating conditions and in the majority of cases returned the vehicle emissions to below certification levels.

The conclusions given in the executive summary of the EPA report are[3]:

- OBD technology is a viable I/M test for 1996 and newer vehicles. The emission reductions available from basing repairs on OBD appear to be at least as large and possibly larger than emission reductions obtained from I/M tailpipe tests.
- OBD did miss some high emitters but performed better than available I/M tailpipe tests.
- Some areas of OBD technology still need to be refined and the vehicles with OBD technology should be monitored for the effect of ageing.
- OBD I/M offers preventative maintenance which allows benefits previously unavailable to I/M programs to be claimed.

4.4 APPLICATION OF US RESULTS TO QUESTIONS ADDRESSED BY DG ENTR STUDY

The data of the EPA study[3] was re-analysed[6] in terms of the different, but not too dissimilar, levels of type approval emissions and OBD thresholds for the comparative US and EU legislation.

These analyses confirmed the general conclusions of the JCS study[7] on the relative importance of NO_X and CO, rather than HC, as the species being emitted by excess emitters. They also indicated that the Emissions Reduction Rate Potential for each of the three gaseous pollutants was <5% although it was pointed out that the methodology used probably underestimated the benefit because of:

- the inclusion of only relatively new vehicles in the sample,
- the lack of consideration of MIL-induced servicing prior to in-service testing, and
- possible differences between US and European driving patterns.

[7] The inspection of in-use cars in order to attain minimum emissions of pollutants and optimum energy efficiency – Main Report, EC DGs for Environment (DG XI) Transport (DG VII) and Energy (DG XVII), LAT AUTh INRETS TNO TÜV Rheinland and TRL, May 1998

4.5 RESULTS OF CITA STUDY

This study involved the artificial creation of potential OBD system faults on a range of vehicle models representative of the European EOBD-fitted fleet and the investigation of the effect of these faults on in-service and type approval emissions test results and on scan tool readout.

One possible manifestation of the relatively recent introduction of the EOBD legislation was the observation that not all of the vehicles examined appeared to be fully compliant with the legislation. Examples included:

- a vehicle that reset the readiness code every time that the ignition was switched off, thereby defeating the main purpose of the readiness test which is to detect tampering,
- a vehicle with the MIL not illuminated but with the MIL status shown as ‘on’ in the live reading display (Mode 1, see Section 3.8.2) on the scan tool.

Of relevance to potential in-service test use was the identification of communications problems between vehicles and some generic scan tools. The study used generic scan tools because these are designed to operate with most/all vehicles. Manufacturer diagnostic readers/scan tools are bespoke for a particular vehicle make. Whilst they may communicate generic data for other vehicle makes they are fundamentally not designed for this purpose. Their bespoke origin, sophistication and price make them unattractive for use as a generic scan tool. The communications problems encountered included:

- inability of the scan tool to draw power from the test vehicle,
- inability of the scan tool to communicate with the test vehicle,
- incomplete communication, resulting in incomplete output of data when some modes are displayed or no data output at all for some of the modes.

These communication problems were believed to have originated principally from there being incompatibilities, or inconsistencies, in the interfacing hardware and protocols. The origins of these are believed to be the relative newness of the implementation of the technology, i.e. technological immaturity, and as such the number of communication problems encountered is expected to decrease as the technology matures.

Key observations from the emissions test programme undertaken in this study included:

- confirmation that the in-service emissions test could lead to errors of commission with respect to type approval standards,
- emissions checking via interrogation of EOBD systems set at current standards could lead to errors of omission with respect to type approval standards,
- there is currently poor correlation between the vehicles which pass/fail the in-service emissions test and vehicles with their MIL on.

The number sample of vehicles (16) and generic scan tool models (4) investigated in this study was small and industry reviewers have criticised the validity of some of the methods used to artificially simulate faults. There was however a degree of consistency in the observations of practical issues which could have a bearing on the reliable use of the currently-used EOBD systems and scan tools as the basis of a substitute for the tailpipe emissions tests for identifying excess emitters.

4.6 KEY LESSONS DRAWN FROM PREVIOUSLY REPORTED PRACTICAL EXPERIENCE

Overall the experience of the studies cited has led each team of researchers to conclude that (E)OBD systems offer the potential to improve the effectiveness of periodic inspection. The CITA study added "but the current tailpipe test should be retained".

The key findings of the US studies were generally more positive than those from the European studies. This is probably a consequence of the earlier implementation date for the US combined with a maturing technology.

It was noted in both the European and US studies that (E)OBD did miss some high emitters.

On the more negative side the US experience indicated the OBD system gave around 1.0% to 1.5% errors of commission and the European CITA study encountered a significant number of snags regarding the EOBD systems.

The European CITA study also encountered a significant number of EOBD system (on-board) to scan tool (off-board) computer communication challenges. The US studies, in contrast, found communication was successful in the vast majority of cases. This difference is probably a further consequence of greater technological maturity of OBD systems in the US.

The experience of these earlier studies is an important input into the next chapter, where the options for and the practicalities of using EOBD systems as part of the roadworthiness test are considered.

5 Options for in-service testing

Key issues addressed in Chapter 5

This chapter draws on the foundations set by the preceding three chapters as the basis for discussing the options for in-service testing. It considers:

- the existing legislative framework for in-service testing,
- the technical options available for interrogating EOBD systems as they are currently specified,
- the strengths and weaknesses associated with the technical options and
- possibilities for overcoming the weaknesses identified.

From these considerations recommendations are reached.

5.1 LEGISLATIVE FRAMEWORK

The recent EU directive 2001/09/EC amends the directive on “Roadworthiness testing for vehicles and their trailers” (96/96/EC) to enable EOBD systems to be included in the annual “MOT” test.

In detail, 2001/09/EC specifies, for exhaust pipe emissions:
(a) in-service limit values for measurements at idling speed,
(b) in-service limit values for measurements at high idling speed,
and that
(c) for motor vehicles equipped with on-board diagnostic systems in accordance with Directive 98/69/EC, Member States may as an alternative to the test specified in item (a) establish the correct functioning of the emission system through the appropriate reading of the OBD device and simultaneous checking of the proper functioning of the OBD system.

This section of the study considers the options available within the current UK testing structure which might be used for “the appropriate reading of the OBD device”.

5.2 OPTIONS AVAILABLE FOR INTERROGATING THE EOBD SYSTEM AT THE IN-SERVICE TEST

Figure 1 of Section 2.2 schematically shows the two options available for the reading/ interrogation of the EOBD system, namely inspection of the MIL light and via a scan tool. These two options each have attractions and challenges. Table 4 attempts to summarise these.

Table 4 Summary of the two approaches to reading a vehicle's EOBD system

	EOBD information accessed by MIL	EOBD information accessed by scan tool
Reader	Eye	(Generic) scan tool[8]
Time required for reading	Around 30 seconds	3 minutes (if successful)[9]
Complexity	Simple, involves solely the vehicle's EOBD system	Moderate, involves both the vehicle's EOBD system and communication with a generic scan tool
Permanent record produced?[10]	No	Yes
Ease of defeating system	Easy	Difficult
Quantity of information available	Small	Large
Likelihood of being able to successfully extract the information available	High	Moderate
Cost	Time only (0.5 min)	Time (3 min) plus £500 - £2,000 (typically £1,500) per scan tool

The phrase " and simultaneously checking of the proper functioning of the OBD system" in the directive is ambiguous. It could be interpreted as checking the MIL light becomes illuminated when the ignition is switched on (to confirm the bulb is operational) and then extinguish if there are no faults (Section 3.8.2 Modes 1 & 3). However, it could be interpreted to mean that the readiness codes (Section 3.8.2 Mode 1) need to be accessed to show that no tampering has occurred.

5.3 FAULTS ENCOUNTERED WITH THE INTERROGATION OF EOBD SYSTEMS

Reliance on the EOBD system to indicate non-compliance with emissions standards does have the problem posed by the small number of vehicles whose emissions are within the standard but whose EOBD system is faulty. This could affect either interrogation option.

For example, in the CITA study a vehicle was found whose EOBD system registered a fault and indicated that the MIL status was on. However, in practice the MIL was not illuminated although the check that occurred at key-on showed the bulb was still operating satisfactorily.

Another example was a vehicle whose readiness codes were reset every time the ignition was turned off. Consequently the aspect of the system that is designed to prevent tampering (e.g. by deleting fault codes by disconnecting the battery) was faulty. This would lead to a

[8] For a decentralised in-service testing system, many test stations will be independent of an OEM and are anticipated to use a generic scan tool rather than a manufacturer's diagnostic reader.
[9] The test time required was quoted by some familiar with the Oregon OBD in-service testing scheme as about 2 minutes.
[10] Currently only the tail pipe emissions test part of the test produces a permanent record, all other items tested are ticked off on a check list – hence this is not a major deficiency.

problem if the in-service test required the EOBD system to indicate both that no faults were stored and that all the readiness codes were set (Section 3.8.2 Modes 1 & 3), since the vehicle would be unable to pass the test even though its emissions may be totally within the standards.

It is recommended that before EOBD becomes part of the mandatory in-service testing procedure the frequency of this type of error of EOBD systems should have been demonstrated to be sufficiently small to be politically acceptable. It is noted that such evidence does not exist at present, and that the frequency of this type of error is likely to reduce as EOBD technology matures (evidence for this view comes from the US experience, see Section 4.2).

5.4 PHILOSOPHY OF THE IN-SERVICE TEST AND OF EOBD

As described in the opening paragraph of this report, the purpose of an EOBD system "is to ensure correct operation of the emissions control system of a vehicle during its lifetime by monitoring emissions related components for deterioration and malfunction". It is not to provide information for annual roadworthiness testing, although coincidentally it might. Rather it is an extension of the increasingly sophisticated diagnostics on modern vehicles. The regulatory framework (Directive 98/69/EC) provides what can be viewed as "minimum standards" with some manufacturers opting to considerably exceed these (primarily in order to facilitate the diagnosis of the engine and its repair if required). This is, generally, more likely for the higher specification (more expensive) end of the product spectrum. Consequently, the level of implementation of EOBD, although always required to be above a threshold, is not uniform.

A corollary to this is that one could envisage the situation of a sophisticated EOBD system having a fault code set, and the MIL illuminated, caused by the detection of a "minor" fault that is not monitored in the majority of vehicles. There is an element of political judgement as to whether this fault, which has a minor effect on emissions, is sufficient reason for this vehicle to fail the MOT test.

Some tenets of the in-service test are that it should be simple, universally applicable, consistent and fair, and cost effective. Discounting the significant number of systems that do not yet appear to comply with the minimum standard specified in Directive 98/69/EC, it is possible that to meet the tenets of the in-service test an MOT scan tool would be required. In essence, this would require some further data processing beyond that currently undertaken by the existing scan tools to overcome variable levels of implementation that exceed the regulations. What might be required is the sequence:

1 establish the communication link
2 read the readiness codes stored
3 read any fault codes stored
4 discern whether any MOT obligatory readiness code(s) are missing
5 discern whether any faults codes set are MOT failing code(s)
6 communicate the outcome to the tester.

Steps 1 to 3 are what a generic tool would currently undertake, whilst steps 4 to 6 would be the additional activities required to make the system more equable across the fleet, i.e. compensating for different levels of implementation. This approach is not available from simply observing whether or not the MIL is illuminated, or whether or not any fault code is set. It also has the benefits of allowing manufacturers to continue to use EOBD as they individually wish, and having a universally applicable interrogation that would not require any changes to the European Directive. In essence it is transferring the emphasis of the making an in-service test equable from the vehicle manufacturers to the in-service test programme through the requirement of an MOT scan tool.

However, the need for a generic MOT scan tool has not been demonstrated (it is discussed here as a solution to a **possible** problem). Further investigation of the experience of other nations' use of (E)OBD and the fault codes encountered within the UK and European fleet is required before an informed decision can be made on the desirability of specifying a generic MOT scan tool, and a quantification the likely cost effectiveness.

An alternative approach could be to oblige the vehicle manufacturers to "modify" EOBD systems such that the MIL became an EOBD status indicator, with the current three possibilities (not illuminated, steady illumination, flashing illumination) augmented by a fourth status (e.g. a steady green illumination) to indicate all readiness codes are set. This would probably require changes in both the EC directives and the ISO standards, and would be a further obligation on the vehicle manufacturers. However, it would have the advantage of enabling the EOBD system to be read, and checked against tampering, without recourse to an external reader.

A different view, which the authors believe is contrary to the philosophy of the UK in-service test, is to aim to use any information available (e.g. from the current EOBD systems) to help reduce emissions. Whilst this view is understandable, it would not currently be universally applicable to all vehicles fitted with EOBD because of the problems encountered and the range of EOBD implementation. Indeed it might be found to be currently impracticable. It might also have the effect contrary to that intended where, because of the regulatory impact of a fault being displayed, vehicle manufacturers "dumb-down" EOBD systems to meet minimum requirements only.

5.5 SUMMARY AND RECOMMENDATIONS

There are two ways information can be obtained from a vehicle's EOBD system as follows:

Inspection of whether the MIL is illuminated. This is quick, cheap and relies solely on the vehicle's EOBD system. However, it is open to abuse.

The use of a scan tool to check readiness codes and fault codes which is more complex. Further, current European experience indicates that it is likely to be unsuccessful in an unacceptably high number of cases. The US experience suggests this is probably temporary, and might reasonably be expected to reduce to an acceptable level with the maturing of the technology.

If the UK were to use paragraph (c) of European Directive 2001/09/EC, the authors' view is that the ease of abuse makes use of the MIL unattractive and currently too many vehicles would fail to communicate satisfactorily via the scan tool to make this viable. The directive indicates that the tester would then have to undertake a low idle test, alongside the existing obligatory high idle test. The tester is likely to become disillusioned and, given the choice specified in Section 5.1 above, would opt for the low-idle test from the outset. The authors' recommendation is that, given the current directive of either measuring tailpipe emissions at normal idle or reading the EOBD system, the in-service test should remain as only the tail pipe measurement in the short term.

The recommendation from this study is, therefore, that whilst offering significant potential, the current state of application of EOBD is not sufficiently mature for this to provide a universally applicable, consistent and fair test. Therefore the authors' do not recommend that the UK use the option of including an EOBD check as part of the in-service test (as described in directive 2001/09/EC) at present. However, it is confidently anticipated that the number of "problems" will reduce markedly with the passing of time, i.e. the maturing and evolution of the technology. In order to provide quantitative information against which the options and desirability for an in-service EOBD test can be assessed, a programme of data collection is recommended, see Section 6.1. In parallel with this, consideration should be given as to whether there is a need to specify a generic MOT scan tool that transcends the different levels of EOBD sophistication to provide a universally applicable tool for in-service use. Also, the growing wealth of experience from outside the UK (both from within Europe and the US) should be monitored to provide additional data.

6 Likely changes from the current position

Key issues addressed in Chapter 6

Following on from the preceding analysis, in this chapter likely changes from the current position are considered. These comprise:
- the further in-depth practical work required to quantify the cost effectiveness and practicality of inspecting EOBD systems at the annual in-service test,
- technical advances that might be anticipated to occur both within and beyond the concept of EOBD and
- possible changes to legislation.

6.1 POSSIBLE PRACTICAL WORK

There are a number of studies involving practical work, planned or underway, to gather further data on (E)OBD within both Europe and the US. The monitoring of the experience and findings of others should be viewed as an important and ongoing aspect of the UK Government's strategy for learning about and monitoring the effectiveness and practicalities of (E)OBD as a technology and its use as part of the in-service roadworthiness testing.

An example data is becoming available from within the US as more states opt for an annual OBD test. It is expected that the analysis of these data will provide statistics on failure rates etc. from vehicles manufactured post 1996. These data will also give information on how failure rates of older vehicles evolve with time. Within Europe Germany is the first country to opt to use the EOBD option provided by Directive 2001/09/EC. The statistics and experience gained within this programme are also anticipated to be useful indicators to help other member states identify when it might be appropriate to introduce EOBD inspection, and some practical details regarding its implementation.

Further data are required before the UK can objectively argue a case regarding the best option for the use of EOBD examination at in-service inspection. The data fall into two distinct areas covering:
- the cost-effectiveness of EOBD systems at identifying excess emitters and
- the practicalities of the in-service testing of all vehicles.

More specifically, regarding the effectiveness of EOBD systems the data sought pertains to:
E1. the number of excess emitters that are correctly identified as such by their EOBD system,
E2. the reduction in the emissions of pollutants that results from the identification and rectification of the vehicles,

E3. the number of errors of commission that occur, i.e. vehicles presented with their MIL illuminated but whose emissions are within the type approval standards and
E4. the number of errors of omission that occur, i.e. whose MIL are not illuminated but whose emissions are outside the threshold limit.

Regarding the practicalities of testing, the information sought pertains to the debates regarding the type of test, the equipment that should be used and the "robustness" of the EOBD/external equipment communications. What is sought is quantification of:
P1. the number of vehicles that are presented for the roadworthiness test with their MIL illuminated,
P2. the number of vehicles tested that successfully communicate with a (generic) scan tool,
P3. the number of vehicles that are presented for the roadworthiness test with their readiness codes correctly set,
P4. the correlation between EOBD indicated MIL illumination and actual MIL illumination,
P5. the number of vehicles that are presented for the roadworthiness test with fault codes set, and
P6. an analysis of the fault codes encountered as input to the debate on the need to specify an MOT scan tool.

A programme of work is suggested to collect data concerning the practicalities of in-service testing. It is strongly recommended that this is run in parallel with, is cross referenced to, but is independent from the new computerised in-service test recording that is due to start in the second half of 2003. (This is to minimise any adverse effects this project might have on the new computerised MoT system.) It is suggested that all vehicles be included that are presented for test whose date of manufacture is post 1/1/2000. The programme suggested is:

Number of test centres involved	Around 5 willing participants who each undertake on average > 10 tests/day.
Locations	Carefully selected to take account of geographic variations (north/south, urban/rural etc.) to try to obtain a statistically representative range of vehicles and driving styles.
Equipment	Stations to be given different generic scan tools
Specific information recorded	Cross-reference to MOT unique test number to provide information on vehicle make, type, mileage, age etc. MIL light on or off? Does scan tool communicate with EOBD system? Status of MIL (from EOBD) Status of readiness codes (from EOBD) Number of fault codes set (from EOBD) Details of fault codes set (if any).
If any of MIL illuminated, fault codes set or MoT fail on tail pipe test	Full MOT tail pipe test results.

If data from 1,000 vehicles were collected overall statistical precision would be expected to be ± 3% for the whole. If data from only 100 vehicles were collected this would reduce to ± 10% and, in the authors' view be insufficiently statistically significant.

It will probably take until January 2006 before sufficient data have been collected to be statistically adequate. However, some valuable data, particularly with regard to the number of vehicles that successfully communicate with the generic scan tools, can be collected earlier.

The collection of data regarding the effectiveness of EOBD systems at identifying excess emitters, is more difficult. There is the fundamental problem that "excess emitter" describes a vehicle whose emissions over a loaded test (the NEDC) is above the standard after appropriate allowance has been made for reasonable deterioration. However, all in-service testing is undertaken using un-loaded tests. Hence the only way that data for items E1 – E3 of the list can be quantified is to take vehicles whose EOBD system has flagged up as faulty and to test them over the NEDC (98/69/EC Type I test), repair them and then retest them over the NEDC. This is exactly what the US EPA did[3] with 201 vehicles. The authors estimate that such a programme of work would have cost not less than $US 0.5 M. Obviously, a smaller sample could be used but at the expense of the results being statistically less significant.

However, even this programme of work would not give any indication of the answer to question E4, the number of errors of omission that occur. To answer this the emissions distribution function from that portion of the whole fleet fitted with EOBD needs to be estimated, such that the proportion that are excess emitters can be identified. Given the answer to question E1 from a programme as outlined above, the difference is that proportion of the EOBD excess emitting fleet that the EOBD systems "missed".

It was the emissions distribution function from the fleet as a whole that the JCS study measured (reference 7) in their 1998 study, although there are some concerns regarding exactly how representative the vehicle sample was (Phase 1 report from this study, reference 1). A similar programme could be envisaged focussed on vehicles fitted with EOBD, but again it would be expensive.

An alternative approach would be to make use of emissions data collected over the regulatory cycle for other programmes, to consider carefully the vehicle sampling methodology in order to estimate how representative the data are of the fleet as a whole, and to scale up appropriately. One such programme generating this type of data is the VCA's in-use compliance testing programme.

6.2 POSSIBLE TECHNICAL ADVANCES

These are sub-divided into those that amount to an extension of the EOBD system and those beyond, or outside, EOBD. Consideration is also restricted to aspects pertinent to improving air quality through in-service inspection in the short to medium term.

6.2.1 Advances to the EOBD system

Some technical advances to the EOBD system that are being considered have been mentioned earlier in this report, e.g. with regard to monitoring for misfire or measuring catalyst activity (details in Appendix 3). Also manufacturers have ongoing refinement of their algorithms predicting the vehicles' emissions performance from the diagnostic sensor outputs.

Another area ripe for technical advances is that of the data stored within the EOBD system. Fundamental vehicle information (e.g. its VIN) could be augmented by other information, e.g. ECU software identification, which could be read as part of the in-service test as a check on possible tampering, e.g. chip tuning. Currently only one freeze frame of sensor information is stored. This could easily be expanded, but this is more associated with diagnosis and repair rather than in-service testing. However, the information stored could be expanded to include vehicle mileage at the time the fault occurred. Indeed, a novel feature of EOBD introduced with the EU regulation is a distance counter which stores the mileage driven with the MIL on (from 2003 for vehicles with an electronic speed input). The intention stated in Clause 14 of the 98/69/EC is to ensure that vehicle owners meet their obligation to repair faults once the EOBD system has indicated their existence.

A further advance would be if all data storage were in non-volatile memory, such as is used in digital cameras and MP3 players. Such data can be erased with the right equipment, and this change would prevent its erasure by disconnecting the power source to the unit. (In terms of cost this memory is typically less than £0.50 / MB, i.e. low.)

6.2.2 Advances beyond EOBD

EOBD is a good concept involving the monitoring of the functionality of the emissions related parts and systems of a vehicle. In the case of a malfunction being detected the driver is alerted, and more rapid repair is likely to occur relative to vehicles not fitted with EOBD. However, the general philosophy of emissions regulation is to set standards and to police that they are being met, not to be involved in the details of the technology used to achieve these standards (except insofar as the standards need to reflect what is technologically feasible and is not unreasonably expensive). The EOBD regulations are, by necessity, not of this genre, and are, as a consequence, relatively complex.

The concept of on-board measurement (OBM) in which the exhaust gas composition is measured directly, is more in keeping with emissions regulation philosophy. It would circumvent the need to use strategies to monitor functionality (e.g. using an oxygen sensor to monitor OSC and **infer** catalyst activity) by measuring the catalysts output directly. OBM would also overcome the potential weakness of EOBD systems failing to detect a number of minor faults that do not individually activate the MIL, or cause excess emissions, but whose cumulative effect is to cause excess emissions.

However, OBM requires relatively cheap, durable, sensitive sensors for CO, NO_X and HC. The lack of availability of maturing sensing technology with these characteristics is the primary barrier preventing the rapid and successful implementation of OBM. Some progress has been achieved, indeed some vehicles are now being fitted with NO_X sensors. Currently there does appear to be a gulf between the laboratory based prototypes and durable mass produced units that could form the basis of an OBM system.

Given the importance of NO_X emissions in terms of air quality, and the trials of on-board NO_X sensors, there is the possibility of OBM being introduced in stages with NO_X on-board measurement alone preceding full implementation. However, whether or not this possibility becomes the route whereby OBM is introduced will need to await debate within the EU.

6.3 CHANGES IN LEGISLATION

Changes in legislation require the coming together of technical possibility and political will (itself dependent on public perception). Because of the need to obtain the agreement of all parties involved changing legislation takes a considerable time. However, it does appear that further changes in the legislation regarding EOBD will occur, potentially regarding:

- specification of EOBD systems for Type Approval,
- methods of testing that systems conform to the regulations, and
- options/methods available for in-service testing.

It appears that the best route forward from the current starting point is to use the existing legislation, gather data on its effectiveness, and police it effectively so that its strengths and weaknesses become better defined. Consensus views should then be reached on the strategies/activities/legislation required to overcome weaknesses. This would be a marked improvement from the current position of unquantified "possibilities". This strategy would both reduce the number of amendments that might be made and speed the reaching of agreement for well argued changes.

The authors' view is that it would be premature to predict such changes. Indeed it may be folly until the development of sensor technology enables OBM to become fitted to vehicles, thereby fundamentally changing the purpose of EOBD.

With regard to in-service testing, it seems very likely that further changes would be appropriate amending directive 2001/09/EC. However, the authors' view is that until more experience has been gained, more data collected and the results debated, the preferred route of MIL or scan tool or enhanced MIL can not be identified, and consequently it is again premature to predict the changes required.

With regard to timescales, vehicles made after 1/1/2001, the date of full implementation, are not due to be presented for roadworthiness testing before January 2004. It is likely to be 2 to 3 years before sufficient data have been collected to be statistically useful, and the shakedown of initial technical difficulties has worked through. Consequently, it is difficult to see how all the basic information could be available before January 2006 to enable the prioritisation of options and the informed debate of the options to ensue. (However, as was noted in Section 6.1, the collection of some data, especially on the success rates for communication, could start very soon.) The information from the US studies, whilst being a very helpful indicator, is unlikely to significantly shorten this timescale for the making of decisions appropriate to Europe.

7 Conclusions and recommendations

During the specification of the work programme the DfT posed some questions to be addressed. The body of the report contains, in a systematic way, the details from which answers to these questions are drawn. In this conclusions and recommendations chapter these questions, written in bold type at the start of each section, are used as the framework for presenting the reports findings.

What are the inconsistencies and deficiencies in current EOBD systems in the context of their potential use in roadworthiness testing?

Some aspects regarding the evolution and philosophy of EOBD are as follows.

- The purpose of an On Board Diagnostic (OBD) system is to ensure correct operation of the emissions control system of a vehicle during its lifetime by monitoring emissions related components for deterioration and malfunction. An important consequence of this definition is the fact that EOBD was not primarily intended for roadworthiness testing.
- In practice EOBD is a development/extension of manufacturers diagnostic readers (extended to cover emissions). A consequence of this is that there is a range of levels of EOBD sophistication above and beyond the minimum requirements laid down within the EC directive.
- The experience of other European studies on EOBD indicate that there are some difficulties to be overcome both in detection of excess emitters (i.e. error of omission) and in the success rate of on-board to off-board computer communications. The US experience, and that from the introduction of other new technologies, suggests this is partially caused by a current lack of maturity of EOBD technology and should be expected to improve with time.
- A further consequence of the newness of the technology is currently a poor level of quantification of its rate of detection of faulty vehicles, and the emissions savings that this rate of detection affords, i.e. its cost effectiveness.
- Whilst it is generally agreed that EOBD has the potential to improve the effectiveness of in-service inspection, the philosophy of this test in the UK is that it should be universally applicable and fairly applied. Given the report's findings the authors recommend that it is premature to propose augmenting the current in-service test with an EOBD system inspection at present.

What is the likely hierarchy of technical options for reading EOBD systems?
Within the current regulations the two principal possibilities are as follows.

- To visually observe the MIL light, using its illumination as an indication of a fault. The weakness of this approach is that its use alone would give no information on readiness codes (which are the manufacturers solution to the regulatory requirement for anti-tampering measures).
- To use a generic scan tool to read both the readiness codes and see if any fault codes are set. The disadvantage of this approach arise from the practical experience of an unacceptably high frequency of unsuccessful attempts to communicate with the EOBD system using a generic scan tool (from the stand-point of its use in in-service testing) and

the possibility that variable levels of implementation might lead to variability in test severity for different vehicle types.

Modifications to these two possibilities are proposed, focussed on reducing the weaknesses identified above.

- The specification of the MIL on-board indication concept could be extended to include a “system ready” light that is illuminated when the readiness codes are set.
- If it were found that that variable levels of implementation might led to unaceptable variable test severity, further data processing could be added into an MOT specified scan tool so that only the lack of readiness codes, or the presence of fault codes that are integral to the MOT test lead to a vehicle being identified as a failure.

What are the current capabilities of scan tools?

- Generic scan tools, able to communicate with all EOBD systems, can be made on the basis of the regulations constraining the information that needs to be stored and the communications protocols that are permitted. Prior to this, the autonomy of the different vehicle manufacturers meant that the specification and manufacture of generic diagnostic fault code readers applicable to all vehicles was not possible.
- Notwithstanding the above, the experience from studies indicates there are challenges. Successful communication was not always achieved, there being problems sometimes in establishing a communications link and at other times regarding the amount of information that could be transferred.
- The connectors, wiring and communication protocols, (including the information available and its format) are defined by ISO standards. A characteristic of these standards, which is distinct from the European directives, is that *they are subject to revision* (words from within the standards). This lack of absolute definitions lead to ambiguities which can hinder universal applicability.
- A further aspect of the EOBD systems is that while fault codes have a prescribed format, some have standardised codes, whereas others are manufacturer specific. However, in principle an in-service test need only be aware of there being a significant fault, not its details. Therefore, for in-service testing a scan tool might be required to undertake further information processing to meet the specific implementation described in the regulations. The above is an inevitable consequence (as opposed to a criticism) of the fault code diagnostic concept.
- The current cost of generic scan tools was found to range from around £500 to £2,000 with an average “generic tool” costing around £1,500.

From the report's assessment, are the inadequacies identified (for potential roadworthiness inspection use) primarily due to problems of concept or consistency of implementation.

The report’s assessment is that the relatively short time between the introduction of EOBD within Europe and this study, and inevitably other European studies which provide some of the input data, means that the majority of inadequacies identified are most probably a consequence of technological immaturity. This is a distinctly different cause from either inadequacies of concept or consistency of implementation, and is a cause that would reasonably be expected to change (i.e. significantly improve) over the next few years.

Given this background, it has been found that a lack of consistency of implementation is a significant issue. It is not primarily a problem of non-compliance but appears to have arisen because EOBD is an extension of fault diagnostics (made possible by the introduction of ECUs) and also because manufacturers use different practical methods of achieving the performance specifications defined in the directive.

From the report's assessment, will *consequential* changes in EOBD type approval regulations be primarily in the formulation or the implementation/policing of the directives?

EOBD seems reasonably well formulated given the basic starting premises. (This is the monitoring of in-use emissions through **diagnostics** rather than direct exhaust gas composition measurement and comparing these with emissions standards.) Changes in implementation might require changes in regulations (e.g. more detailed specification) or might involve developing and using an MOT scan tool (which would not require a change in the regulations).

If it were decided to use visual inspection that included an indication that readiness codes were set, this would probably be best introduced by making changes in the type approval regulations.

If OBM technology were to advance to the stage of being a practical likelihood, the authors recommend that consideration be given to using OBM as the primary technique to monitor in-service emissions, i.e. superseding EOBD. This too would involve a major revision of the regulations.

What is an estimate of timeframe for formulating and implementing possible amendments to the roadworthiness directive to incorporate EOBD-based inspection concepts?

Directive 98/69/EC specifies that full implementation of EOBD should occur by 1/1/2001 for all new vehicles. Within the current UK's in-service testing framework, of annually testing 3-year-old vehicles, this means the first of these vehicles are not required to be tested before 1/1/2004. If it is viewed prudent to wait until some experience from pilot studies is available it is difficult to see how key data could be available before early 2006.

This five-year delay from full implementation within the fleet to the start of testing has precedents. In the US the date for full implementation of OBD-II was 1st January 1996. By 1st January 2001 a number of US states, but far from all, had introduced an OBD check as part of their I&M programme. In some states this was preceded by, for example, an 18 month period during which an OBD check was carried out but it made no difference to the outcome of the I&M test. (Its inclusion was to get both testers and the public used to the test and to "advise" where a vehicle would be failed in the future.)

Given the time required for debate and the reaching of a consensus position, it is estimated that the passing EC amending directives would occur not earlier than 2008.

What further in-depth analytical or practical work is required to make good inadequacies of currently available information on which to base recommendations on the viability of EOBD based inspection concepts?

Estimations of the cost effectiveness of testing options for vehicles that are in excess of three years old will need to await the availability of a representative sample of vehicles from which data can be collected. The data required will need to cover both the effectiveness and the practicality of testing, and these will change with technological maturity.

A programme of work is recommended to address the latter. It involves a pilot study in around 5 carefully chosen test centres that is run alongside the new UK computerised MOT recording scheme. Different test centres should be given different generic scan tools and all eligible vehicles should be tested. Parameters to be investigated include:

- MIL light on or off?
- Does scan tool communicate with EOBD system?
- Status of MIL (from EOBD).
- Status of readiness codes (from EOBD).
- Number of fault codes set (from EOBD).
- Details of fault codes set (if any).

In the analysis of the data, full MOT tail pipe test results should also be included if the MIL was illuminated or if fault codes were set or if the vehicle failed the MOT fail on tail pipe emissions.

With regard to quantifying the effectiveness of EOBD systems, there is the fundamental problem that in-service test centres are only equipped for measuring emissions from unloaded drive cycles, and there is a poor correlation between these emissions and those from loaded (real world) driving. The US solution to this was to “acquire” around 200 OBD failures and to test them over the regulatory cycle (FTP). It is recommended that this is the approach adopted. However, the size of the sample required will depend on the statistical significance that is adjudged to be politically optimal (balancing the cost of the research programme with increased statistical significance the more vehicles that are tested) and the results from the pilot studies (defining the likely number of failures encountered).

8 Glossary

CAN	Controller area network (a serial bus system developed for automotive applications that provides a further hardware option for reading EOBD data through the EOBD – scan tool connector.
CARB	California Air Resources Board
CITA	Comité International de l'Inspection Technique Automobile (CITA) the international association of organisations undertaking, supervising or otherwise involved with the compulsory inspection of motor vehicles and their trailers
Confirmed fault	EOBD system detected a fault that has been repeated and gone from being a presumed fault (Section 3.5)
CNG	Compressed natural gas
DTC	Diagnostic trouble codes (another name for fault codes - Section 3.5)
ECU	Electronic control unit, also called the PCM
EOBD	European on-board diagnostics
EPA	Environmental Protection Agency (a US government department)
FTP	Federal test protocol (the US equivalent of the European NEDC)
HEGO	Heated exhaust gas oxygen sensor (another name for an oxygen concentration sensor - Section 3.3.2)
I/M	Inspection and maintenance
IM240	A 240 second duration dynamometer test used by some US states for their in-service testing
ISO	International Organisation for Standardisation (a world wide federation of national standards bodies)
JCS	Joint Commission Study (A study on inspection of in-use cars by the EC DGs for Environment (DG XI) Transport (DG VII) and Energy (DG XVII)
Lambda (λ) sensor	Commonly used name for what is actually an oxygen concentration sensor (Section 3.3.2)
LPG	Liquid petroleum gas
MIL	Malfunction indication lamp (used to warn the driver the EOBD system has detected a fault – Section 3.6)
NEDC	New European driving cycle (the Type 1 test specified in 98/69/EC – Section 3.4)
OBD	On-board diagnostics
OBD I, OBD II	The US standards for On-board diagnostics version 1, and 2 (Chapter 1)

OBM	On-board monitoring (direct measurement of exhaust gas concentration, as opposed it measuring diagnostic sensors as in EOBD – Section 6.2.2)
OSC	Oxygen storage capacity (an aspect of catalysts that is monitored and taken as representative of their activity – Section 3.3.3)
PCM	Powertrain control module (another name for the ECU)
Presumed fault	EOBD system detected fault that requires either duplicating (to turn to confirmed fault) or erasing if found to not be repeatable (Section 3.5)
Readiness codes	Codes indicating that the EOBD systems have completed their checking routines – used as anti-tampering strategy because resetting the EOBD system resets not only the MIL but also the readiness codes (Section 3.7.2 Mode 1)
SAE	Society of Automotive Engineers
UEGO	Universal exhaust gas oxygen sensor (another name for an oxygen concentration sensor - Section 3.3.2)
VCA	Vehicle Certification Agency (the UK's national approval authority for new road vehicles, an executive Agency of the Department for Transport)
VIN	Vehicle identification number, a unique number stamped on every vehicle
Vehicle family	a term from the EU directive, a manufacturers grouping of vehicle types which have similar EOBD characteristics and which only requires a single EOBD approval (Section 2.4)
Vehicle type	a term from the EU directive, a category of power driven vehicles which needs to pass Type I – VI tests to gain type approval (Section 2.4)

Appendices

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Appendix 1	Sections of Directive 98/69/EC that relate to type approval of EOBD systems
Appendix 2	Further information on sensors and diagnostic strategies
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Appendix 1
Sections of Directive 98/69/EC that relate to Type Approval of EOBD systems

Appendix 1 Sections of Directive 98/69/EC that relate to Type Approval of EOBD systems

DIRECTIVE 98/69/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
of 13 October 1998
relating to measures to be taken against air pollution by emissions from motor vehicles and amending Council Directive 70/220/EEC
(OJ L 350, 28.12.1998, p. 1)

Clauses:

(14) Whereas new provisions for on-board diagnostics (OBD) should be introduced with a view to permitting an immediate detection of failure of anti-pollution vehicle equipment and thus allowing a significant upgrading of the maintenance of initial emissions performance on in-service vehicles through periodic or kerbside control ;

"**C1** Whereas, however, OBD are at a less developed stage for diesel vehicles and can be fitted on new types of such vehicles from 2003 on; 3 whereas installing an on-board measurement system (OBM) or other systems to detect any faults by measuring individual pollutants emitted shall be permissible provided that the OBD system integrity is maintained; whereas in order for the Member States to ensure that vehicle owners meet their obligation to repair faults once they have been indicated, the distance travelled since the fault is indicated shall be recorded; whereas on-board diagnostics systems must offer unrestricted and standardised access; whereas motor vehicle manufacturers must provide the information required for the diagnosis, servicing or repair of the vehicle; whereas such access and such information are required to ensure that vehicles may be inspected, serviced and repaired without hindrance throughout the European Union, and that competition in the market for vehicle parts and repairs is not distorted to the disadvantage of part manufacturers, independent vehicle-part wholesalers, independent repair garages and consumers; whereas manufacturers of spare or retrofit parts will be obliged to make the parts they manufacture compatible with the on-board diagnostic system concerned with a view to fault-free operation assuring the user against malfunctions;

Articles:

Article 3

1. Not later than 31 December 1999, the Commission shall submit a proposal to the European Parliament and to the Council confirming or complementing this Directive. The measures contained in the proposal shall take effect from 1 January 2005. The proposal shall contain:

- Category N1 , Classes II and III limit values for cold start in low temperature ambient air (266 K) (_ 7° C),
- Community provisions for improved roadworthiness testing,
- the threshold limit values for OBD for 2005/6 for M1 and N1 vehicles,
- examination of Type V testing, including the possibility of abolishing it.

2. After 31 December 1999 the Commission shall submit further proposals for legislation to come into force after 2005 which consider:

- modification to the durability requirements, including extending the durability test,
- fuel quality standards including in particular in the light of vehicle technology,
- the contribution of possible measures, including those relating to fuels and vehicles, to the attainment of longer term Community objectives on air quality, taking into account technological developments and the results of new air pollution related research including effects of particulate matter on human health,
- the potential and feasibility of local measures to reduce vehicle emissions; in this context the contribution of transport and other policy measures such as traffic management, urban public transport, enhanced inspection and maintenance and vehicle scrappage schemes should be evaluated,
- the particular situation of captive fleets and the potential for emission reductions related to the use by such fleets of fuels with very stringent environmental specifications,
- the potential emission reductions to be gained from fixing the environmental specifications of fuels to be used in agricultural tractors as covered by Directive 74/150/EEC and in internal combustion engines to be installed in non-road mobile machinery as covered by Directive 97/68/EC,
- requirements for the operation of an on-board measurement system (OBM).

3. All proposals shall take into account the following background considerations:

- evaluation of the impact of the provisions of this Directive in terms of their contribution to air quality, examination of technical feasibility and cost-effectiveness including an evaluation of the benefits and availability of enhanced technology,

- compatibility with the attainment of other Community objectives, such as regarding the attainment of air quality objectives and other related objectives such as acidification and eutrophication and the reduction of greenhouse gas emissions,

- noxious pollutant emissions in the Community from transport and non-transport sources and an estimate of the contribution that existing and pending and potential emission reduction measures from all sources could make towards improving air quality,

  - emissions from direct-injection petrol engines including particulate emissions,

  - developments in exhaust purification at full load,

  - development of alternative fuels and new propulsion technologies,

  - progress towards the industrial availability of key after-treatment systems such as DeNOx catalysts and traps and the technical feasibility of achieving the implementation date for diesel engines,

  - improvements in the test procedures for small particulates,

  - refinery technologies and the supply situation and qualities of crude oil available to the Community,

- the contribution that selective and differentiated fiscal measures could make to reducing vehicle emissions without any negative impact on the functioning of the internal market, taking into account the effects of revenue losses on neighbouring countries.

Article 4

1. By 1 January 2000, the Commission shall submit a report to the European Parliament and the Council on the drawing up of a standard electronic format for repair information taking account of relevant international standards.

By 30 June 2002 the Commission shall submit a report to the European Parliament and the Council on the development of on-board diagnostics (OBD) giving its opinion on the need for an extension of the OBD procedure and on requirements for the operation of an on-board measurement system (OBM). On the basis of the report, the Commission will submit a proposal for measures to enter into force no later than 1 January 2005 to include the technical specifications and corresponding annexes in order to provide for the type approval of OBM systems ensuring at least equivalent levels of monitoring to the OBD system and which shall be compatible with these systems.

The Commission shall submit a report to the European Parliament and the Council on the extension of OBD to cover other electronic vehicle control systems relating to active and passive safety, *inter alia* in a manner which is compatible with emission control systems.

2. By 1 January 2001 the Commission shall take appropriate measures to ensure that replacement or retro-fitted components can be brought to the market. Such measures shall include suitable approval procedures for replacement parts to be defined as soon as possible for those emission

control components that are critical to the correct functioning of OBD systems.

3. By 30 June 2000 the Commission shall take appropriate measures to ensue that the development of replacement or retro-fit components which are critical to the correct functioning of the OBD system is not restricted by the unavailability of pertinent information, unless that information is covered by intellectual property rights or constitutes specific know-how of the manufacturers or the OEM (Original Equipment Manufacturers) suppliers: in this case the necessary technical information shall not be improperly withheld.

4. In addition the Commission shall submit, by 30 June 2000, appropriate proposals to ensure that spare and retrofit parts are compatible *inter alia* with the specifications of the appropriate on-board diagnostic system, so that repair, replacement and fault-free operation are possible. The type-approval procedure laid down in the Annex to this Directive shall serve as a basis for this.

ANNEX

AMENDMENTS TO THE ANNEXES TO DIRECTIVE 70/220/EEC

ANNEX XI: ON-BOARD-DIAGNOSTICS (OBD) FOR MOTOR VEHICLES

Appendix 1: Functional aspects of OBD systems

Appendix 2: Essential characteristics of the vehicle family'

ANNEX I

2. The heading reads as follows:

'*SCOPE, DEFINITIONS, APPLICATION FOR EC TYPE-APPROVAL, GRANTING OF EC TYPE-APPROVAL, REQUIREMENTS AND TESTS, EXTENSION OF EC TYPE-APPROVAL, CONFORMITY OF PRODUC-TION AND IN-SERVICE VEHICLES, ON-BOARD DIAGNOSTIC (OBD) SYSTEMS*'.

3. Section 1:

The first sentence reads as follows:

'This Directive applies to

- tailpipe emissions at normal and low ambient temperature, evaporative emissions, emissions of crankcase gases, the durability of anti-pollution devices and on-board diagnostic (OBD) systems of motor vehicles equipped with positive-ignition engines,

and

- tailpipe emissions, the durability of anti-pollution devices and on-board diagnostic (OBD) systems of vehicles of category M1 and N1 ([11]), equipped with compression-ignition engines covered by Article 1 of Directive 70/220/EEC in the version of Directive 83/351/EEC, with the exception of those vehicles of categories N1 for which type-approval has been granted pursuant to Directive 88/77/EEC ([12]).'

4. New sections 2.13, 2.14, 2.15 and 2.16 are added to read as follows:

'2.13. 'OBD' an on-board diagnostic system for emission control which has the capability of identifying the likely area of malfunction by means of fault codes stored in computer memory.

2.14. 'In-service test' means the test and evaluation of conformity conducted in accordance with section 7.1.7 of this Annex.

2.15. 'Properly maintained and used' means, for the purpose of a test vehicle, that such a vehicle satisfies the criteria for acceptance of a selected vehicle laid down in section 2 of Appendix 3 to this Annex.

[11] As defined in Part A of Annex II to Directive 70/156/EEC.
[12] OJ L 36, 9.2.1998, p. 33.

2.16. ‘Defeat device’ means any element of design which senses temperature, vehicle speed, engine RPM, transmission gear, manifold vacuum or any other parameter for the purpose of activating, modulating, delaying or deactivating the operation of any part of the emission control system, that reduces the effectiveness of the emission control system under conditions which may reasonably be expected to be encountered in normal vehicle operation and use. Such an element of design may not be considered a defeat device if:

I. the need for the device is justified in terms of protecting the engine against damage or accident and for safe operation of the vehicle, or

II. the device does not function beyond the requirements of engine starting, or

III. conditions are substantially included in the Type I or Type VI test procedures.’

5. Sections 3 to 3.2.1 read as follows:

‘3. APPLICATION FOR EC TYPE-APPROVAL

3.1. The application for EC type-approval pursuant to Article 3 (4) of Directive 70/156/EEC of a vehicle type with regard to its tailpipe emissions, evaporative emissions, durability of anti-pollution devices as well as to its on-board diagnostic (OBD) system must be submitted by the vehicle manufacturer.

Should the application concern an on-board diagnostic (OBD) system the procedure described in Annex XI, section 3 must be followed.

3.1.1. Should the application concern an on-board diagnostic (OBD) system, it must be accompanied by the additional information required in section 3.2.12.2.8 of Annex II together with:

3.1.1.1. a declaration by the manufacturer of:

3.1.1.1.1. in the case of vehicles equipped with positive-ignition engines, the percentage of misfires out of a total number of firing events that would result in emissions exceeding the limits given in section 3.3.2 of Annex XI if that percentage of misfire had been present from the start of a type I test as described in section 5.3.1 of Annex III;

3.1.1.1.2. in the case of vehicles equipped with positive-ignition engines, the percentage of misfires out of a total number of firing events that could lead to an exhaust catalyst, or catalysts, overheating prior to causing irreversible damage;

3.1.1.2. detailed written information fully describing the functional operation characteristics of the OBD system, including a listing of all relevant parts of the vehicle’s emission control system, i.e. sensors, actuators and components, that are monitored by the OBD system;

3.1.1.3. a description of the malfunction indicator (MI) used by the

OBD system to signal the presence of a fault to a driver of the vehicle;

3.1.1.4. the manufacturer must describe provisions taken to prevent tampering with and modification of the emission control computer;

3.1.1.5. when appropriate, copies of other type-approvals with the relevant data to enable extensions of approvals;

3.1.1.6. if applicable, the particulars of the vehicle family as referred to in Annex XI, Appendix 2.

3.1.2. For the tests described in section 3 of Annex XI, a vehicle representative of the vehicle type or vehicle family fitted with the OBD system to be approved must be submitted to the technical service responsible for the type-approval test. If the technical service determines that the submitted vehicle does not fully represent the vehicle type or vehicle family described in Annex XI, Appendix 2, an alternative and if necessary an additional vehicle must be submitted for test in accordance with section 3 of Annex XI.

3.2. A model of the information document relating to tailpipe emissions, evaporative emissions, durability and the on-board diagnostic (OBD) system is given in Annex II.

3.2.1. Where appropriate, copies of other type-approvals with the relevant data to enable extension of approvals and establishment of deterioration factors must be submitted.'

6. Sections 4 to 4.2 read as follows:

'4. GRANTING OF EC TYPE-APPROVAL

4.1. If the relevant requirements are satisfied, EC type-approval is granted pursuant to Article 4 (3) of Directive 70/156/EEC.

4.2. A model of the EC type-approval certificate relating to tailpipe emissions, evaporative emissions, durability and the on-board diagnostic (OBD) system is given in Annex X.'

7. Section 5:

The note is replaced by the following text:

'*Note:*

As an alternative to the requirements of this section, vehicle manufacturers whose world-wide annual production is less than 10 000 units may obtain EC type-approval on the basis of the corresponding technical requirements in:

- the California Code of Regulations, Title 13, Sections 1960.1 (f) (2) or (g) (1) and (g) (2), 1960.1 (p) applicable to 1996 and later model year vehicles, 1968.1, 1976 and 1975, applicable to 1995 and later model year light-duty vehicles, published by Barclay's Publishing.

Different routes for type-approval and extensions

Type-approval test	Positive-ignition engined vehicles of categories M and N	Compression-ignition engined vehicles of categories M1 and N1
Type I	Yes (maximum mass < 3,5 t)	Yes (maximum mass 4 3,5 t)
Type II	Yes	—
Type III	Yes	—
Type IV	Yes (maximum mass < 3,5 t)	—
Type V	Yes (maximum mass < 3,5 t)	Yes (maximum mass 4 3,5 t)
Type VI	Yes (vehicles in Category M1 and Category N1, Class 1 (1)	–
Extension	Section 6	— Section 6 —M2 and N2 with reference mass not more than 2 840 kg (2)
On-board diagnostics	Yes in accordance with section 8.1	Yes in accordance with section 8.2 and 8.3

(1) The Commission will as soon as possible, but not later than 31 December 1999, propose value limits for Classes II and III, in accordance with the procedure laid down in Article 13 of Directive 70/156/EEC. These value limits shall be applied no later than 2003.

(2) The Commission will study further the question of extending the type-approval test to vehicles in Categories M2 and N2 with a reference mass not exceeding 2 840 kg and put forward proposals no later than 2004 in accordance with the procedure laid down in Article 13 of Directive 70/156/EEC, for measures to be applied in 2005.’

12. Sections 5.2.1 and 5.2.3 are replaced by the following:

‘5.2.1. Positive-ignition engined vehicles must be subject to the following tests:

— Type I (verifying the average tailpipe emissions after a cold start),

— Type II (carbon monoxide emission at idling speed),

— Type III (emission of crankcase gases),

— Type IV (evaporation emissions),

— Type V (durability of anti-pollution control devices),

— Type VI (verifying the average low ambient temperature carbon monoxide and hydrocarbon tailpipe emissions after a cold start,

— OBD-test.’

19. A new section 6.4 is added to read as follows:

‘6.4. **On-board diagnostics**

6.4.1. Approval granted to a vehicle type with respect to the OBD system may be extended to different vehicle types belonging to the same vehicle-OBD family as described in Annex XI, Appendix 2. The engine emission control system must be identical to that of the vehicle already approved and comply with the description of the OBD engine family given in Annex XI, Appendix 2, regardless of the following vehicle characteristics:

— engine accessories,

— tyres,

— equivalent inertia,

— cooling system,

— overall gear ratio,

— transmission type,

— type of bodywork

21. A new title and section 7.1.6 are added to read as follows:

‘***On-board Diagnostics (OBD)***

7.1.6. If a verification of the performance of the OBD system is to be carried out, it must be conducted in accordance with the following:

7.1.6.1. When the approval authority determines that the quality of production seems unsatisfactory a vehicle is randomly taken from the series and subjected to the tests described in Annex XI, Appendix 1.

7.1.6.2. The production is deemed to conform if this vehicle meets the requirements of the tests described in Annex XI, Appendix 1.

7.1.6.3. If the vehicle taken from the series does not satisfy the requirements of section 7.1.6.1 a further random sample of four vehicles must be taken from the series and subjected to the tests described in Annex XI, Appendix 1. The tests may be carried out on vehicles which have been run in for no more than 15 000 km.

7.1.6.4. The production is deemed to conform if at least 3 vehicles meet the requirements of the tests described in Annex XI, Appendix 1.’

24. A new section 8 is added to read as follows:

‘8. ON-BOARD DIAGNOSTIC (OBD) SYSTEM FOR MOTOR VEHICLES

8.1. Vehicles of Category M1 and N1 equipped with positive-ignition engines must be fitted with an onboard diagnostic (OBD) system for emission control in accordance with Annex XI.

8.2. Vehicles of category M1 equipped with compression-ignition engines, except

— vehicles designed to carry more than six occupants including the driver,

— vehicles whose maximum mass exceeds 2 500 kg,

from 1 January 2003 for new types and from 1 January 2004 for all types, must be fitted with an on-board diagnostic (OBD) system for emission control in accordance with Annex XI. Where new types of compression-ingnition engined vehicles entering into service prior to this date are fitted with an OBD system, the provisions of sections 6.5.3 to 6.5.3.5 of Annex XI, Appendix 1, are applicable.

8.3. New types of Category M1 exempted by section 8.2, and new types of vehicles in Category N1 class I equipped with compression-ignition engines, must, from 1 January 2005, be fitted with an on-board diagnostic (OBD) system for emission control in accordance with Annex XI. New types of vehicles in Category N1 Classes II and III equipped with compression-ignition engines must, from 1 January 2006, be fitted with on-board diagnostic (OBD) systems for emission control in accordance with Annex XI.

Where compression-ignition engined vehicles entering into service prior to the dates given in this section are fitted with OBD systems, the provisions of sections 6.5.3 to 6.5.3.5 of Annex XI, Appendix 1, are applicable.

8.4 Vehicles of other Categories

Vehicles of other Categories or vehicles of Category M1 and N1 not covered by 8.1, 8.2 or 8.3, may be fitted with an on-board diagnostic system. In this case, sections sections 6.5.3 to 6.5.3.5 of Annex XI, Appendix 1, are applicable.’

25. New Appendices 3 and 4 are are added as follows:

Appendix 3

IN-SERVICE CONFORMITY CHECK

1. INTRODUCTION

This Appendix sets out the criteria referred to in section 7.1.7 of this Annex regarding the selection of vehicles for testing and the procedures for the in-service conformity control.

2. SELECTION CRITERIA

The criteria for acceptance of a selected vehicle are defined in sections 2.1 to 2.8 of this Appendix. Information is collected by vehicle examination and an interview with the owner/driver.

2.1. The vehicle must belong to a vehicle type that is type-approved under this Directive and covered by a certificate of conformity in accordance with Directive 70/156/EEC. It must be registered and used in the European Community.

2.2. The vehicle must have been in service for at least 15 000 km or 6 months, whichever is the later, and for no more than 80 000 km or 5 years, whichever is the sooner.

2.3. There must be a maintenance record to show that the vehicle has been properly maintained, e. g. has been serviced in accordance with the manufacturer's recommendations.

2.4. The vehicle must exhibit no indications of abuse (e. g. racing, overloading, misfuelling, or other misuse), or other factors (e. g. tampering) that could affect emission performance. In the case of vehicles fitted with an OBD system, the fault code and mileage information stored in the computer are taken into account. A vehicle must not be selected for testing if the information stored in the computer shows that the vehicle has operated after a fault code was stored and a relatively prompt repair was not carried out.

2.5. There must have been no unauthorized major repair to the engine or major repair of the vehicle.

2.6. The lead content and sulphur content of a fuel sample from the vehicle tank must meet applicable standards and there must be no evidence of misfuelling. Checks may be done in the tailpipe, etc.

2.7. There must be no indication of any problem that might jeopardize the safety of laboratory personnel.

2.8. All anti-pollution system components on the vehicle must be in conformity with the applicable type-approval.

3. DIAGNOSIS AND MAINTENANCE

Diagnosis and any normal maintenance necessary must be performed on vehicles accepted for testing, prior to measuring exhaust emissions, in accordance with the procedure laid down in section 3.1 to 3.7.

3.1. The following checks must be carried out: checks on air filter, all drive belts, all fluid levels, radiator cap, all vacuum hoses and electrical wiring related to the antipollution system for integrity; checks on ignition, fuel metering and anti-pollution device components for maladjustments and/or tampering. All discrepancies must be recorded.

3.2. The OBD system shall be checked for proper functioning. Any malfunction indications in the OBD memory must be recorded and the requisite repairs must be carried out. If the OBD malfunction indicator registers a malfunction during a pre-conditioning cycle, the fault may be identified and repaired.
The test may be re-run and the results of that repaired vehicle used.

3.3. The ignition system must be checked and defective components replaced, for example spark plugs, cables, etc.

3.4. The compression must be checked. If the result is unsatisfactory the vehicle is rejected.

3.5. The engine parameters must be checked to the manufacturer's specifications and adjusted if necessary.

3.6. If the vehicle is within 800 km of a scheduled maintenance service, that service must be performed according to the manufacturer's instructions. Regardless of odometer reading, the oil and air filter may be changed at the request of the manufacturer.

3.7. Upon acceptance of the vehicle, the fuel must be replaced with appropriate emission test reference fuel, unless the manufac-turer accepts the use of market fuel.

4. IN-SERVICE TESTING

4.1. When a check on vehicles is deemed necessary, emission tests in accordance with Annex III to this Directive are performed on pre-conditioned vehicles selected in accordance with the requirements of sections 2 and 3 of this Appendix.

4.2. Vehicles equipped with an OBD system may be checked for proper in-service functionality of the malfunction indication, etc., in relation to levels of emissions (e. g. the malfunction indication limits defined in Annex XI to this Directive) for the type-approved specifications.

4.3. The OBD system may be checked, for example, for levels of emissions above the applicable limit values with no malfunction indication, systematic erroneous activation of the malfunction indication and identified faulty or deteriorated components in the OBD system.

4.4. If a component or system operates in a manner not covered by the particulars in the type-approval certificate and/or informa-tion package for such vehicle types and such deviation has not been authorized under Article 5 (3) or (4) of Directive 70/156/ EEC, with no malfunction indication by the OBD, the component or system must not be replaced prior to emission testing, unless it is determined that the component or system has been tampered with or abused in such a manner that the OBD does not detect the resulting malfunction.

ANNEX XI

42. A new Annex XI is added to read as follows:

'*ANNEX XI*

ON-BOARD DIAGNOSTICS (OBD) FOR MOTOR VEHICLES

1. INTRODUTION

This Annex applies to the functional aspects of on-board diagnostic (OBD) system for the emission control of motor vehicles.

2. DEFINITIONS

For the purposes of this Annex:

2.1. 'OBD' means an on-board diagnostic system for emission control which must have the capability of identifying the likely area of malfunction by means of fault codes stored in computer memory.

2.2. 'Vehicle type' means a category of power-driven vehicles which do not differ in such essential engine and OBD system characteristics as defined in Appendix 2.

2.3. 'Vehicle family' means a manufacturer's grouping of vehicles which, through their design, are expected to have similar exhaust emission and OBD system characteristics. Each engine of this family must have complied with the requirements of this Directive.

2.4. 'Emission control system' means the electronic engine manage-ment controller and any emission-related component in the exhaust or evaporative system which supplies an input to or receives an output from this controller.

2.5. 'Malfunction indicator (MI)' means a visible or audible indicator that clearly informs the driver of the vehicle in the event of a malfunction of any emission-related component connected to the OBD system, or the OBD system itself.

2.6. 'Malfunction' means the failure of an emission-related component or system that would result in emissions exceeding the limits in section 3.3.2.

2.7. 'Secondary air' refers to air introduced into the exhaust system by means of a pump or aspirator valve or other means that is intended to aid in the oxidation of HC and CO contained in the exhaust gas stream.

2.8. 'Engine misfire' means lack of combustion in the cylinder of a positive-ignition engine due to absence of spark, poor fuel metering, poor compression or any other cause. In terms of OBD monitoring it is that percentage of misfires out of a total number of firing events (as declared by the manufacturer) that would result in emissions exceeding the limits given in section 3.3.2 or. that percentage that could lead to an exhaust catalyst, or catalysts, overheating causing irreversible damage.

2.9. 'Type I test' means the driving cycle (Parts One and Two) used for emission approvals, as detailed in Annex III, Appendix 1.

2.10. 'A driving cycle' consists of engine start-up, driving mode where a malfunction would be detected if present, and engine shut-off.

2.11. 'A warm-up cycle' means sufficient vehicle operation such that the coolant temperature has risen by a least 22 °K from engine starting and reaches a minimum temperature of 343 °K (70 °C).

2.12. 'Fuel trim' refers to feedback adjustments to the base fuel schedule. Short-term fuel trim refers to dynamic or instanta-neous adjustments. Long-term fuel trim refers to much more gradual adjustments to the fuel calibration schedule than short-term trim adjustments. These long-term adjustments compen-sate for vehicle differences and gradual changes that occur over time.

2.13. 'Calculated load value' refers to an indication of the current airflow divided by peak airflow, where peak airflow is corrected for altitude, if available. This definition provides a dimension-less number that is not engine specific and provides the service technician with an indication of the proportion of engine capacity that is being used (with wide open throttle as 100 %);

$$CLV = \frac{\text{Current airflow}}{\text{Peak airflow (at sea level)}} \times \frac{\text{Atmospheric pressure (at sea level)}}{\text{Barometric pressure}}$$

2.14. 'Permanent emission default mode' refers to a case where the engine management controller permanently switches to a setting that does not require an input from a failed component or system where such a failed component or system would result in an increase in emissions from the vehicle to a level above the limits given in section 3.3.2.

2.15. 'Power take-off unit' means an engine-driven output provision for the purposes of powering auxiliary, vehicle mounted, equipment.

2.16. 'Access' means the availability of all emission-related OBD data including all fault codes required for the inspection, diagnosis, servicing or repair of emissions-related parts of the vehicle, via the serial interface for the standard diagnostic connection (pursuant to Appendix 1, section 6.5.3.5 of this Annex).

2.17. 'Unrestricted' means

— access not dependent on an access code obtainable only from the manufacturer, or a similar device, or

— access allowing evaluation of the data produced without the need for any unique decoding information, unless that information itself is standardised.

2.18. 'Standardised' means that all data stream information, including all fault codes used, shall be produced only in accordance with industry standards which, by virtue of the fact that their format and their permitted options are clearly defined, provide for a maximum level of harmonisation in the motor vehicle industry, and whose use is expressly permitted in this Directive.

2.19 'Repair information' means all information required for diagnosis, servicing, inspection, periodic monitoring or repair of the vehicle and which the manufacturers provide for their authorised dealers/repair shops. Where necessary, such information shall include service handbooks, technical manuals, diagnosis information (e.g. minimum and maximum theoretical values for measurements), wiring diagrams, the software calibration identification number applicable to a vehicle type, instructions for individual and special cases, information provided concerning tools and equipment, data record information and two-directional monitoring and test data. The manufacturer shall not be obliged to make available that information which is covered by intellectual property rights or constitutes specific know-how of manufacturers and/or OEM suppliers; in this case the necessary technical information shall not be improperly withheld.

3. REQUIREMENTS AND TESTS

3.1. All vehicles must be equipped with an OBD system so designed, constructed and installed in a vehicle as to enable it to identify types of deterioration or malfunction over the entire life of the vehicle. In achieving this objective the approval authority must accept that vehicles which have travelled distances in excess of the Type V durability distance, referred to in 3.3.1, may show some deterioration in OBD system performance such that the emission limits given in 3.3.2 may be exceeded before the OBD system signals a failure to the driver of the vehicle.

3.1.1 Access to the OBD system required for the inspection, diagnosis, servicing or repair of the vehicle must be unrestricted and standardised. All emission-related fault codes must be consistent with ISO DIS 15031-6 (SAE J 2012, dated July 1996).

3.1.2. No later than three months after the manufacturer has provided any authorised dealer or repair shop within the Community with repair information, the manufacturer shall make that informa-tion (including all subsequent amendments and supplements) available upon reasonable and non-discriminatory payment and shall notify the approval authority accordingly.
In the event of failure to comply with these provisions the approval authority shall take appropriate measures to ensure that repair information is available, in accordance with the procedures laid down for type-approval and in-service surveys.

3.2. The OBD system must be so designed, constructed and installed in a vehicle as to enable it to comply with the requirements of this Annex during conditions of normal use.

3.2.1. *Temporary disablement of the OBD system*

3.2.1.1. A manufacturer may disable the OBD system if its ability to monitor is affected by low fuel levels. Disablement must not occur when the fuel tank level is above 20 % of the nominal capacity of the fuel tank.

3.2.1.2. A manufacturer may disable the OBD system at ambient engine starting temperatures below 266 °K (-7 °C) or at elevations over 2 500 metres above sea level provided the manufacturer submits data and/or an engineering evaluation which adequately demonstrate that monitoring would be unreliable when such conditions exist. A manufacturer may also request disablement of the OBD system at other ambient engine starting temperatures if he demonstrates to the authority with data and/or an engineering evaluation that misdiagnosis would occur under such conditions.

3.2.1.3. For vehicles designed to accommodate the installation of power take-off units, disablement of affected monitoring systems is permitted provided disablement occurs only when the power take-off unit is active.

3.2.2. *Engine misfire — vehicles equipped with positive-ignition engines*

3.2.2.1. Manufacturers may adopt higher misfire percentage malfunction criteria than those declared to the authority, under specific engine speed and load conditions where it can be demonstrated to the authority that the detection of lower levels of misfire would be unreliable.

3.2.2.2. Manufacturers who can demonstrate to the authority that the detection of higher levels of misfire percentages is still not feasible may disable the misfire monitoring system when such conditions exist.

3.3. **Description of tests**

3.3.1. The test are carried out on the vehicle used for the Type V durability test, given in Annex VIII, and using the test procedure in Appendix I to this Annex. Tests are carried out at the conclusion of the Type V durability testing. When no Type V durability testing is carried out, or at the request of the manufacturer, a suitably aged and representative vehicle may be used for these OBD demonstration tests.

3.3.2. The OBD system must indicate the failure of an emission-related component or system when that failure results in an increase in emissions above the limits given below:

		Reference Mass	Mass of Carbon Dioxide		Mass of hydrocarb ons		Mass of oxides of nitrogen		Mass of Particulate (1)
		(RW) (kg)	(CO) L1 (g/km)		(HC) L2 (g/km)		(NOx) L3 (g/km)		(PM) L4 (g/km)
Category	Class		Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Diesel
M (2)	-	All	3.2	3.2	0.4	0.4	0.6	1.2	0.18
N1 (3) (4)	I	RW<1305	3.2	3.2	0.4	0.4	0.6	1.2	0.18
	II	1305<RW <1760	5.8	4	0.5	0.5	0.7	1.6	0.23
	III	1760<RW	7.3	4.8	0.6	0.6	0.8	1.9	0.28

(1) For compression ignition engines.
(2) Except vehicles the maximum mass of which exceeds 2 500 kg.
(3) And those Category M vehicles which are specified in note 2.
(4) The Commission proposal referred to in Article 3(1) of this Directive shall contain the threshold limit values for OBD for 2005/6 for M1 and N1 vehicles.

3.3.3. *Monitoring requirements for vehicles equipped with positive-ignition engines*

In satisfying the requirements of 3.3.2 the OBD system must, at a minimum, monitor for:

3.3.3.1. reduction in the efficiency of the catalytic converter with respect to the emissions of HC only;

3.3.3.2. the presence of engine misfire in the engine operating region bounded by the following lines:

(a) a maximum speed of 4 500min _1 or 1 000 min _1 greater than the highest speed occurring during a Type I test cycle, whichever is the lower;

(b) the positive torque line (i. e. engine load with the transmission in neutral);

(c) a line joining the following engine operating points: the positive torque line at 3 000 min _1 and a point on the maximum speed line defined in (a) above with the engine's manifold vacuum at 13,33 kPa lower than that at the positive torque line.

3.3.3.3. oxygen sensor deterioration

3.3.3.4. other emission control system components or systems, or emission-related powertrain components or systems which are connected to a computer, the failure of which may result in tailpipe emissions exceeding the limits given in 3.3.2;

3.3.3.5. any other emission-related powertrain component connected to a computer must be monitored for circuit continuity;

3.3.3.6. the electronic evaporative emission purge control must, at a minimum, be monitored for circuit continuity.

3.3.4. *Monitoring requirements for vehicles equipped with compres-sion-ignition engines*

In satisfying the requirements of 3.3.2 the OBD system must monitor:

3.3.4.1. Where fitted, reduction in the efficiency of the catalytic converter;

3.3.4.2. Where fitted, the functionality and integrity of the particulate trap;

3.3.4.3. The fuel-injection system electronic fuel quantity and timing actuator(s) is/are monitored for circuit continuity and total functional failure;

3.3.4.4. Other emission control system components or systems, or emission-related powertrain components or systems, which are connected to a computer, the failure of which may result in tailpipe emissions exceeding the limits given in 3.3.2. Examples of such systems or components are those for monitoring and control of air mass-flow, air volumetric flow (and temperature), boost pressure and inlet manifold pressure (and relevant sensors to enable these functions to be carried out).

3.3.4.5. Any other emission-related powertrain component connected to a computer must be monitored for circuit continuity.

3.3.5. Manufacturers may demonstrate to the approval authority that certain components or systems need not be monitored if, in the event of their total failure or removal, emissions do not exceed the emission limits given in 3.3.2.

3.4. A sequence of diagnostic checks must be initiated at each engine start and completed at least once provided that the correct test conditions are met. The test conditions must be selected in such a way that they all occur under normal driving as represented by the Type I test.

3.5. **Activation of malfunction indicator (MI)**

3.5.1. The OBD system must incorporate a malfunction indicator readily perceivable to the vehicle operator. The MI must not be used for any other purpose except to indicate emergency start-up or limp-home routines to the driver. The MI must be visible in all reasonable lighting conditions. When activated, it must display a symbol in conformity with ISO 2575 ([1]). A vehicle must not be equipped with more than one general purpose MI for emission-related problems. Separate specific purpose tell-tales (e. g. brake system, fasten seat belt, oil pressure, etc.) are permitted. The use of red for an MI is prohibited.

3.5.2. For strategies requiring more than two preconditioning cycles for MI activation, the manufacturer must provide data and/or an

[1] International Standard ISO 2575-1982 (E), entitled 'Road vehicles — Symbols for controls indicators and tell-tales', Symbol Number 4.36.

engineering evaluation which adequately demonstrates that the monitoring system is equally effective and timely in detecting component deterioration. Strategies requiring on average more than 10 driving cycles for MI activation are not accepted. The MI must also activate whenever the engine control enters a permanent emission default mode of operation if the emission limits given in 3.3.2 are exceeded. The MI must operate in a distinct warning mode, e. g. a flashing light, under any period during which engine misfire occurs at a level likely to cause catalyst damage, as specified by the manufacturer. The MI must also activate when the vehicle's ignition is in the 'key-on' position before engine starting or cranking and de-activate after engine starting if no malfunction has previously been detected.

3.6. **Fault code storage**

The OBD system must record code(s) indicating the status of the emission-control system. Separate status codes must be used to identify correctly functioning emission control systems and those emission control systems which need further vehicle operation to be fully evaluated. Fault codes that cause MI activation due to deterioration or malfunction or permanent emission default modes of operation must be stored and that fault code must identify the type of malfunction.

3.6.1. The distance travelled by the vehicle since the MI was activated must be available at any instant through the serial port on the standard link connector ([1]).

3.6.2. In the case of vehicles equipped with positive-ignition engines, misfiring cylinders need not be uniquely identified if a distinct single or multiple cylinder misfire fault code is stored.

3.7. **Extinguishing the MI**

3.7.1. For misfire malfunctions at levels likely to cause catalyst damage (as specified by the manufacturer), the MI may be switched to the normal mode of activation if the misfire is not present any more, or if the engine is operated after changes to speed and load conditions where the level of misfire will not cause catalyst damage.

3.7.2. For all other malfunctions, the MI may be de-activated after three subsequent sequential driving cycles during which the monitoring system responsible for activating the MI ceases to detect the malfunction and if no other malfunction has been identified that would independently activate the MI.

3.8. **Erasing a fault code**

3.8.1. The OBD system may erase a fault code and the distance

[1] This requirement is only applicable to vehicles with an electronic speed input to the engine management provided the ISO standards are completed within a lead time compatible with the application of the technology. It applies to all vehicles entering into service from 1 January 2005.

travelled and freeze-frame information if the same fault is not re-registered in at least 40 engine warm-up cycles.

Appendix 1

FUNCTIONAL ASPECTS OF ON-BOARD DIAGNOSTIC (OBD) SYSTEMS

1. INTRODUCTION

This Appendix describes the procedure of the test according to section 5 of this Annex. The procedure describes a method for checking the function of the on-board diagnostic (OBD) system installed on the vehicle by failure simulation of relevant systems in the engine management or emission control system. It also sets procedures for determining the durability of OBD systems.

The manufacturer must make available the defective components and/or electrical devices which would be used to simulate failures. When measured over the Type I test cycle, such defective components or devices must not cause the vehicle emissions to exceed the limits of section 3.3.2 by more than 20 %.

When the vehicle is tested with the defective component or device fitted, the OBD system is approved if the MI is activated.

2. DESCRIPTION OF TEST

2.1. The testing of OBD systems consists of the following phases:

— simulation of malfunction of a component of the engine management or emission control system,

— preconditioning of the vehicle with a simulated malfunction over preconditioning specified "**C1** in section 6.2

— driving the vehicle with a simulated malfunction over the Type I test cycle and measuring the emissions of the vehicle,

— determining whether the OBD system reacts to the simulated malfunction and indicates malfunction in an appropriate manner to the vehicle driver.

2.2. Alternatively, at the request of the manufacturer, malfunction of one or more components may be electronically simulated according to the requirements of section 6.

2.3. Manufacturers may request that monitoring take place outside the Type I test cycle if it can be demonstrated to the authority that monitoring during conditions encountered during the Type I test cycle would impose restrictive monitoring conditions when the vehicle is used in service.

3. TEST VEHICLE AND FUEL

3.1. **Vehicle**
The test vehicle must meet the requirements of section 3.1 of Annex III.

3.2. **Fuel**
The appropriate reference fuel as described in Annex IX must be used for testing.

4. TEST TEMPERATURE AND PRESSURE

4.1. The test temperature and pressure must meet the requirements of the Type I test as described in Annex III.

5. TEST EQUIPMENT

5.1 Chassis dynamometer

The chassis dynamometer must meet the requirements of Annex III.

6. OBD TEST PROCEDURE

6.1. The operating cycle on the chassis dynamometer must meet the requirements of Annex III.

6.2. **Vehicle preconditioning**

6.2.1. According to the engine type and after introduction of one of the failure modes given in 6.3, the vehicle must be preconditioned by driving at least two consecutive Type I tests (Parts One and Two). For compression-ignition engined vehicles an additional preconditioning of two Part Two cycles is permitted.

6.2.2. At the request of the manufacturer, alternative preconditioning methods may be used.

6.3. **Failure modes to be tested**

6.3.1. *Positive-ignition engined vehicles:*

6.3.1.1. Replacement of the catalyst with a deteriorated or defective catalyst or electronic simulation of such a failure.

6.3.1.2. Engine misfire conditions according to the conditions for misfire monitoring given in section 3.3.3.2 of this Annex.

6.3.1.3. Replacement of the oxygen sensor with a deteriorated or defective oxygen sensor or electronic simulation of such a failure.

6.3.1.4. Electrical disconnection of any other emission-related component connected to a powertrain management computer.

6.3.1.5. Electrical disconnection of the electronic evaporative purge control device (if equipped). For this specific failure mode, the Type I test must not be performed.

6.3.2. *Compression-ignition engined vehicles:*

6.3.2.1. Where fitted, replacement of the catalyst with a deteriorated or defective catalyst or electronic simulation of such a failure.

6.3.2.2. Where fitted, total removal of the particulate trap or, where sensors are an integral part of the trap, a defective trap assembly.

6.3.2.3. Electrical disconnection of any fuelling system electronic fuel quantity and timing actuator.

6.3.2.4. Electrical disconnection of any other emission-related compo-nent connected to a powertrain management computer.

6.3.2.5. In meeting the requirements of 6.3.2.3 and 6.3.2.4, and with the agreement of the approval authority, the manufacturer must take appropriate steps to demonstrate that the OBD system will indicate a fault when disconnection occurs.

6.4. **OBD system test**

6.4.1. *Vehicles fitted with positive-ignition engines:*

6.4.1.1. After vehicle preconditioning according to 6.2, the test vehicle is driven over a Type I test (Parts One and Two). The MI must activate before the end of this test under any of the conditions given in 6.4.1.2 to 6.4.1.5. The technical service may substitute those conditions by others in accordance with 6.4.1.6. However, the total number of failures simulated must not exceed 4 for the purpose of type-approval.

6.4.1.2. Replacement of a catalyst with a deteriorated or defective catalyst or electronic simulation of a deteriorated or defective catalyst that results in emissions exceeding the HC limit given in section 3.3.2 of this Annex.

6.4.1.3. An induced misfire condition according to the conditions for misfire monitoring given in section 3.3.3.2 of this Annex that results in emissions exceeding any of the limits given in 3.3.2.

6.4.1.4. Replacement of an oxygen sensor with a deteriorated or defective oxygen sensor or electronic simulation of a deterio-rated or defective oxygen sensor that results in emissions exceeding any of the limits given in section 3.3.2 of this Annex.

6.4.1.5. Electrical disconnection of the electronic evaporative purge control device (if equipped).

6.4.1.6. Electrical disconnection of any other emission-related power-train component connected to a computer that results in emissions exceeding any of the limits given in section 3.3.2 of this Annex.

6.4.2. *Vehicles fitted with compression-ignition engines:*

6.4.2.1. After vehicle preconditioning according to 6.2, the test vehicle is driven over a Type I test (Parts One and Two). The MI must activate before the end of this test under any of the conditions given in 6.4.2.2 to 6.4.2.5. The technical service may substitute those conditions by others in accordance with 6.4.2.5. However, the total number of failures simulated must not exceed four for the purposes of type approval.

6.4.2.2. Where fitted, replacement of a catalyst with a deteriorated or defective catalyst or electronic simulation of a deteriorated or defective catalyst that results in emissions exceeding limits given in section 3.3.2 of this Annex.

6.4.2.3. Where fitted, total removal of the particulate trap or replacement of the particulate trap with a defective particulate trap meeting the conditions of 6.3.2.2 that results in emissions exceeding the limits given in section 3.3.2 of this Annex.

6.4.2.4. With reference to 6.3.2.5, disconnection of any fuelling system electronic fuel quantity and timing actuator that results in emissions exceeding any of the limits given in section 3.3.2 of this Annex.

6.4.2.5. With reference to 6.3.2.5, disconnection of any other emission-related powertrain component connected to a computer that results in emissions exceeding any of the limits given in section 3.3.2 of this Annex.

6.5. **Diagnostic signals**

6.5.1.1. Upon determination of the first malfunction of any component or system, ‘freeze-frame’ engine conditions present at the time must be stored in computer memory. Should a subsequent fuel system or misfire malfunction occur, any previously stored freeze-frame conditions must be replaced by the fuel system or misfire conditions (whichever occurs first). Stored engine conditions must include, but are not limited to calculated load value, engine speed, fuel trim value(s) (if available), fuel pressure (if available), vehicle speed (if available), coolant temperature, intake manifold pressure (if available), closed- or open-loop operation (if available) and the fault code which caused the data to be stored. The manufacturer must choose the most appropriate set of conditions facilitating effective repairs for freeze-frame storage. Only one frame of data is required. Manufacturers may choose to store additional frames provided that at least the required frame can be read by a generic scan tool meeting the specifications of 6.5.3.2 and 6.5.3.3. If the fault code causing the conditions to be stored is erased in accordance with section 3.7 of this Annex, the stored engine conditions may also be erased.

6.5.1.2. If available, the following signals in addition to the required freeze-frame information must be made available on demand through the serial port on the standardized data link connector, if the information is available to the on-board computer or can be determined using information available to the on-board computer: diagnostic trouble codes, engine coolant temperature, fuel control system status (closed-loop, open-loop, other), fuel trim, ignition timing advance, intake air temperature, manifold air pressure, air flow rate, engine speed, throttle position sensor output value, secondary air status (upstream, downstream or atmosphere), calculated load value, vehicle speed and fuel pressure.

The signals must be provided in standard units based on the specifications given in 6.5.3. Actual signals must be clearly identified separately from default value or limp-home signals. In addition, the capability to perform bi-directional diagnostic control based on the specifications given in 6.5.3 must be made available on demand through the serial port on the standardized data link connector according to the specifications given in 6.5.3.

6.5.1.3. For all emission control systems for which specific on-board evaluation tests are conducted (catalyst, oxygen sensor, etc.), except misfire detection, fuel system monitoring and comprehensive component monitoring, the results of the most recent test performed by the vehicle and the limits to which the system is compared must be made available through the serial data port on the standardized data link connector according to the specifications given in 6.5.3. For the monitored components and systems excepted above, a pass/fail indication for the most recent test results must be available through the data link connector.

6.5.1.4. The OBD requirements to which the vehicle is certified (i. e. this Annex or the alternative requirements specified in section 5 of Annex I) and the major emission control systems monitored by the OBD system consistent with 6.5.3.3 must be available through the serial data port on the standardized data link connector according to the specifications given in 6.5.3.

6.5.2. The emission control diagnostic system is not required to evaluate components during malfunction if such evaluation would result in a risk to safety or component failure.

6.5.3. The emission control diagnostic system must provide for standardised and unrestricted access and conform with the following ISO and/or SAE standards. Some of the ISO standards have been derived from Society of Automotive Engineers Standards and Recommended Practices. Where this is the case, the appropriate SAE reference appears in parentheses.

6.5.3.1. One of the following standards with the restrictions as described must be used as the on-board to off-board communications link:

ISO 9141-2 ‘Road Vehicles — Diagnostic Systems — CARB Requirements for the Interchange of Digital Information’;

ISO 11519-4 ‘Road Vehicles — Low Speed Serial Data Communication — Part 4: Class B Data Communication Interface (SAE J1850)’. Emission-related messages must use the cyclic redundancy check and the three-byte header and not use inter-byte separation or checksums.

ISO DIS 14230 — Part 4 'Road Vehicles — Diagnostic Systems — Keyword Protocol 2000'.

6.5.3.2. Test equipment and diagnostic tools needed to communicate with OBD systems must meet or exceed the functional specification given in ISO DIS 15031-4.

6.5.3.3. Basic diagnostic data, (as specified in 6.5.1) and bi-directional control information must be provided using the format and units described in ISO DIS 15031-5 and must be available using a diagnostic tool meeting the requirements of ISO DIS 15031-4.

6.5.3.4. When a fault is registered, the manufacturer must identify the fault using the most appropriate fault code consistent with those given in section 6.3 of ISO DIS 15031-6 (SAE J2012 — dated July 1996), relating to '… Powertrain system diagnostic trouble codes'. The fault codes must be fully accessible by standardized diagnostic equipment complying with the provisions of 6.5.3.2.

The note in section 6.3 of ISO DIS 15031-6 (SAE J2012 — dated July 1996) immediately preceding the list of fault codes in the same section does not apply.

6.5.3.5. The connection interface between the vehicle and the diagnostic tester must meet all the requirements of ISO DIS 15031-3. The installation position must be subject to agreement of the approval authority such that it is readily accessible by service personnel but protected from tampering by non-qualified personnel.

6.5.3.6. The manufacturer must also make accessible, where appropriate upon payment, to repairers who are not undertakings within the distribution system, the technical information required for the repair or maintenance of motor vehicles unless that information is covered by an intellectual property right or constitutes essential, secret know-how which is identified in an appropriate form; in such case, the necessary technical information must not be withheld improperly.

Appendix 2

ESSENTIAL CHARACTERISTICS OF THE VEHICLE FAMILY

1. PARAMETERS DEFINING THE OBD FAMILY

The OBD family may be defined by basic design parameters which must be common to vehicles within the family. In some cases there may be interaction of parameters. These effects must also be taken into consideration to ensure that only vehicles with similar exhaust emission characteristics are included within an OBD family.

2. To this end, those vehicle types whose parameters described below are identical are considered to belong to the same engine-emission

control/OBD system combination.

Engine:

— combustion process (i. e. positive-ignition, compression-ignition, two-stroke, four-stroke),

— method of engine fuelling (i. e. carburettor or fuel injection).

Emission control system:

— type of catalytic converter (i. e. oxidation, three-way, heated catalyst, other),

— type of particulate trap,

— secondary air injection (i. e. with or without),

— exhaust gas recirculation (i. e. with or without)

OBD parts and functioning:

— the methods of OBD functional monitoring, malfunction detection and malfunction indication to the vehicle driver.'

Appendix 2 Further information on sensors and diagnostic strategies

Contents

Further technical details about zirconia oxygen sensors

Strategies for monitoring catalyst activity

Strategies for monitoring misfire

Appendix 2 Further information on sensors and diagnostic strategies

FURTHER TECHNICAL DETAILS ABOUT ZIRCONIA OXYGEN SENSORS

Zirconia oxygen sensors require temperatures of at least 350°C to operate. To achieve this temperature more quickly (and allow fuelling control to be under closed loop feedback control from the oxygen sensor) most sensors have heaters built into them. Another advantage of the sensors having an in-built heater is that they can be located further down exhaust stream. This improves their durability by making them less susceptible to thermal excursions within the vehicle's exhaust. Oxygen sensor light-off times are typically about 20 seconds. There are some planar sensors in development that can light off in 10-15 sec.

Oxygen sensors control AFR to within +/- 2% at steady state. Transients are not so good due to fuel film build up in the inlet manifold, which also occur when the engine is cold.
Their response time is in the order of 30-50 ms.

Diagnostic strategies for the detection of oxygen sensor deterioration
The ECU will monitor the oxygen sensor voltage output (and consequently the oxygen concentration in the exhaust before the catalyst) against stored values to derive diagnostic information. Some of the parameters monitored are

- Rich to lean threshold voltage
- Lean to rich threshold voltage
- Low sensor voltage for switch time calculation
- High sensor voltage for switch time calculation
- Rich to lean sensor switch time
- Lean to rich sensor switch time
- Minimum sensor voltage for test cycle
- Maximum sensor voltage for test cycle
- Time between sensor transitions

The result is averaged over a manufacturer specified number of cycles and compared with a threshold value. If this value is exceeded, a fault code is stored. If the threshold is exceeded in the next set of averaged cycles, the MIL will be illuminated.

Oxygen sensor failure and error modes.
The vehicle's exhaust can in some fault conditions become hot enough to melt the oxygen sensor, thereby causing it to fail.

Circuit Failure.
Electrical connectors can fail in the harsh environments of the sensor and the vehicle's wiring loom.

Sensor heater element failure.
Inadequate heating reduces the signal amplitude of the oxygen sensor and changes the voltage/oxygen concentration calibration characteristics. Consequently for a "cool" oxygen sensor the start of closed loop operation will be delayed and emissions will increase during operation. Control circuits are monitored by the ECU and compared against stored values. Test sequence values outside threshold limits will results in a fault code being recorded.

Poisoning.
Contaminated air on the reference side of the electrode, leaded fuel, and rich mixture can contaminate the oxygen sensor. Using silicon spray during sensor installation can also cause problems. Contamination may be temporary resulting in many returned sensors performing normally when tested.

STRATEGIES FOR MONITORING CATALYST ACTIVITY

In Section xy in the main body of the report it was noted that the ability of the catalyst to operate efficiently is dependent on it maintaining a sufficient oxygen storage capacity and the engine's control system providing both the correct range of lambda and at the right frequency. This forms the basis for the most widely used strategy for monitoring catalyst activity. Fluctuations in the feed gas air/fuel ratio will be damped by the catalyst's OSC downstream of the catalyst. Comparison of the pre- and post-catalyst oxygen sensor signals is used to derive the OSC of the catalyst. The problem is obtaining sufficient correlation between OSC and catalyst efficiency under normal driving conditions.

The reason for this problem is that catalyst deterioration is due to either
- Loss of OSC (mainly due to thermal ageing).
- Loss of surface area (mainly due to poison deposition).

The two mechanisms cannot be directly correlated and the quantification of OSC does not measure directly loss of activity due to poisoning.

Studies have shown that increases in HC emissions correlate better to loss of catalyst surface area than OSC. However, the correlation of OBD index with HC emissions has high uncertainty and depends on
- The type of emission control system.
- The type of catalyst.
- Vehicle history (thermal loading).
- Fuelling (poison build up from Sulphur and additives).
- Accuracy and repeatability of OSC measurement (response and deterioration of λ sensors)
- Accuracy and repeatability of HC emissions measurement in Type Approval test.

Clearly, there is scope for improvements in the diagnosis of catalyst activity. One strategy being researched is the use of thermal sensing to measure the temperature differential caused by the exothermic reactions in catalytic converter. The attraction of this approach is that it measures catalytic conversion directly. However, these sensors will need high stability and short response times for this application. Cost and durability are issues at present.

Another possibility is to use HC sensors based on HC 's ionising in contact with hot metallic surfaces. As yet this sensor technology is also at the R&D stage. There are practicality, cost and durability issues to be addressed before this could be widely used.

STRATEGIES FOR MONITORING MISFIRE

In the main body of the report is was described how an engine misfiring for about 2% of the time can raise emissions by up to 50% whilst if engine misfire occurs in excess of about 17% of the time catalyst damage will occur. This accounts for the importance of identifying misfire to keep emission low (both short and medium term). Five strategies for achieving this were listed, and will not be described in more detail.

Crank speed fluctuation
The presence of a misfire results in the absence of a power stroke. This temporarily interrupts the provision of power by the engine to the vehicle and causes a discontinuity in the crank shaft's velocity (starting with a deceleration). The detection of this can form the basis for misfire monitoring. The technique has its challenges, vis:
- the accuracy is very dependent on the algorithms used for signal analysis,
- detection is very difficult for light load high engine speed, and
- monitoring is disabled during poor road conditions or rapid clutch engagement.

Ionising Current Monitoring
In this strategy the spark plug is used as an electrode and the ion current is monitored. If no ion generating flame is produced by the spark, no current flows through the measurement circuit during the "power" stroke of the cycle. This ion current/time trace is quite different from that observed for a cycle when normal combustion occurs. This strategy is reported to have proved 100% effective at monitoring for misfires on dynamometer based tests.

Exhaust pressure analysis.
this involves using a pressure sensor in exhaust manifold combined with Fourier analysis as the first stage of the signal processing. It can detect single misfires and it is possible to identify which cylinder is misfiring. This strategy has been demonstrated to detect all misfires up to 6000rpm for all engine configurations, loads, and fuels. It uses a ceramic capacitive sensor which has a short response time and good durability.

Cylinder pressure sensing.
This potential future technology for misfire detection gives good information on knock, misfire, peak pressure location, and combustion quality. However, the sensors are expensive and, as yet, are not sufficiently durable for production.

Magnetostrictive sensing analysis.
This possible future strategy induces an electric field in the engine crankshaft to measure engine stress fluctuations. It is at the start of its development and at present the response is poor, with a noisy signal.

Appendix 3
Scan tools and associated protocols

Contents

Readiness codes

Fault codes

Scan tool to EOBD system connector

Appendix 3 Scan tools and associated protocols

Readiness codes

ISO DIS 15031-5 (in its Appendix B) specifies that in Mode 1 eleven systems may be monitored (detailing the binary bits to be set for each, including encoding to indicate if the system is fitted/active). Three systems are listed as being continuously monitored: misfire, fuel trim and comprehensive components. The other eight systems are monitored after the EOBD driving cycle. Most European vehicles have four of these eight systems monitored: catalyst, evaporative system, oxygen sensors and oxygen sensor heaters, whilst EGR, air conditioning, secondary air injection and heated catalyst are more vehicle specific.

The scan tool displays whether a test routine has been run on each of the 11 systems. Each system can be in one of three states:

- Ready (test in question has been run)
- Not ready (test not yet run)
- Not applicable (system not fitted to that vehicle)

Fault codes

Example of Diagnostic Trouble Code.

P1260

P Powertrain
B Body
C Chassis

0 Standardised code (ISO/SAE)
1 Manufacturer specific code

System number
0 Overall system
1 Secondary Air Injection system
2 Fuel system
3 Ignition system/ Misfire
4 Exhaust gas monitoring
5 Idle speed control/ Cruise control
6 Input/Output signals from control units
7 Transmission

Identification numbers of individual component or system.
Hence P1260 reveals the EOBD system has detected a powertrain fault, within the fuel system, and the engineer should refer to the manufacturer's manual to find out what their specific code 60 indicates, and the rectification procedure.

Scan tool to EOBD system connector

The Assignment of each pin is standardized in SAE J1962. ISO 15031-3 adds a CAN connection. The table below shows the different plug contacts.

Table 1 – Assignment of pins

Pin	ISO 15031-3	SAE J 1962
1	Manufacturer specific	Manufacturer specific
2	+J1850	+J1850
3	Manufacturer specific	Manufacturer specific
4	Chassis -	Chassis -
5	Signal -	Signal -
6	CAN H	Manufacturer specific
7	K-Line	K-Line
8	Manufacturer specific	Manufacturer specific
9	Manufacturer specific	Manufacturer specific
10	-J1850	-J1850
11	Manufacturer specific	Manufacturer specific
12	Manufacturer specific	Manufacturer specific
13	Manufacturer specific	Manufacturer specific
14	CAN L	Manufacturer specific
15	L-Line	L-Line
16	+ UBat	+Ubat