LAT / AUTh

The Inspection of In-Use Cars in Order to Attain Minimum Emissions of Pollutants and Optimum Energy Efficiency

Main Report

May 1998

Project funded by the European Commission

Directorate Generals for Environment (DG XI),
Transport (DG VII) and Energy (DG XVII)

The Inspection of In-Use Cars in Order to Attain Minimum Emissions of Pollutants and Optimum Energy Efficiency

by

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Preface

This project was jointly sponsored by the Directorate Generals for the Environment (DGXI), Transport (DG VII) and Energy (DG XVII) of the European Commission and it is entitled "Inspection of In-Use Cars in Order to Attain Minimum Emissions of Pollutants and Optimum Energy Efficiency". LAT/AUTH (Greece) -the coordinator of the consortium -, INRETS (France), TNO (The Netherlands), TÜV Rheinland (Germany) and TRL (United Kingdom) jointly undertook the project. Moreover, three other institutes collaborated with the consortium, on the basis of nationally sponsored projects: MTC (Sweden), IVL (Sweden) and VKM-Thd (Austria).

This is the main report of the project. It summarises a series of detailed reports and provides the basic conclusions of the work. The detailed reports on which this report is based are the following:

1. **REVIEW OF SHORT TESTS**, by LAT/AUTH, LAT Report 9502, Thessaloniki 1995.
2. **DEVELOPMENT OF SHORT DRIVING CYCLES**, by INRETS and TÜV, Lyon, 1995.
3. **TEST PROTOCOLS AND RESULTS**, by INRETS, Lyon 1998.
4. **TECHNICAL SPECIFICATIONS FOR TRANSIENT SHORT TESTS**, by TÜV, Cologne 1998.
5. **SHORT TEST EVALUATION**, by LAT/AUTH, Thessaloniki 1998.
6. **REMOTE SENSING**, by TRL, Crawthorn, 1998.
7. **COST EFFECTIVENESS OF I/M**, by TNO, Delft 1998.

1. Introduction

1.1 Objectives

An Inspection and Maintenance (I/M) program aims to ensure that motor vehicle emission control systems are functioning properly throughout the lifetime of the vehicle. Hence it is by definition a large-scale project which involves, apart from national and local authorities and inspection stations, all car owners. Therefore it can only be effective if it is technically sound, socially acceptable and not too costly. Among these features, the technical aspects (which one can group under the name "test procedures") are crucial and have to be considered carefully before one or more proposals are made. These test procedures have to be relatively simple, of short duration and of low cost. In addition, they have also to yield reliable results, especially when compared with the emissions of the car, as measured according to the legislated cycles, as well as according to other cycles more representative of the real life conditions.

Basic aim of the project was to investigate and develop a series of alternative solutions of well-documented cost/effectiveness for the inspection of passenger cars in terms of their actual emissions and fuel consumption. Especially in the case of three-way catalyst (TWC) and diesel vehicles it was felt necessary to investigate procedures, which in theory have a larger potential in detecting wrong engine and/or catalyst, related settings and eventual defective components. In this respect it was examined if emission measurements under load may be better at identifying faults than measurements at idle speed. For each particular solution, its cost was assessed in detail (covering installation and operation) and its effectiveness estimated as anticipated reduction in the actual and future emissions of the fleet, on the basis of measured data.

However, the real effects of any I/M programme depend directly on the frequency of the periodic inspection (i.e. the intervals in which the car has to be checked). It is evident though that it is not known what happens to the emissions of the car during these intervals. Recent measurements of real life vehicle emissions have shown that the effects strongly depend on the ability of the system to identify at earlier stages (i.e. before the mandatory inspection) the gross polluters and to "eliminate" them from the actual usage. To this aim, the possibility of using remote sensing techniques in order to identify the high emitters was also investigated, not as means for legislation, but merely as a means of tracing the results of an enacted I/M system.

The major objectives of the study are summarised below:

- To review a large set of short tests for the in-use passenger cars, which inspection centres could perform in the near future. Such tests were found in the international literature (national regulations included) or proposed by the study team.
- To study the performance of these short tests in terms of identification possibilities of high emitting cars. The results of the short tests performed will be compared to the emission levels as measured according to both European legislated and representative driving cycles.
- To study the performance of one remote sensing technique, especially when coupled to short tests.

- To study and quantify the likely impact of vehicle maintenance on the global emissions of car fleets across Europe and the ability of the short tests to verify the effectiveness of maintenance.
- To study the technical, human and financial conditions of each test.
- To propose a set of short tests for the European legislation, chosen to be technically feasible and environmentally effective.

The focus is on catalyst equipped cars of the current technology, as they will constitute the major part of the fleet in the turn of the century, i.e. when it is envisaged to introduce enhanced I/M schemes at European level as well. Nevertheless, both conventional spark-ignition and diesel cars are also covered by the study.

1.2 Duration

The project was completed in three phases (starting in August 1994) as follows:

Phase I: August 1994 to September 1995 (EC Contracts: B4-3040/94/000107/MAR/B3, B4-1031/94/000782 and B2-7040/94/002248)[1]

Phase II: January 1996 to December 1996 (EC Contracts: B4-3040/95/000492/MAR/D3, B2-7040/95/004055, B4-1031/95/002118)[2]

Phase III: September 1997 to April 1998 (EC Contract: B4-3040/97/000305/MAR/D3)

[1] LAT/AUTH, INRETS, TNO, TüV, TRL (1995): Inspection of In-Use Cars in Order to Attain Minimum Emissions of Pollutants and Optimum Energy Efficiency - Phase 1, Final Report to the EC, EC Study Contracts B4-3040/94/000107/MAR/B3, B4-1031/94000782, B2-7040/94/002248, Thessaloniki, Greece

[2] LAT/AUTH, INRETS, TNO, TüV, TRL (1996): Inspection of In-Use Cars in Order to Attain Minimum Emissions of Pollutants and Optimum Energy Efficiency - Phase 2, Final Report to the EC, EC Study Contracts B4-3040/95/000492/MAR/D3, B4-1031/95/002118, B2-7040/95/004055, Thessaloniki, Greece.

2. I/M Worldwide

2.1 Short tests for exhaust emissions

According to the available literature the short tests which have been so far developed in the United States and Europe for exhaust emission testing can be classified in three major categories: (a) no-load, (b) steady-state loaded and (c) transient loaded short tests.

2.1.1 No-Load Short Tests

The term denotes all tests during which no external load is exerted and the car operates with the transmission in neutral position.

Idle / fast idle test

The test involves carbon monoxide (CO), hydrocarbons (HC) and eventually carbon dioxide (CO_2) concentration measurements in the raw exhaust gas at idle speed and/or a higher engine speed (2000 ÷ 3000 rpm). The test could last from less than one minute in the case of a one-speed idle test without pre-conditioning to about 10 minutes in the case of a two-speed test with "second chance" test including pre-conditioning (Pucher 1989, Tierney et al. 1991, Laurikko 1994). A garage-type non-dispersive infrared (NDIR) analyser capable of measuring CO, HC and CO_2 concentrations is sufficient.

Today idle / fast idle tests are still widely used tests in I/M programs because they are the fastest, cheapest and easiest to perform with the minimum possible testing equipment. For carburetted cars they could effectively identify malfunctioning mixture preparation systems of by checking the performance of the carburettor's idle mixture orifice in the idle test and the main fuel-metering orifice in the fast idle test. However, modern cars equipped with electronic fuel injection and ignition systems and three-way catalysts may have a defect (such as defective sensors and degraded catalyst efficiency - Pidgeon et al. 1991, Richter et al. 1993) that cannot be detected through their pollutant emissions at idle; even worse, the great bulk of emissions may be generated during transient engine operation. An additional drawback is the negligible amount of NOx emissions at idle.

Idle / fast idle tests with lambda test

For catalyst equipped cars a lambda test may be coupled with an idle / fast idle test in order to check the performance of the mixture preparation system. Three types of tests can be performed:

1. The air/fuel ratio is indirectly determined through measurement of CO_2, CO, O_2 and HC concentrations at fast idle (2000 ÷ 3000 rpm) in the raw exhaust (Pucher 1989, Richter et al. 1993).
2. The air/fuel ratio is artificially modified by adding oxygen, propane or recirculated exhaust gas to the intake air, or by tampering and then the response of the lambda control system is checked (Richter et al. 1993). Long response times would imply that the oxygen sensor is

degraded, while no response would mean that the lambda control system is out of operation (DEKRA/RWTÜV 1994).

3. One or more of the characteristics of the electronic lambda control circuit are measured and compared with auto manufacturers' specifications (Pucher 1989).

Germany has adopted since December 1993 a test that involves both test types 1 and 2 (Verkehrsblatt 1993); preliminary investigations have shown that the test performs fairly well with excess emitters (Richter et al. 1993). A combined idle / fast idle / lambda test (involving lambda test types 1 and 2) is also in force in Austria, where it has also demonstrated satisfactory effectiveness (Pucher et al. 1990). A similar test (but with lambda test type 1 only) is also foreseen for three-way catalyst cars in all EU countries with Directive 92/55/EC, which came into force in 1997.

INCOLL/AUTONAT

This test was devised by Lars Collin of the University of Technology of Göteborg, called INCOLL (Collin 1985); recently a similar technique was also proposed by the French "Centre de Recherche en Machine Thérmiques", called AUTONAT (CRMT 1994). The car engine is accelerated and decelerated rapidly so that the load that the engine has to overcome in order to accelerate its rotating and reciprocating parts (including flywheel and gearbox) approximates its load during a normal driving cycle. The accelerator pedal is actuated according to the corresponding "driving schedule" through an electronically controlled mechanism, while either the raw exhaust concentrations are continuously measured or diluted exhaust is collected and analysed after the end of the test. While the performance of the actual test cycle needs only about 2 to 5 minutes, it takes some time (~30 min in the case of AUTONAT) to obtain the relationship between accelerator pedal position and engine speed and load for each car type.

Both systems have demonstrated reasonably good correlation with emissions in legislated cycles, even in the case of catalyst cars. However, the finding of an old U.S. Environmental Protection Agency (EPA) study that "...the INCOLL system as tested requires a unique inertial cycle for each engine/transmission combination. This approach is much more complicated than the presently accepted 'one test for all vehicles' approach to I/M." (Smuda 1980) is still valid.

2.1.2 Steady-state loaded tests

As NOx emissions at no-load conditions are negligible, a loaded test is therefore necessary in order to measure NOx emission levels, which constitute a critical issue for urban air pollution. The simplest loaded tests are the steady-state loaded tests. These involve a dynamometer with steady-state power absorption. A simulation of the car's inertia weight is not required because there is no transient phase in the emission test: the car is driven at constant speed and load, and pollutant concentrations (CO, HC, NOx and CO_2) are measured during the load phase.

Already in the seventies several loaded tests have been developed in the US such as the Federal 3-Mode Test, the Clayton Key-Mode Test and the CalVIP (Berg 1982). However their implementation was limited due to the high cost of the dynamometer and the NOx analyser.

More recently and due to the introduction of 3-way catalyst equipped cars, the Acceleration Simulation Mode (ASM) Tests were developed and evaluated. According to the ASM principle the car is driven on a chassis dynamometer at a constant speed and steady-state power absorption that is equal to the actual road load of the car during acceleration. Thus one can achieve a

realistic simulation of the car's load at a specific driving mode without the need of flywheels for inertia simulation. However, at high speed / high acceleration combinations the required power absorption is too high to be achieved without engine overheating problems (Austin et al. 1989). Pollutant concentrations (CO, HC, NOx) are in principle measured in the raw exhaust. Each steady-state test mode would require about 10 minutes for preparation, pre-conditioning, actual testing and documentation.

Austin et al. compared several speed / load combinations with idle tests and already developed steady-state loaded tests as well as with transient loaded test. The best results were obtained from the ASM 5015 test, which has a constant speed of *15* mph (24 km/h) and a steady-state load equal to *50*% of the load required to accelerate at 1.47 m/s^2 (the maximum acceleration rate on the FTP) at the speed of 15 mph. A further conclusion, however, was that "...no loaded mode testing program should be implemented until the next generation of Test Analyser Systems is available" because for an ASM test "it is necessary to use a relatively complicated set of emission standards and dynamometer load settings." Finally, a recent EPA finding states that "even in a maximum annual program covering all weight classes, ... the ASM test yields insufficient benefits to meet the performance standard for HC, CO and NOx." (Pidgeon et al. 1993).

In the late 80s in Europe the association of German TÜV also investigated a similar loaded test. The car is driven at 50 km/h and at 7 kW dynamometer power absorption in the third gear (position "D" for cars with automatic transmission) and then idles; pollutant concentrations (CO, HC, NOx) in the raw exhaust are measured at the end of both the loaded and the idling phases (Voss et al. 1987a, b). Vehicle preparation, pre-conditioning, test phase and documentation take on the average about 10 minutes. The study concluded that the test is much more appropriate for the inspection of catalyst cars than a simple idle / fast idle test. The authors point out that, in order to improve the performance of the test, type-specific reference values (and not fixed values) have to be used as cut-points that determine whether a car passes or fails the short test.

2.1.3 Transient loaded tests

In transient tests cars are driven on the dynamometer according to a specific driving schedule; their main differences from type approval tests are the duration of the driving cycle and the hot start[(*)]. Since exhaust gas emissions are expressed in mass units, a CVS system and laboratory-quality analysers are required in order to detect low pollutant concentrations in the diluted exhaust sample. A multiple-curve dynamometer with flywheels is also required in order to simulate the instantaneous road load and the necessary power to accelerate the inertia masses of each car.

A number of transient loaded short tests were developed in the 70s in the United States and were examined as to their correlation with FTP 75 (Berg 1982). However, the cost of the implementation of such tests for generalised I/M programs was prohibitive, and thus the idea was abandoned. The fact that cars equipped with three-way catalysts were just starting to enter the U.S. market in the late 70s and the performance of these tests with such cars had not been examined yet must have played a role in that decision too.

[(*)] It is unlikely that a short cycle will detect shortcomings in the cold start behaviour

Recently though the interest for transient short tests was renewed. Thus first the CDH 226 test was developed by the Colorado Department of Health (CDH) and aimed at achieving high correlation with the FTP, especially for three-way catalyst cars. Numerous studies have demonstrated correlation coefficients of 0.79 to 0.96 for all three pollutants (Ragazzi et al. 1985, Austin et al. 1989, Klausmeier 1994). Excess emission identification rates were about 90% for all three pollutants at 5% errors of commission (Ragazzi et al. 1985).

However, the U.S. EPA decided to develop a more transient alternative to the CDH 226 in order to simulate better the FTP (Pidgeon et al. 1991) and therefore came up with the IM 240, illustrated in Figure 1. Emissions in the diluted exhaust gas are normally derived on a mass basis with a CVS and the test takes in total about 10 minutes to perform. The IM 240 showed correlation coefficients (R^2) with the FTP hot start portion of 0.89 to 0.97 for all three pollutants; another test sample had coefficients of 0.54 to 0.82 with the full FTP (Klausmeier 1994).

The EPA proposes that states or regions, which will have to implement the so-called "Enhanced I/M Schemes", enforce the IM240 at least for the cars of the newest model years. Studies evaluating alternative loaded test procedures are under way as well (Walsh 1994, Klausmeier 1994).

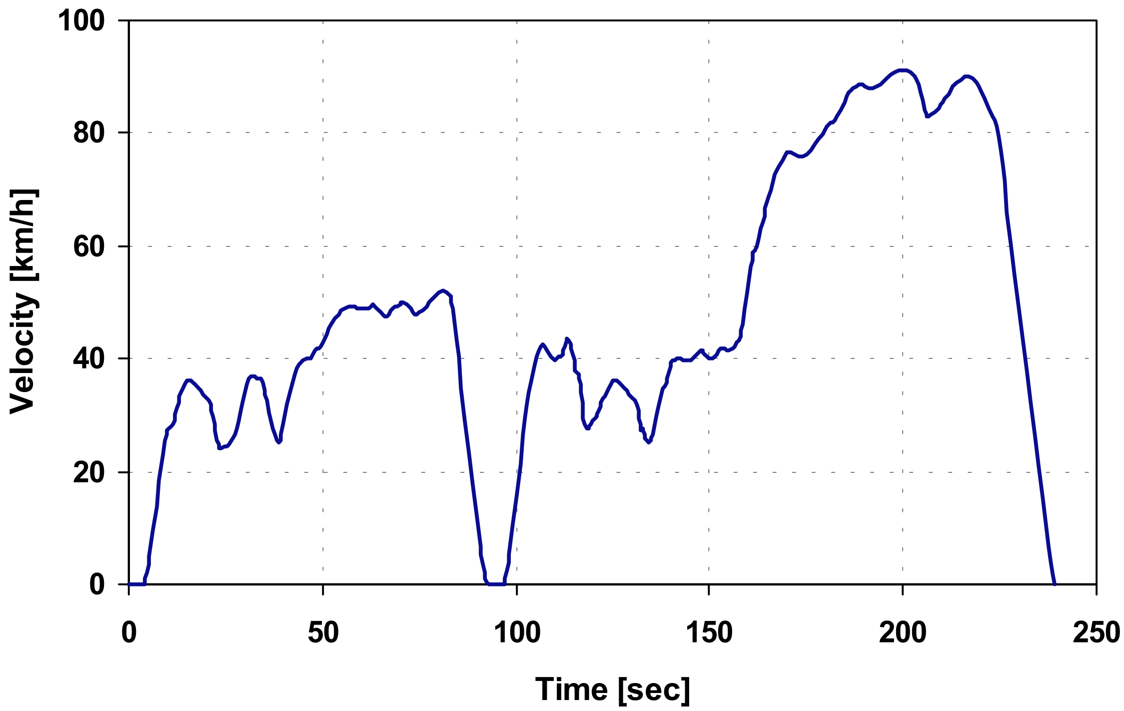

Figure 1 The IM240 short driving cycle

2.2 Short tests for evaporative emissions

Aim of a short test for the control of evaporative emissions of gasoline cars equipped with a carbon canister is to make sure that the canister retains fuel vapour coming from the fuel tank

and purges it to the engine so that it is burnt together with the injected fuel. What follows is an excerpt from a study conducted by Radian Corp. that briefly describes and reviews two relevant short test procedures developed in the U.S. (Klausmeier 1994):

"EPA's proposed evaporative system involves disconnecting two vapour lines that are located under the hood of the vehicle. The line from the fuel tank is disconnected and nitrogen gas is injected to assure that the system can hold pressure and therefore retain evaporative emissions. The line from the canister to the engine is disconnected and a flowmeter is installed to determine if the canister is being purged of evaporative emissions. There are obvious problems with these approaches. Disconnecting lines in a high volume inspection environment has potential to introduce problems in the vehicles. Furthermore, on many of the vehicles, lines cannot be easily disconnected. Radian conducted a study in-house where we performed purge and pressure tests on 151 employee vehicles. We found that 15% of the vehicles could not be tested because the canisters were inaccessible. Many of the vehicles that we considered testable were difficult to inspect. New Jersey has been conducting a pilot Enhanced I/M program which includes performing EPA's purge pressure test. New Jersey estimates that 35% of their vehicles cannot be tested.

Environmental Systems Products (ESP) has developed an alternative test whereby helium is injected in the fuel tank to confirm that the evaporative system is collecting vapours and routing them to the engine. The helium test avoids the problems associated with disconnecting the fuel tank and canister purge vapour lines. Including a functional gas cap check along with the helium test would help assure that many high emitting vehicles are identified."

2.3 Remote sensing

This section briefly considers the principles of remote sensing systems and describes the University of Denver's FEAT instrument in rather more detail, since it was also used in this study and being the most widely reported and most established.

An optical remote sensor is conventionally set up to transmit a beam of radiation across a parcel of air to be investigated. This involves the siting of a transmitter, normally a radiation source, at one location and a receiver at another. The path between these two points defines the optical path. This basic system may be modified through the use of targets such as a physical structure or reflector, actual aerosols or indeed molecules that may be used to reflect the transmission beam back onto the receiver. The determination of changes to a particular property of the original transmission beam may be identified through the use of a large range of detectors measuring a wide range of properties.

In the majority of applications, absorption of the transmitted radiation is used to determine the concentration of a particular gas species within the beam path. Individual gas species absorb radiation at characteristic wavelength absorption spectra. The measurement of radiation intensity at a selected wavelengths may be used to determine the concentration of individual species, through application of Beer-Lambert law.

Optical remote sensors may be conveniently group into two distinct classes, monochromatic and spectrally broad band. The former group contains laser long-path absorption and differential absorption lidar and the latter group contains the more familiar Fourier transform infrared (FTIR) spectrometer, Ultra-violet spectrometer and correlation radiometers. The broad band detectors may

be further subdivided into dispersive and non-dispersive. The dispersive systems (e.g. FTIR) are essentially open path spectrometers. The non-dispersive sensors (e.g. correlation radiometers) involve the comparison of the radiation beam after it has passed through two alternating filters.

Optical remote sensors have, for many years, been used to measure the ambient concentration of a wide range of gas species, largely within the area of gas leakage monitoring (e.g. DIAL) and more recently through general environmental monitoring (e.g. OPSIS).

It should be noted that the absorption spectra are subject to a number of interferences within atmospheric monitoring. These include interference from substances such as water vapour and indeed dependency on temperature and pressure (altitude).

The application of remote sensing systems to the measurement of vehicle emissions is not new. As early as 1971, experimentation at the Lockhead Missiles and Space Corporation, under contract to the California Air Resources Board, attempted to construct a remote vehicle exhaust measurement system. Subsequently to this early research, a number of remote sensing systems has been developed. In most cases, their operational principles are very similar.

2.3.1 LASAIR system

The LASAIR system was developed by Unisearch Associates Inc. and is essentially a prototype near infrared (NIR) tuneable diode laser absorption spectrometer. This system is designed to remotely measure the vehicle exhaust concentration of carbon monoxide and carbon dioxide and in addition, temperature (Schiff et al, 1995).

The LASAIR system uses laser diodes as the light source. These diodes are relatively inexpensive and operate at room temperatures. They operate in the near infrared, between 0.78 and 2.7 mm. Detection limits within this region are reported to be within the parts per billion range. The majority of the laser output from the diode laser, is directed towards a transmission mirror. A small fraction of this light is diverted through a 10 cm optical cell, filled with a 50:50 mixture of CO and CO_2. This cell is used for two purposes: one to lock the laser onto the particular absorption bands and secondly as an internal calibration standard. The primary beam is transmitted across the road to a retroreflector, which can be located up to a distance of 1000 meters. The reflected beam is subsequently focused onto a detector using a Cassegrain telescope.

Measurements are achieved through the variation of the current passing through the laser, and the subsequent frequency change in the emitted radiation. This frequency is scanned over the CO and CO_2 absorption bands. The ratio of CO to CO_2 is thus derived and reference against both the gas ratio within the reference cell and also through the periodic introduction of calibration gases into the measurement path. A full description of this system may be found elsewhere (Schiff et al, 1994).

2.3.2 HUGHES 'Smog Dog'

The Hughes system was developed at the General Motors (GM) Research and Development Centre in 1988 (Stephens et al, 1991, Cadle et al, 1994). The initial system was developed to remotely measure the vehicle exhaust concentration of carbon monoxide, and in 1988 its capabilities were extended to include the measurement of hydrocarbons. The system is now very similar to the Denver University FEAT system.

The original Hughes system comprised an infrared source and detector units, positioned on opposite sides of the road. The system operated by measuring the intensity of the IR beam, both with and without the presence of an exhaust plume. The original system operated using three independent detectors for CO, CO_2 and a reference channel, tuned through the use of beam splitters to 4.6, 4.3 and 3.9 mm, respectively. The detector unit also contained an optical chopper with a frequency of 120 Hz, resulting in an 8.3 millisecond measurement time resolution. More recent Hughes systems have seen an increase in this chopper frequency to 200 Hz, providing more rapid measurement periods.

2.3.3 The University of Denver (FEAT) remote sensing system

The FEAT (Fuel Efficiency Automobile Test) system is based upon a conventional non-dispersive infra-red (NDIR) gas analyser (Bishop et al, 1990, 1992, 1994, Stedman 1989, Zhang et al. 1993). The impetus for its original development was with regard to vehicle fuel economy issues, and it therefore initially concentrated on the detection of carbon dioxide and carbon monoxide. The early version of the system comprised two detectors with in-line bandpass filters corresponding with wavelengths of 4.6 and 4.4 mm for carbon monoxide and carbon dioxide respectively. The carbon monoxide channel was also used as a reference channel by means of a rotating gas filter wheel, one half of which contained a mixture of carbon monoxide and hydrogen and the other half nitrogen. The original detectors were liquid nitrogen cooled. Thus, the original system was quite bulky, and complex in operation.

However, significant changes have now been incorporated. The system in its more recent form consists of four components, namely an infra-red source, detector, computer and a video system. Under the standard operating procedures the IR source is positioned on one side of a single lane of traffic and the detector on the opposite side. The IR beam, generated by the source unit, is directed horizontally towards the detector. The distance between the source and detector units is thus typically 6 to 15 metres with the IR beam nominally positioned at a height of between 20 and 30 centimetres above the road surface, corresponding with the height of the exhaust plume from most light duty vehicles.

The system takes advantage of the principle that the majority of gas species will absorb light at particular wavelengths. In the specific case of carbon monoxide, carbon dioxide and hydrocarbons, all three compounds or groups of compounds will absorb in the infra-red spectrum (wavelength of between 2.5 and 25mm). The FEAT unit (instrument number 3007)[(*)], incorporates four Peltier cooled lead selenide detectors, with optical filters allowing the specific measurement of carbon monoxide at 4.6mm, carbon dioxide at 4.3mm, hydrocarbons at 3.4mm and a background reference channel at 3.9mm.

Within the detector unit the IR beam is directed on to the four individual detectors through the use of a spinning twelve faceted polygon mirror, which sweeps the incoming IR across four, focusing mirrors. The introduction of vehicle exhaust into the IR beam results in a reduction in IR intensity, which may be detected as a voltage reduction. This voltage reduction, measured by the four individual detectors may be used to determine the concentration of CO, CO_2 and HC at a point in the exhaust plume. The fourth, or reference channel, uses a wavelength which is not affected by

[(*)] Units in this series are numbered sequentially from 3000. Because the system is continuously under development by the University of Denver team, there are some differences between individual units.

any component within vehicle exhaust and is thus used to correct for other background variations which may affect the IR intensity recorded at the detector.

The FEAT system operates by continuously measuring the intensity of the IR beam. As a vehicle passes through the beam path, the voltages recorded at the detector drop to zero. This beam block is used to indicate the presence of vehicle, which both triggers the video system to record an image of the passing vehicle and also triggers the measurement procedure. Voltages are recorded both before the beam is broken and during the beam block, thus enabling the determination of background concentrations. As the vehicle continues through the beam, the beam is reformed and the change in intensity of the beam, due to the presence of vehicle exhaust is recorded. Instantaneous measurements of CO, HC and CO_2 are recorded at a frequency of approximately 125 Hz, over a period of 0.5 seconds.

The precise position of an exhaust plume relative to the IR beam may vary widely depending on the type and indeed model of vehicle passing through the beam and the beam height and orientation. The true concentration of exhaust gas at different points within any exhaust plume may vary widely, and indeed reduces due to standard dispersion processes after emission. Therefore the FEAT system software calculates the average CO/CO_2 and HC/CO_2 molar ratios from the instantaneous measurements, which theoretically remain the same within the exhaust plume, irrespective of its dispersion and subsequent dilution. These molar ratios are subsequently converted to true concentrations, though a software solution based on the chemistry of hydrocarbon fuel combustion in motor vehicles (Bishop et al, 1989). The FEAT software further operates a number of data rejection criteria. As a large number of data points are recorded, the software is able to interrogate the data scatter and reject entire vehicle data sets, if the data scatter is excessive. In addition if the signal received at the FEAT unit is insufficient, then again that individual vehicle will be rejected. Rejected beam blocks are recorded by the FEAT system as invalid data.

System calibration is integral to the system performance. Initial calibration is undertaken during manufacture through the use of a calibrated gas cells. The results from these calibrations are used to generate calibration curves, which are implemented within the FEAT system software. During FEAT system usage, daily calibration checks are undertaken by introducing a certified gas mixture (containing carbon monoxide, carbon dioxide and propane) into the path of the beam. The results from this daily calibration procedure are used to adjust the derived FEAT data, for site specific variations in FEAT system performance.

The derived FEAT data is recorded in a number of different formats. The video image is instantaneously transmitted to a monitor and additionally recorded on a video tape. Superimposed onto this video image (from which vehicle details including registration may be derived) are the vehicle's associated emission concentrations (CO, HC and CO_2), and the time and date at which the measurement beam was broken. In addition, this concentration data and associated beam block time details are recorded numerically onto computer media.

It should also be noted that the FEAT system has recently been developed (by the University of Denver team) to extend its capability to measure oxides of nitrogen and visible smoke in addition to the pollutants considered in this work. The measurement of oxides of nitrogen would be beneficial because of the general trade-off between emissions of carbon monoxide and oxides of nitrogen (high CO emitters often emit little NO_X and vice versa), while a visible smoke measurement would be more appropriate for diesel vehicles as it is this property that is restricted by in-use regulations.

3. Experimental

3.1 Test protocols

On the basis of the above review and on additional investigations performed in the framework of the study the test protocols for gasoline and diesel vehicles which were adopted and used by all partners for the laboratory tests are presented in Figure 2.

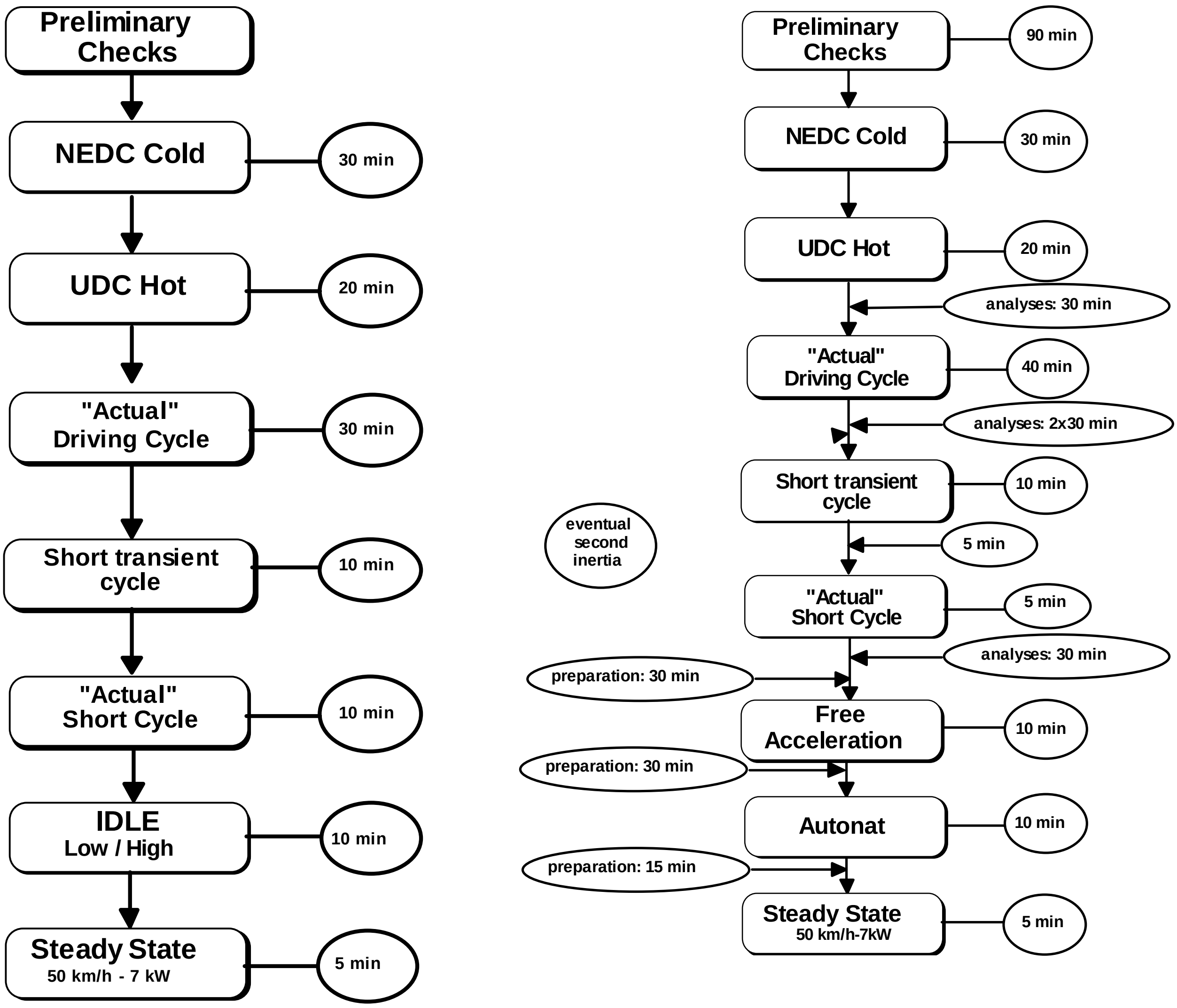

Figure 2 Test protocol for gasoline (left) and diesel vehicles (right)

3.1.1 Preliminary Checks

As a first step a number of visual checks is performed before the emission test starts, in order to ensure that specific components of the car exist and/or operate properly. Such checks include: visual inspection and check of components (e.g. component numbers, existence, completeness, leaks, damage), engine set at idle, direct component testing (e.g. oxygen sensor, catalyst), check of tyre size and pressure etc.

3.1.2 Long Cycles

At a second step, the New European Driving Cycle (NEDC) is performed under cold-start conditions (according to the legislation) in order to obtain the reference emissions of the vehicle at the as received conditions (Figure 3). The cycle is also followed by a hot start Urban Driving Cycle (UDC) in order to enable the acquisition of hot operating behaviour of the car, as the short tests will be performed under hot operation conditions.

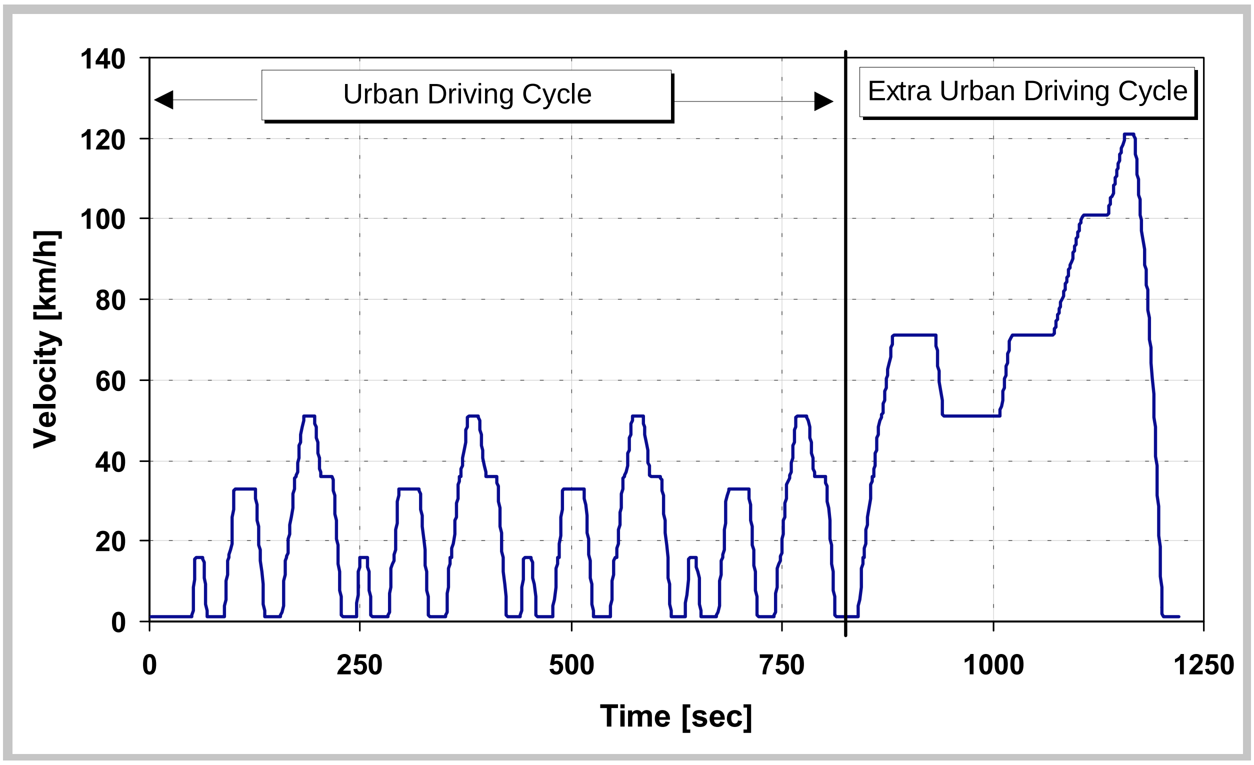

Figure 3 The New European Driving Cycle (NEDC)

In addition to the legislated cycle, a real-world "actual" cycle is also performed in order to be used for the further evaluation of the overall effectiveness of the I/M schemes. The cycle used is shown in Figure 4. It was developed by INRETS on the basis of large scale driving behaviour measurements in three EC countries (France, Germany and United Kingdom) in the framework of the DRIVE - "Modelling of emissions and consumption in urban areas - Modem" project (Joumard et al. 1992, André et al. 1993). As it can be seen in Figure 5 the cycle consists of four parts: a slow urban (speeds hardly exceeding 30 km/h), a road (with speeds up to 100 km/h), a free flow urban (with speeds up to 60 km/h) and a motorway part (with speeds exceeding 120 km/h).

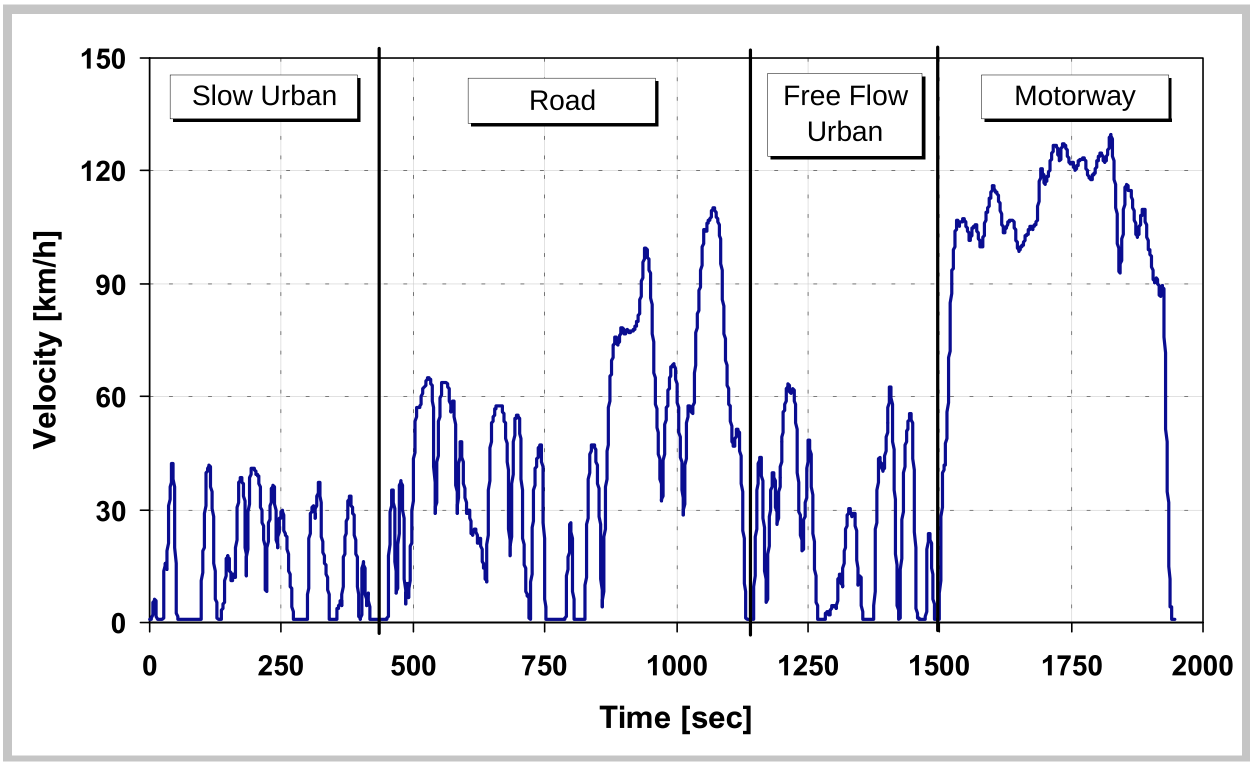

Figure 4 The Modem "actual" driving cycle

3.1.3 Short Transient Cycles

Following the long cycles, two transient short tests are performed. These include:

- A short transient cycle specially developed by TÜV Rheinland, taking into account mainly the kinematics characteristics of the NEDC. In this respect the objectives were (a) to achieve an average speed of the short test similar to that of the type approval test as the exhaust emission level of a vehicle is mainly determined by the average speed of a cycle and (b) to approximate in the short cycle the average and the standard deviation of the parameter speed x acceleration of the type approval test, as it is also known (Hassel et al. 1993, TÜV 1993) that acceleration and deceleration influence the emission behaviour as well. Thus the short cycle displayed in Figure 5 was selected for the test protocol. Its duration is limited to about 200 sec and its speed to 90 km/h, to avoid noise emissions and tire problems. As a general rule, the cycle is performed twice, the first repetition considered as pre-conditioning.
- In addition to the above mentioned test, an actual short test specifically developed by INRETS in the framework of this project is used, which was constructed in order to simulate the long Modem cycle. This is displayed in Figure 6.

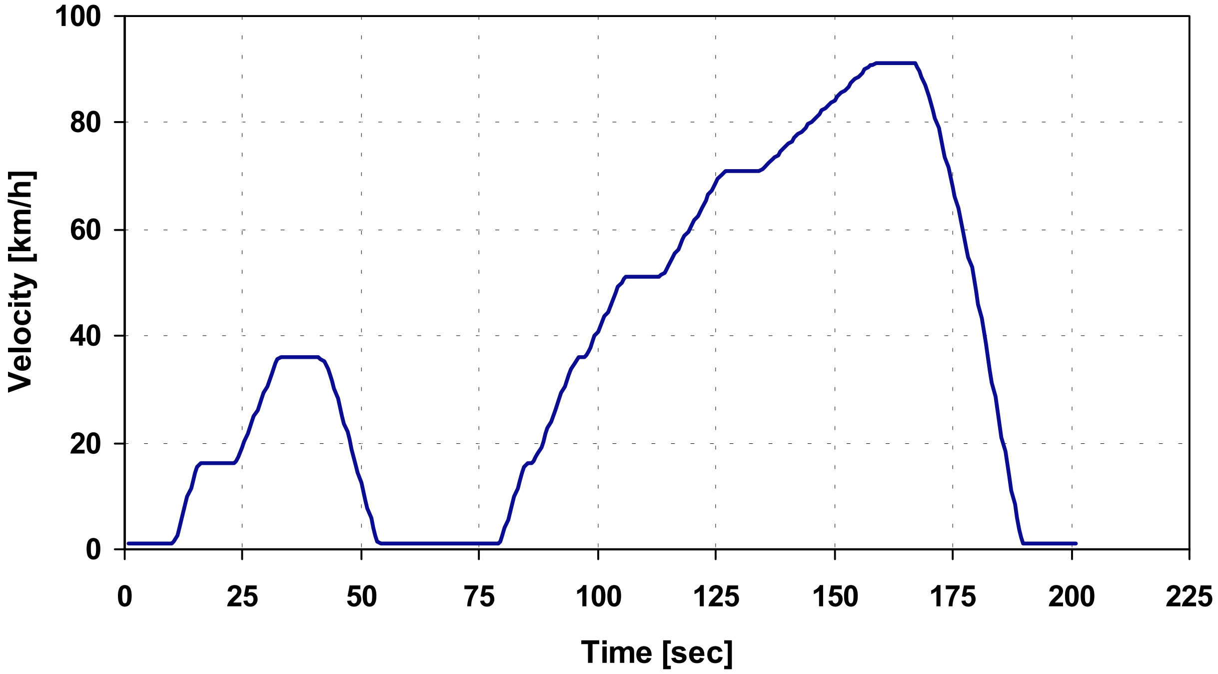

Figure 5 The TÜV short driving cycle

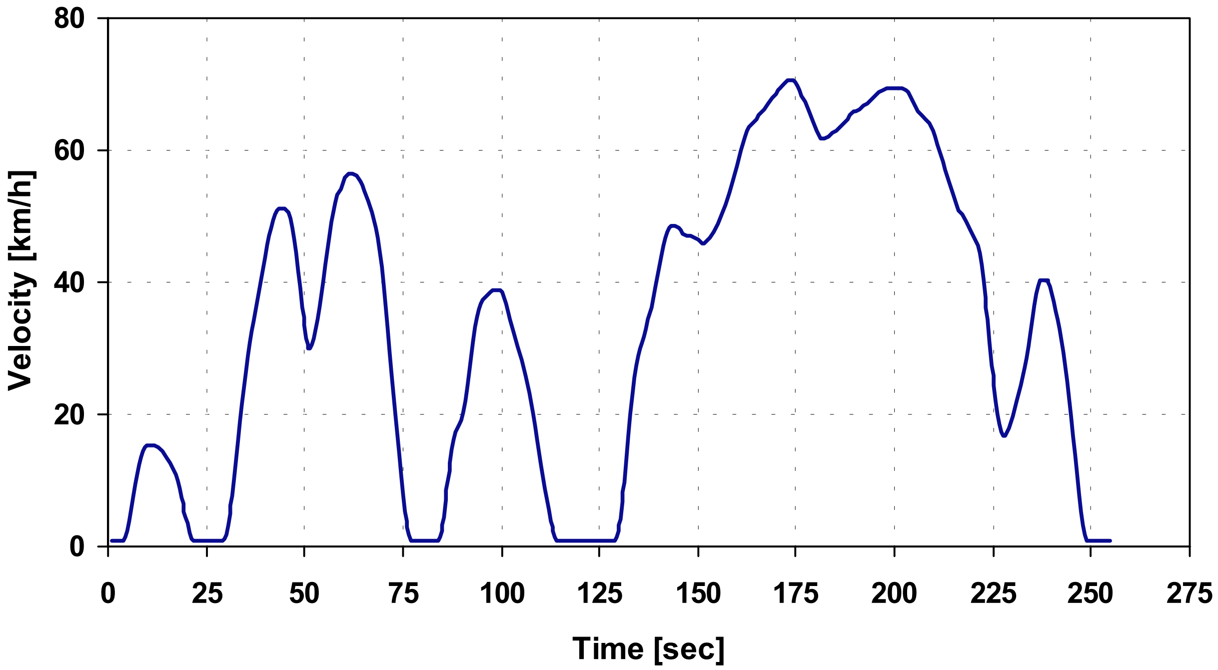

Figure 6 The Modem short driving cycle

Table 1 gives a summary of the characteristics of the above driving cycles.

Table 1 Characteristics of all driving cycles

name	duration (s)	distance (m)	speed (km/h)	accel. st. dev. (m/s^2)	% total distance (%)
ECE15 (UDC)	780	4 052	18.7	0.487	
EUDC	400	6 955	62.6	0.395	
NEDC (= ECE15 + EUDC)	1180	11 007	33.6	0.458	
modem IM slow urban	428	1 705	14.3	0.583	17.4
modem IM free-flow urban	355	2 248	22.8	0.702	40.5
modem IM road	712	8 485	42.9	0.685	12.4
modem IM motorway	452	12 683	101.1	0.418	29.7
modem weighted			49.22		
TÜV-A	200	1 969	35.4	0.535	
modem IM short	255	2 246	31.7	0.723	

name	idling duration (s)	running speed (km/h)	maximum speed (km/h)
ECE15	252	27.6	50.0
EUDC	41	69.7	120.0
NEDC (= ECE15 + EUDC)	293	44.7	120.0
modem IM slow urban	134	20.9	42.3
modem IM free-flow urban	71	28.5	62.3
modem IM road	96	49.6	109.2
modem IM motorway	11	103.5	128.7
modem weighted			
TÜV-A	51	47.6	90.0
modem IM short	51	39.6	69.7

3.1.4 No-load and steady-state loaded tests

The short cycles are followed by a no-load test at idle and fast idle and finally by a steady state loaded test at 50 km/h and 7 kW power absorption. Especially as regards the steady-state loaded test, it has to be recalled that according to the Directive 91/441/EEC, 7 kW corresponds to the load exerted on a medium-sized car at a constant speed of 90 km/h, whereas the power absorbed

at 50 km/h constant speed is about 1,5 kW. A calculation shows that the 50 km/h - 7 kW test is equivalent to a European ASM 4050 (i.e. 50 km/h and 40% of the NEDC's maximum acceleration), which is a quite high load. Therefore an additional mode might also be of interest, at the same speed but at lower power absorption (e.g. 50km/h and 4 kW).

3.1.5 Additional elements

As regards the emission measurements two possibilities are explored in parallel: (a) continuous concentration measurements either in the raw or the diluted exhaust gas and (b) average bag values. In addition two types of analysers are used: laboratory quality analysers and garage type ones, in order to enable comparisons and deduce the corresponding cost estimates. Finally alternative simplified inertia settings are also used in order to investigate the possibilities of a simpler dynamometer in the case of transient short tests.

3.2 Remote sensing

The test work consists of the following elements:

- remote sensing of CO, HC and NO
- roadside tailpipe emissions tests including idle and fast idle on a sample of vehicles followed a later date by
- dynamometer tests on a sub-sample of vehicles subjected to roadside tests

The remote sensing system was set up on a road selected by the host partner, based on selection criteria supplied by TRL. Ideally, this required:

- a road where vehicles would be under slight load (e.g. slight uphill gradient).
- road layout suitable for locating the source and detector on either side of a single lane of traffic.
- a 'safe' area further down the road where selected vehicles can be stopped for a roadside emissions test.

TRL personnel operated the remote sensing site. As the vehicle passed through the remote sensing system, an image of the back of the vehicle and the measured emissions were displayed on the monitor (Figure 7).

Any interesting vehicles were reported to the roadside test site where police officers stopped the vehicle for further tests (apart from Delft where, because the remote sensing site was on a slip road onto a motorway, police motorcyclists pursued the selected vehicles and lead them to the roadside test site located in a motorway services a short distance away). The selection criteria depended on the vehicles passing through the test site - ideally catalyst cars (based on the vehicle's registration number) with high CO emissions were targeted, but in the absence of such vehicles other vehicles with valid remote sensing readings were selected.

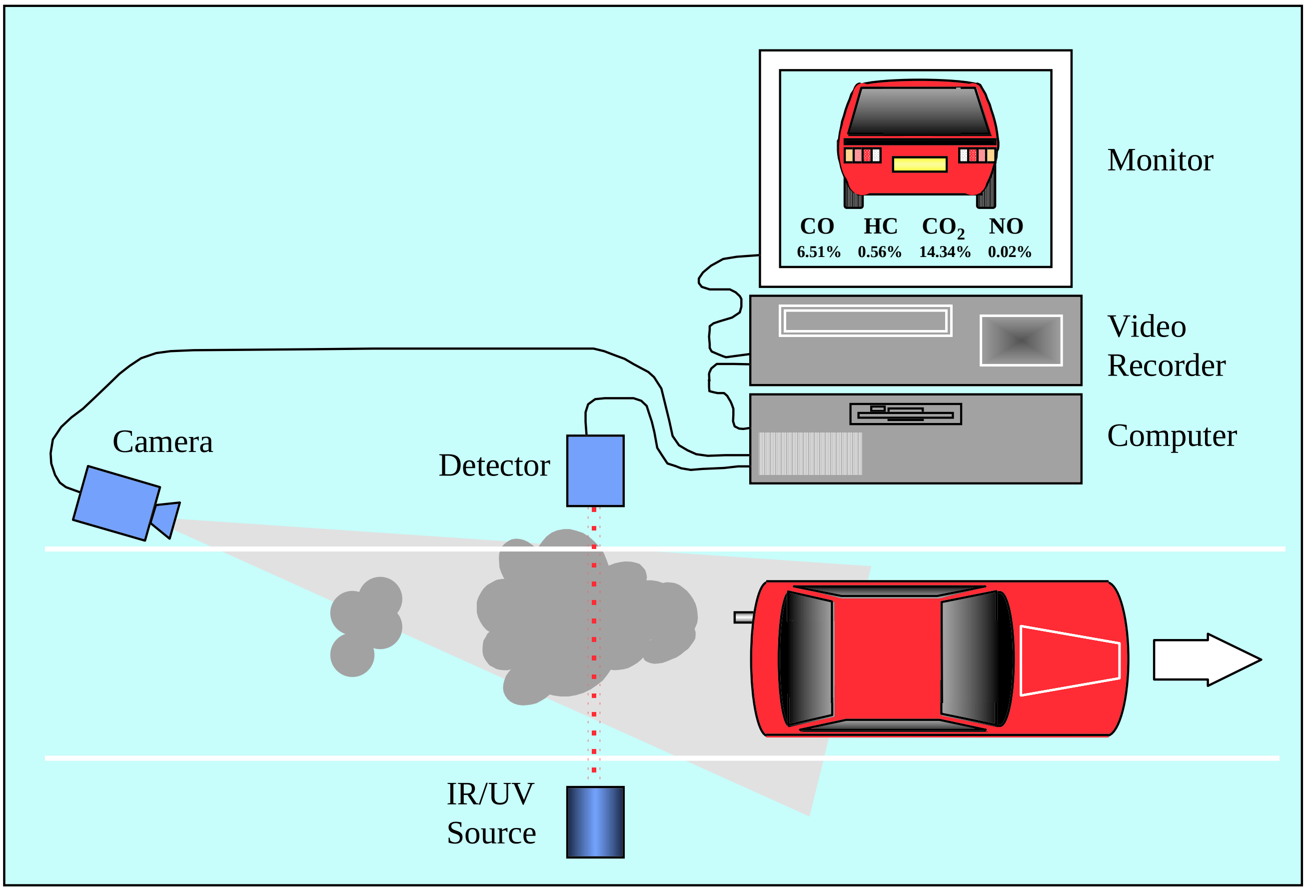

Figure 7 Operation of remote sensing system

4. Vehicle Samples and Test Results

4.1 Character of the TWC sample tested in the laboratory

In principle the selection of vehicles was random(*) and differed in each country, in order to account for (a) the particular characteristics of the in-use fleet per country and (b) the future trends. However, and since the hypothesis is that a small percentage of high emitters is responsible for a large percentage of total emissions, the purpose of the exercise was also to identify gross emitters. Therefore, a certain minimum share of high emitters (exceeding the standards) was also necessary. This was realised mainly by selecting a number of vehicles from groups where high emitters can be expected, e.g. high mileage vehicles and national inspection programs (Becker et al. , 1993; Richter et al., 1993). Despite the fact that this creates a conflict, it also ascertains that sufficient high emitters are part of the selection and offers the possibility to check the validity of the short tests considered.

In order to quantify the likely effects of maintenance on exhaust emissions, the vehicles that were identified as gross polluters (emitting more than 50% the emission standard) were maintained and then re-tested. Depending on the partner, maintenance was conducted either at garages of average level (as the latter is defined in each country) or at authorised dealers who in principle can ensure high quality repair.

Table 2 presents all measurements carried out by all collaborative institutes. In total 342 tests were performed by all partners on 261 cars, as 81 cars were re-tested after they had undergone maintenance. The test sample included 41 conventional (non catalyst) gasoline cars, 192 cars equipped with three-way catalytic converters (including some LPG powered cars), and 28 diesel cars. As already mentioned, the main part of the vehicle sample was chosen randomly, while some cars were chosen as a priori high emitters, on the basis of national programs (i.e. the German Abgasuntersuchung and the Dutch In-Use Compliance programs). Furthermore, a number of cars were selected as high emitters with the aid of remote sensing measurements carried out with a FEAT device for a period of one week in the cities of Thessaloniki, Lyon, Delft, Leicester and Emberton (one site in each city). These remote sensing tests, apart of facilitating the identification of high emitters, gave also valuable indications about the likely performance of remote sensing under different European conditions.

Focusing on the catalyst equipped cars of the test sample, Figure 8 presents the average values (and the related scatter) of vehicle mass, power output, engine capacity, and mileage for each laboratory and for the total sample. It is clearly seen that some of the most important differences between the countries involved are reflected in the sample. Thus in Germany (TÜV), the Netherlands (TNO) and the UK (TRL) the cars are of higher mass and engine capacity compared to Greece (LAT) and France (INRETS). The average European car in the sample has a mass of

(*) Despite the fact that the sample is considered as random, it has to be stressed that there is a certain bias, due to the voluntary participation in the test programme; in general, owners of well maintained cars are suspected to have a higher willingness to participate in such tests.

about 1000 kg and is equipped with an engine of 1.6 l and 70 kW power output. The average mileage of the sample (approximately 60 000 km) is higher than the European mean because, as already mentioned, the emphasis of these tests was on relatively old cars that should be more likely to have excess emissions.

Table 2 Distribution of test vehicles with respect to technology, type of choice and number of vehicles tested again after maintenance

	Maintenance	Random	German AU (TÜV)	High emitters (TNO)	Remote sensing tests	Total
conventional	before	14	-	-	27	41
gasoline	after	7	-	-	15	22
gas. 3-way	before	135	16	12	29	192
catalyst	after	23	17	7	9	56
diesel	before	20	8	-	-	28
	after	-	3	-	-	3
total	before	169	24	12	56	261
	after	30	20	7	24	81

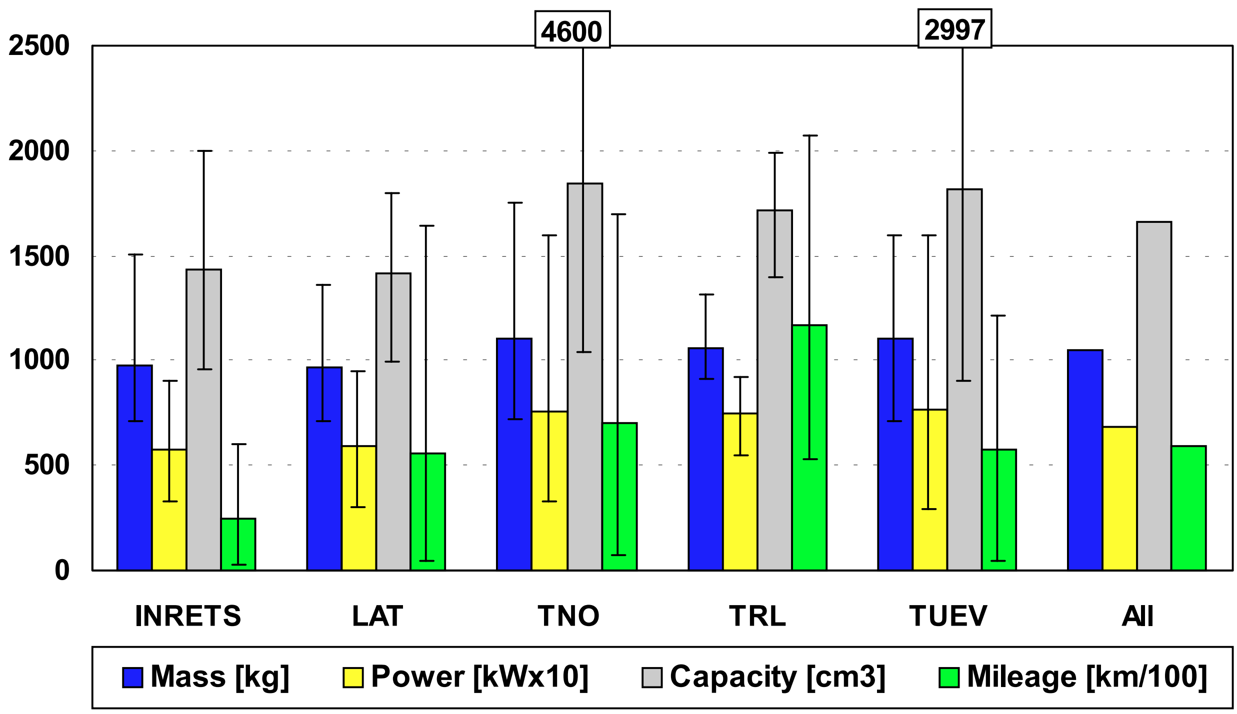

Figure 8 Main characteristics of the test sample of the TWC vehicles

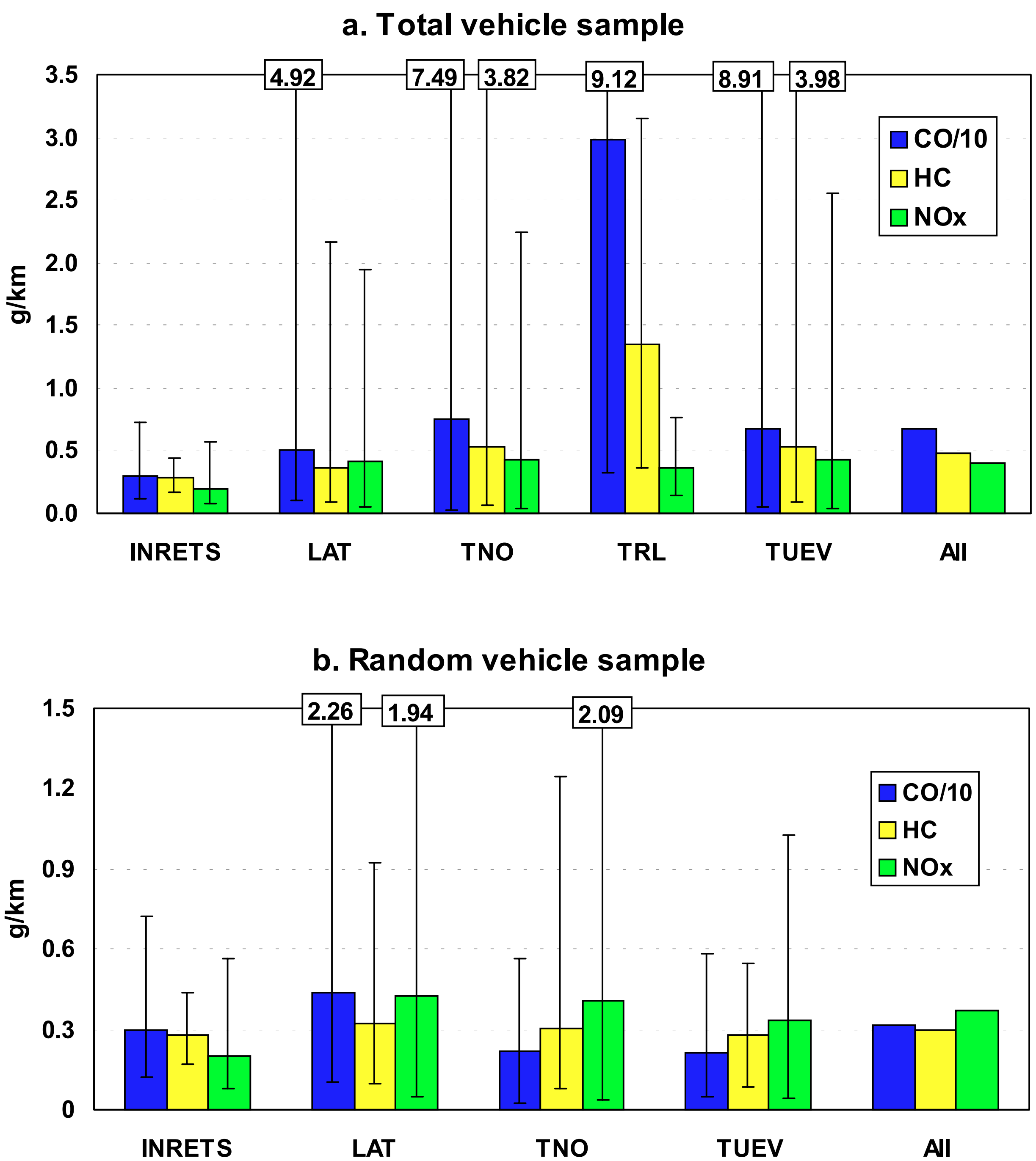

Figure 9 Emission results over the NEDC of the TWC vehicles

The identity of the sample of catalyst equipped cars in terms of their emissions behaviour over the NEDC is depicted in Figure 9 (total and random vehicle sample). It is noted that the total sample complies to a very large extent with the initial specifications of the project, i.e. it includes a relatively large amount of high emitters. Despite this fact, it is of particular interest to stress that on average the car sample has emission levels which are below the emission standards of Directive 91/441/ EEC as regards HC and NOx (1.13 g/km composite standard for HC+NOx); only the CO average figure is about double as much as the conformity of production emission

standard (3.16 g/km). This remark is also confirmed by the experience (common to all partners) that cars of current three-way catalyst technology perform much better than what the American experience indicates. More specifically, it was not a simple exercise to locate a gross emitting car, while the catalyst itself was very rarely the cause of high emissions. Note that there are no randomly chosen vehicles from TRL since all vehicles from this laboratory have been selected on the basis of remote sensing.

Figure 10 presents the distribution of TWC vehicles over NEDC cold emissions. High polluters are defined as the vehicles emitting above the type approval standard and very high polluters those emitting above 1.5 the type approval standard. In these figures the pollutant(s) which is (are) responsible for considering a vehicle as a high or a very high polluter can be determined. The 3 digits in the legend text refer to CO, HC and NOx respectively while 0 and 1 indicate whether the particular pollutant is below or above the emission standard (or 50% above emission standard). For instance 101 is the percentage of high (or very high) polluters both in CO and NOx. From the figures it can be derived that most of the randomly chosen vehicles are low polluters. Firstly CO and secondly NOx are the main responsible for the high (or very high) polluters. There are no vehicles emitting only high levels of HC or both HC and NOx. There are also very few vehicles emitting high levels of all three pollutants. The above remarks seem to lead to the conclusion that when a vehicle is a high polluter it can be detected by measuring CO and perhaps NOx, while further measurement of HC provides no added value.

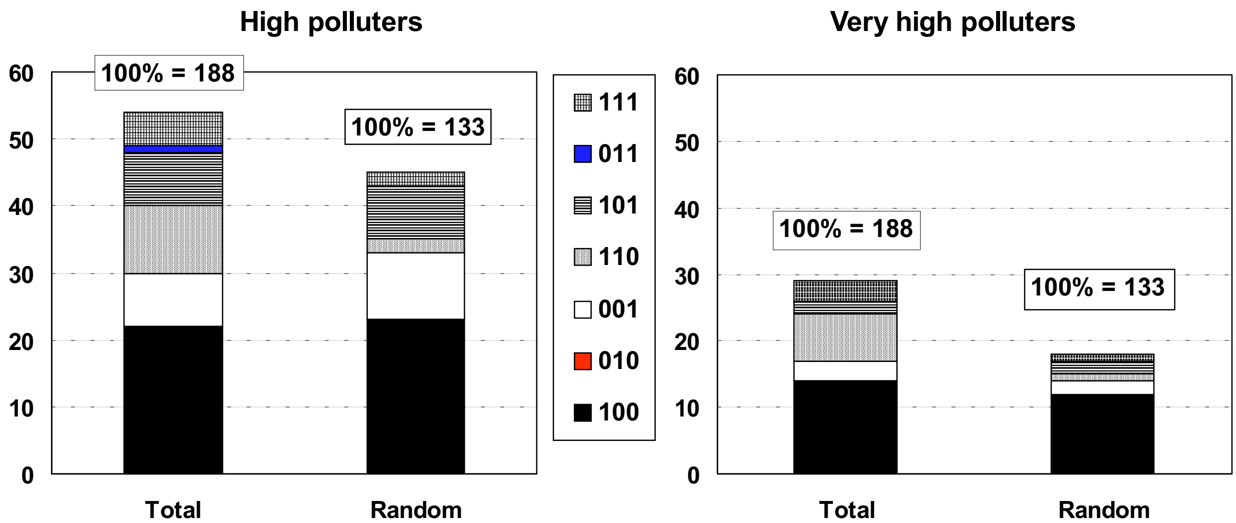

Figure 10 Distribution of TWC vehicles according to NEDC cold emissions

4.2 Selected overall test results from the TWC sample

4.2.1 Driving cycle correlations

Every emission test makes use of a particular part of the engine's speed-torque map and has its own particular weighting of engine conditions. A strict correlation of the results of two different tests is therefore by definition excluded. Even so, one may expect that an engine or vehicle that shows excessive emissions of one particular component in a certain test, especially as a consequence of a certain defect, is likely to show excessive emissions of the same component in another, similar test. This expectation is the basis for the attempt to correlate the two short transient tests regarding the main vehicle pollutants i.e. CO, HC and NOx. These correlations are presented in Figure 11 (a, b and c) for TWC vehicles.

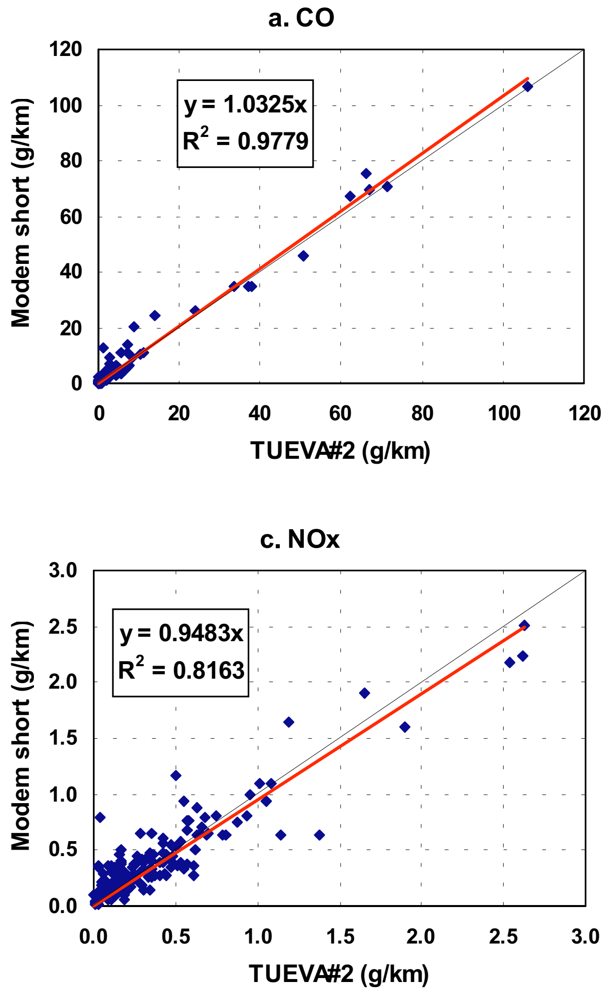

Figure 11 Transient short tests correlation (TWC vehicles)

Figure 11 results show clearly that, despite the initial expectations mainly coming from the different cycle dynamics, the two short tests yield equal emissions, with the exception of HC,

where Modem short cycle leads to more than 20% higher emissions than TÜV short cycle. This analysis shows that the two cycles can be considered as largely equivalent.

It is also interesting to correlate the two long cycles in order to attempt an investigation of the question: is NEDC representative of the actual driving conditions?. This correlation has been calculated for all pollutants i.e. CO, CO_2, HC and NOx and it is depicted in Figure 12 (a, b, c and d) for TWC equipped vehicles.

The results show that compared to NEDC the emissions over Modem are

- generally lower as regards CO and HC
- generally higher as regards NOx
- practically the same as regards CO_2.

Bearing in mind that the NEDC is a cold start cycle, while Modem was always driven under hot engine and catalyst conditions, it is clear that cold start extra emissions (very important in the case of CO and HC) are responsible for the deviation from the general expectation that the Modem emissions should be generally higher than the ones over the NEDC, due to the much higher dynamics of the latter. This expectation is confirmed in the case of NOx emissions, where cold start plays a minor role. A very interesting additional result is that CO_2 emissions over both cycles are equal.

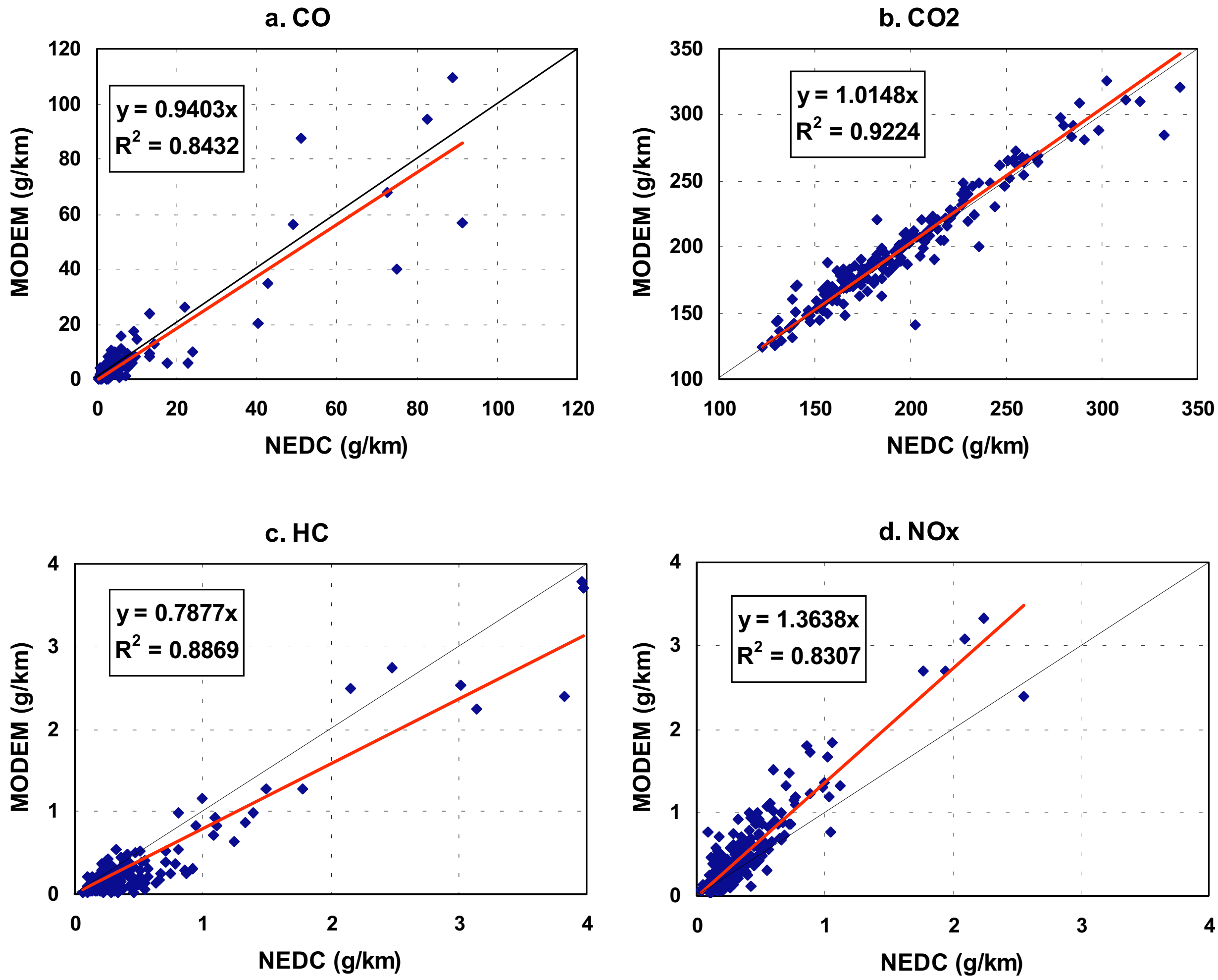

Figure 12 Long cycles correlation (TWC vehicles)

4.2.2 Effect of maintenance on the emissions

The effect of maintenance on car emissions is illustrated in the case of TWC cars in Figures 13-15. Figures 13 and 14 present comparatively the cumulative distributions of NEDC emissions as a function of the vehicle fleet before and after maintenance for the total and random vehicle samples respectively. It can be seen that in the "as-received" case of the total sample some of the observations frequently quoted from US studies (e.g. Guenther et al. 1992) are reproduced: 10% of the cars emit over 50-60% of CO emissions and somewhat less than 40% of HC and NOx emissions. After the high emitters are maintained, 10% of the vehicle fleet is responsible for about 25 to 40% of - lower overall - total emissions. In the case of the random vehicle sample, results are not so impressive. It has been found that 20% of the vehicle fleet accounts for not more than 45% of CO and NOx emissions and less in HC emissions. Since the average European TWC vehicle is a low polluter the effect of maintenance appears to have a small impact on the overall emissions.

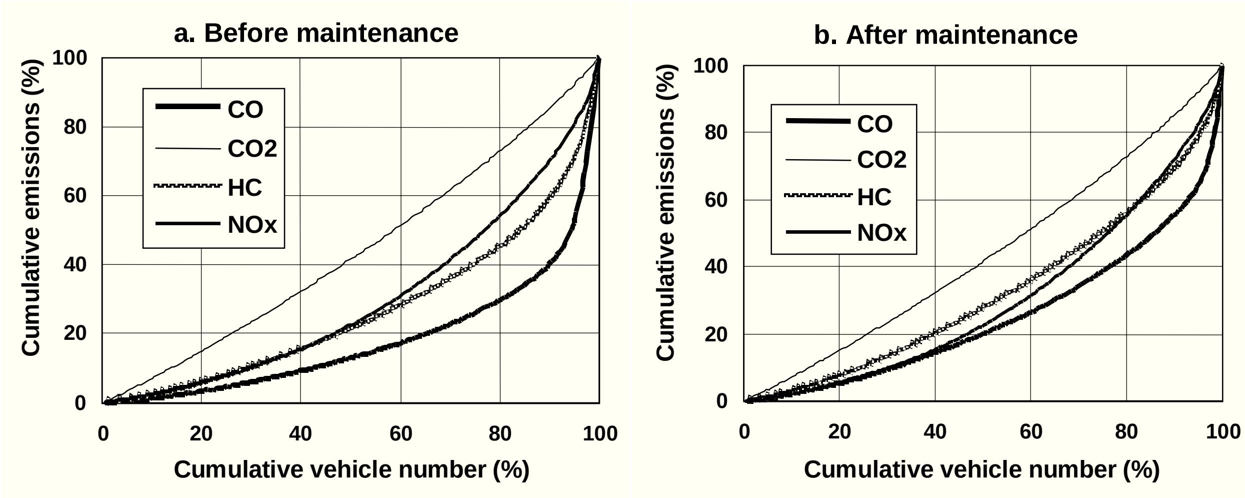

Figure 13 Cumulative distribution of the emissions of the total TWC vehicle sample on the basis of the NEDC test results

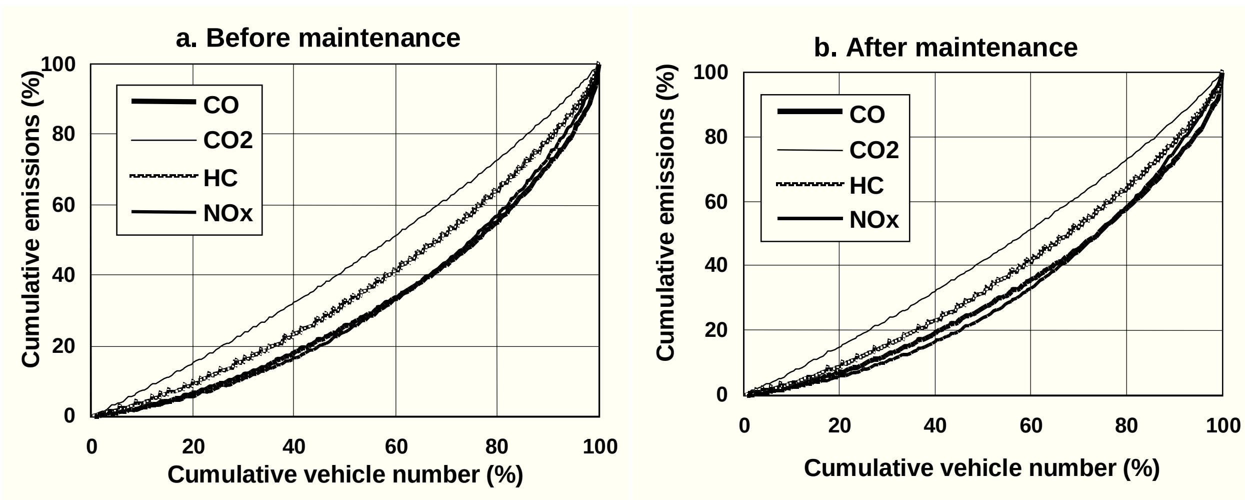

Figure 14 Cumulative distribution of the emissions of the random TWC vehicle sample on the basis of the NEDC test results

The potential of maintenance is illustrated in Figure 15. After maintenance of some of the high polluters, total CO emissions were reduced by about 35%, HC emissions by 25%, while the potential in reducing NOx emissions was lower than 10%. In evaluating these results, however, the following points have to be kept in mind: (a) the sample should not be considered as representative of the actual in-use European fleets; the share of gross emitters is higher than what should be expected in the actual fleets; (b) the selectivity of this scheme is maximum as the NEDC was used for the identification of high emitters; (c) some of the highest emitters did not undergo maintenance for practical reasons. If all high emitters had been repaired, the emission benefits would be approximately 50% for CO and 35% for HC. On the basis of the above points it should be considered that the results in Figure 15 are rather optimistic. This is also supported by the findings of other projects running in parallel in Europe (e.g. VROM 1994), which evaluate that the potential of a realistic I/M program should be close to 10% for CO, 5% for HC and 0 to 5% for NOx. Finally it is worth stressing that a negligible overall effect on CO_2 is expected after maintenance.

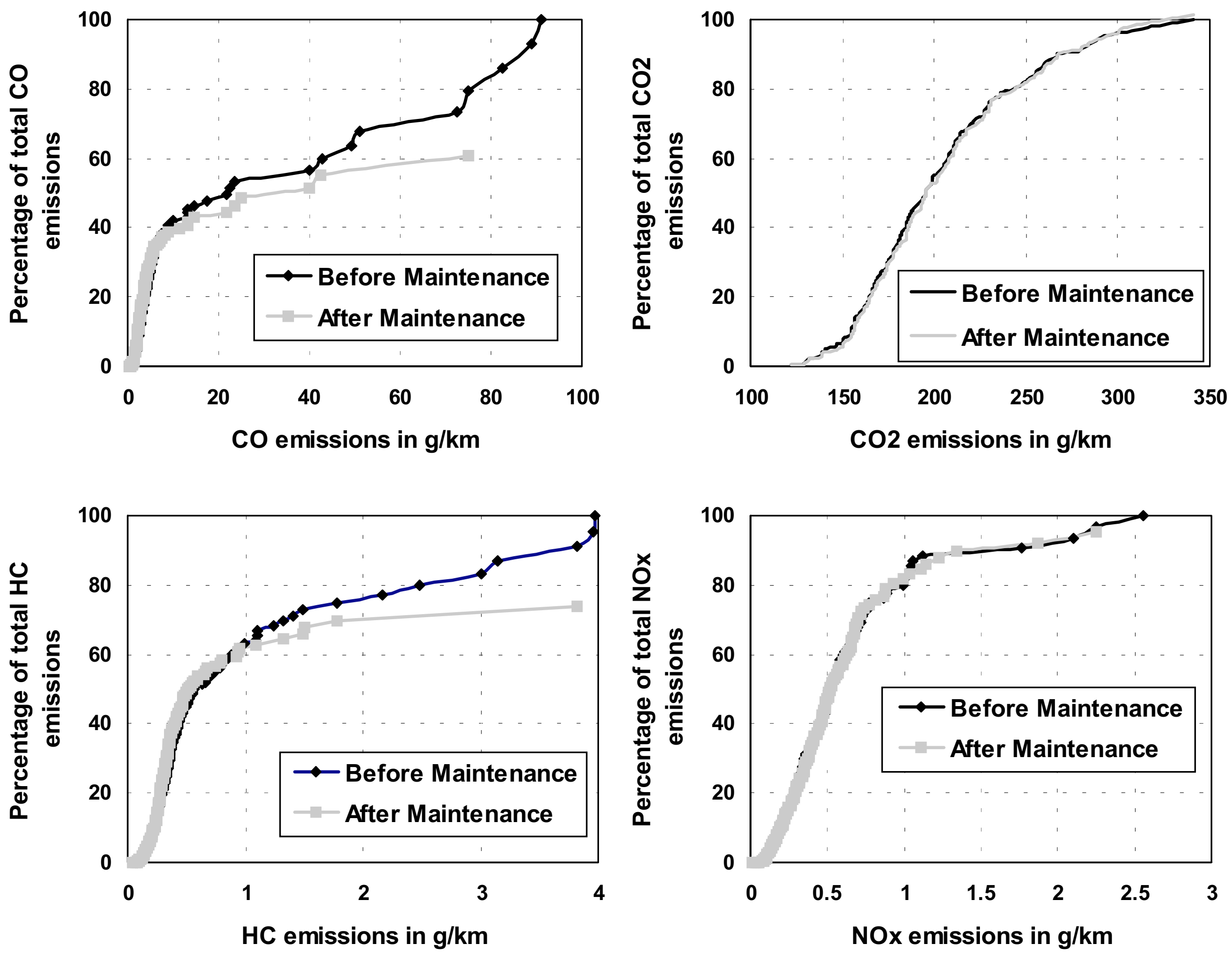

Figure 15 The potential of maintenance to reduce the emissions of the TWC car fleet on the basis of the NEDC test results.

4.3 Remote sensing

4.3.1 Number of measurements

At each site, several thousand remote sensing results were obtained. Not all of the remote sensing results are valid. If a HGV or a car with a trailer/caravan attached to it passes though the beam, the beam is broken and remade several times (the beam is set at a height typical of the exhaust level on most cars, so that it sees a multi-axle HGV as several vehicles). When this occurs, it is indicated on the remote sensing data as a reset.

The remote sensing system calculates the emissions by measuring the ratios between CO/CO_2, HC/CO_2 etc. many times immediately after the vehicle has passed (i.e. when the broken beam in re-made). As the exhaust plume disperses, the concentration becomes more dilute, but the ratios should remain fairly constant. If the standard deviation of these ratios is too high the reading is rejected (the data files contain flags indicating ‘V’ valid and ‘X’ invalid readings). Table 3 shows the total number of valid readings (based on the flags previously mentioned) after rejecting all the readings where resets have occurred.

As can be seen from this table, a total of over 83,000 readings have been collected from these five sites, with over 76,000 valid CO readings. The majority of these vehicles are cars, but the total will also include, in smaller numbers, light goods vehicles, motorcycles etc. For CO and CO_2 , the success rate (i.e. the number of valid readings) is high, presumably due to their presence in relatively high concentrations. For HC and especially NO, which are present in much smaller concentrations, the number of valid readings is much lower.

Table 3 Number of valid remote sensing readings, idle and dynamometer tests

Location	No. of Vehicles	Number of Valid Readings						No. of Idle Tests	Dyno Test + Repeats
		CO	CO_2	HC	NO	Opac	Speed		
Thessaloniki	30682	29880	30227	28394	9526	25248	25004	161	11 + 4
Lyon	13422	11801	11999	7758	891	5601	12335	228	
Delft	16993	14828	14928	6666	1370	4705	15864	154	16 + 2
Emberton	7687	6092	6209	2871	643	1418	7172	199	
									20 + 10
Leicester	14749	14189	14331	12283	3493	5651	8878	304	
Total	**83533**	**76790**	**77694**	**57972**	**15923**	**42623**	**69253**	**1046**	**47 + 16**

The table also shows the total number of vehicles stopped for a roadside idle test and selected for further dynamometer based tests (repeats indicate the number of vehicles sent for servicing and

then repeat tested). Comparison of the number of remote sensing reading and the number of idle tests shows one potential advantage of using a remote sensing detector.

4.3.2 Emission distributions

From the large amount of remote sensing data, emissions distributions can be derived. Figure 16 shows the distributions of the valid carbon monoxide readings at the five different sites (the numbers in the legend refer to the number of readings at each site that the distribution is based on). All five sites show similar trends - a high number of vehicles with low CO concentration and a small number of vehicles with very high concentrations

The CO distributions show that there were a high number of low emitting vehicles in Delft, while in Thessaloniki there were a lower number of low-emitting numbers. Conversely, in the middle of the scale, Thessaloniki has the slightly higher number of high emitters, with Deft having the lowest number.

This could indicate the emissions characteristics of the vehicles passing the remote sensing detector (i.e. cleanest vehicles in Delft etc.) or it could be due to differences in the remote sensing sites. Because the site in Thessaloniki was uphill, the vehicle’s engine would be under greater load and therefore their emissions higher. In Delft, the remote sensing site was downhill and the vehicles may have been under little load as they passed, resulting in lower emissions being detected.

4.3.3 Effect of age on emissions

It is possible to tell the age of the vehicles in some countries by the number plate - part of the number indicates when the vehicle was first registered. In the UK, this is very simple - the last letter (1966-1983) or the first letter (1983-current) of the registration number indicates the year of registration. This letter currently changes (increments) annually every August, so for the majority of cars the age can be easily determined (apart from a small number of vehicles with personalised number plates). Some of the other countries use other methods for determining the age of the car or the number plate (in some countries a new registration number is issued when the vehicle changes owners).

After extracting the registration number details from the remote sensing video tapes, it is therefore possible to sort the data according to vehicle age. Figure 17 shows the average emissions of the vehicles at the two UK sites. Both sites show decreasing CO emissions with decreasing vehicle age with a large decrease with the introduction of catalyst cars.

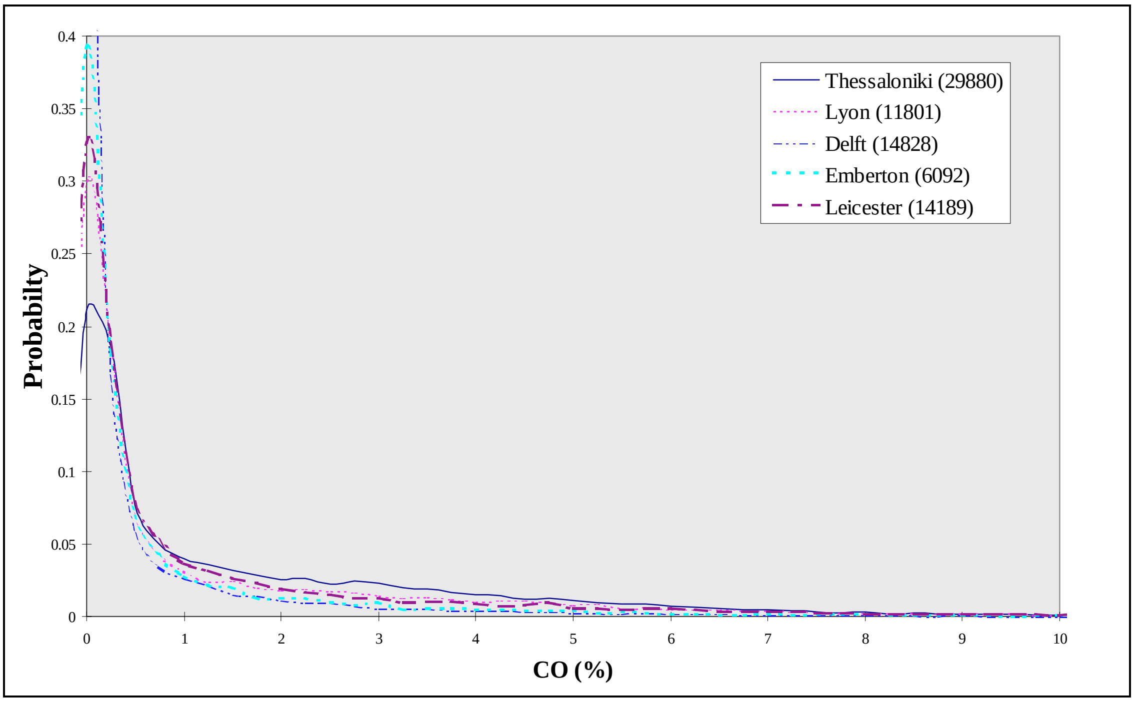

Figure 16 CO distribution at the five remote sensing sites

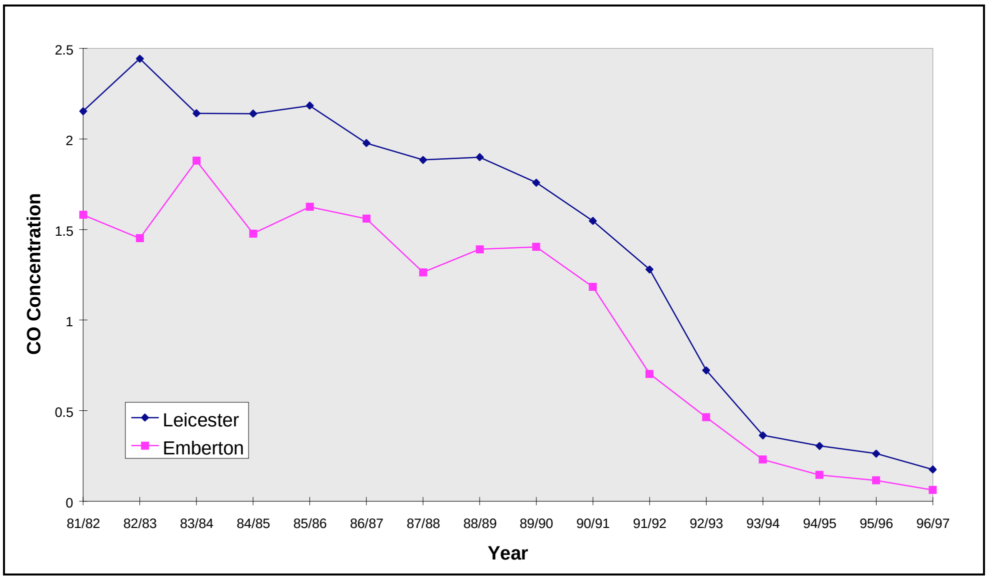

Figure 17 Average CO emissions by vehicle age

5. Analysis of the Test Results

5.1 Short tests

5.1.1 Methodology

The short tests to be evaluated are shown in Table 4 together with their abbreviations.

Table 4 Short tests

Short test	Abbreviation
meTÜV	Mass emissions in TÜVA#2
ralaTÜV	Raw average concentration with laboratory analysers in TÜVA#2
ragaTÜV	Raw average concentration with garage analysers in TÜVA#2
meMS	Mass emissions in modem short
ralaMS	Raw average concentration with laboratory analysers in modem short
ragaMS	Raw average concentration with garage analysers in modem short
Idle	Idle
H-Idle	High idle
ga50-7	Steady state loaded with garage analysers
la50-7	Steady state loaded with laboratory analysers
FAS	Free acceleration smoke
AUTONAT	Autonat

Figure 18 presents the basic concept upon which this analysis is based and it is a correlation chart between each short test and the type approval cycle of the vehicles as regards a particular pollutant. Actually there are as many such charts as the number of pollutants measured by each short test. This means that there are three charts (CO, HC and NOx) for the short tests using laboratory analysers and two (CO and HC) for those using garage ones. The first horizontal line represents the emission standard of the vehicles (conformity of production), while the above parallel line a percentage above it. This line has been drawn in order to distinguish the high (groups 3 and 4) and the very high polluters (groups 5 and 6) according to the type approval of the vehicles. The emission standard of the vehicles refers to CO and HC+NOx, therefore the need of splitting this standard is raised since each short test is measuring HC and NOx separately. This splitting has been made according to the low polluters of the sample in order not

to come up with misleading results due to an engine malfunction. It has been found that the percentage of HC in HC+NOx is 53% for TWC, 47% for conventional and oxi-cat and 15% for diesel vehicles. The vertical line, which is referred to as cut-point, is a limit for approving or not a vehicle according to each short test.

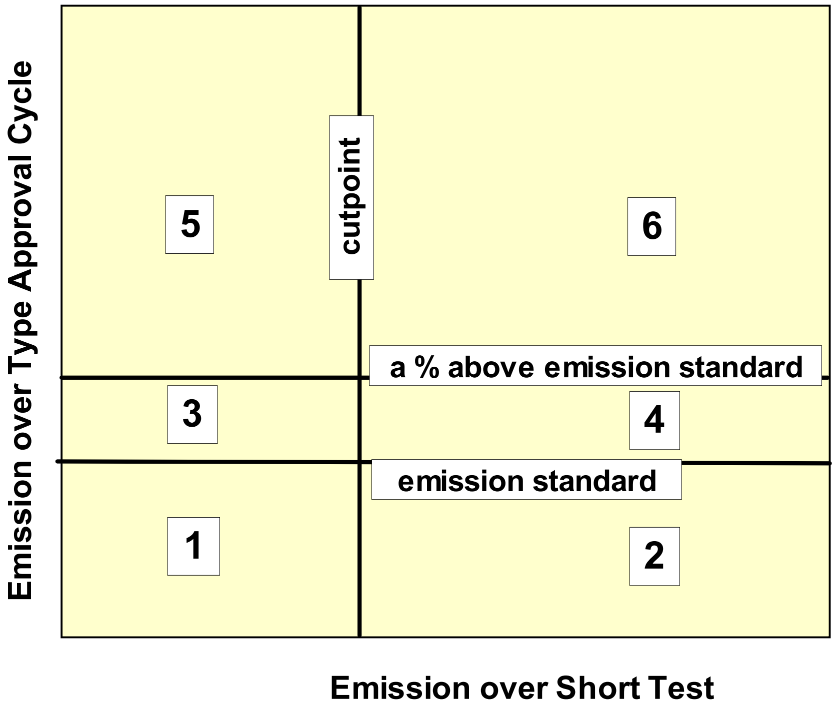

Figure 18 Basic chart

The vehicles in group 1 are referred to as *low polluters* and the very high polluters in group 6 are referred to as *vehicles to be sent to maintenance*. The vehicles in group 2 are *the errors of commission* which are wrongly detected by the short test, while those in group 5 are *the errors of omission* which are wrongly not detected by the short test. The errors of commission and omission should be as low as possible with regard to legal protection of citizens and environmental benefit respectively. The way the vehicles in groups 3 and 4 are treated is described below.

Since there are two or three charts (one for each pollutant) an “overlapping” among vehicles’ pollutants is bound to occur. This means that a particular vehicle could be placed either in different or in the same group according to its emissions. Therefore a vehicle is referred to as to be sent to maintenance when at least one pollutant lies in group 6. A vehicle is an error of commission when at least one pollutant lies in group 2, but no one in group 6 (in that case the vehicle would be referred to as to be sent to maintenance). A vehicle is referred to as a low polluter when all pollutants lay in group 1.

The basic concept of this methodology is to identify the vehicles in group 6, send them to maintenance and make them emit afterwards as the low polluters in group 1. Such approach assumes that all vehicles sent to maintenance receive the best repair, i.e. after maintenance the vehicles emit the same as if they were brand new. Actually, this does not always occur and this

is the reason why the achieved emission reduction is referred to as "potential". The vehicles in group 2, which are also detected by the short test are not taken into account since they are actually low polluters and they emit the same after maintenance as well. These vehicles may have an effect on the cost of the program since the maintenance team is searching for faults, which do not actually exist. The environmental benefit after maintenance by the vehicles in group 4 is supposed to be quite small and it is neither taken into account, since the malfunction of these vehicles seems to be minor and perhaps non repairable. This applies when the percentage above standard for considering a vehicle as a very high polluter is not too high (e.g. 50%) and it is the worst case assumption. Therefore these vehicles are also referred to as vehicles with low environmental benefit.

The parameters that have been taken into consideration and characterise a short test are the following:

- Percentage of errors of commission (P2)
- Percentage of vehicles to be sent to maintenance (P6)[(*)]
- Environmental benefit according to the type approval cycle (Emission Reduction Rate Potential: ERRP)
- Environmental benefit according to Modem "actual" cycle (ERRP - Modem)

P2 should be minimised (legal protection of citizens), P6 should be minimised as well (minimum number of vehicles maintained), while the ERRPs should be maximised (environmental benefit). These parameters characterise adequately the short test without taking into account the errors of omission, because the main objective is an acceptable reduction of the emissions with the minimum cost.

Before evaluating short tests an internal cut-point optimisation is implemented within each short test taking into account the above parameters. Mainly the errors of commission are taken into consideration and should not exceed 5% of the vehicles tested with the particular short test without a dramatic decrease in the emission reduction potential. After a thorough sensitivity analysis it has been found that the environmental benefit is barely sensitive to a range of cut-points near the selected one, which is referred to as optimum.

[(*)] The optimisation was conducted using P6 only. However, the vehicles actually sent to maintenance are the sum P2+P4+P6, despite the fact that P2 and P4 cars lead to only minor (if at all) environmental benefit. It is noted that in the cost-effectiveness calculations that follow the repair costs of P2+P4+P6 cars were taken into account.

5.1.2 TWC equipped vehicles results

The sample has been extended by using the TWC equipped LPG powered vehicles as well. Figures 19-20 (a and b) show the parameters of each short test (ERRPs on the basis of the Modem test results, P6 and P2) both for total and random vehicle sample targeting to the very high polluters (a=50% above standard) with the optimum cut-points which are presented in Table 5.

Table 5 TWC vehicles cut-points

Short test	**Total vehicle sample**			**Random vehicle sample**		
	CO	**HC**	**NOx**	**CO**	**HC**	**NOx**
meTÜV	2.5	0.3	0.5	2	0.3	0.5
ralaTÜV	0.35	1200	500	0.3	1100	400
ragaTÜV	0.25	500	-	0.2	500	-
meMS	3	0.4	0.6	3	0.4	0.6
ralaMS	0.3	1100	500	0.3	1000	500
ragaMS	0.2	600	-	0.2	600	-
Idle	0.3	900	-	0.2	900	-
H-Idle	0.2	700	-	0.2	600	-
ga50-7	0.25	600	-	0.2	400	-
la50-7	0.25	600	800	0.2	600	800
CO: in % except for mass emissions in g/km HC: in ppmC1 except for mass emissions in g/km NOx: in ppm except for mass emissions in g/km						

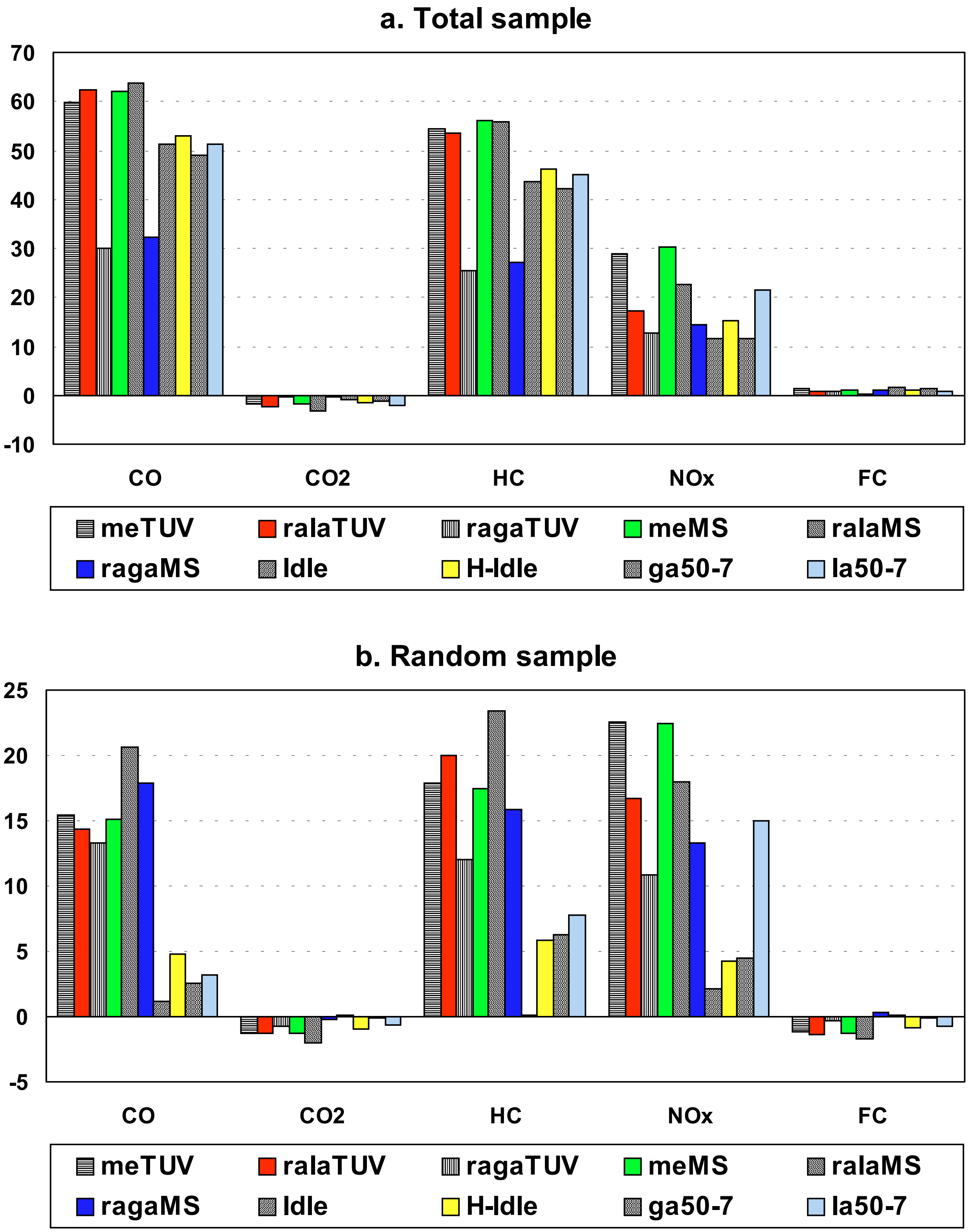

Figure 19 TWC vehicles: ERRPs (in %) according to Modem

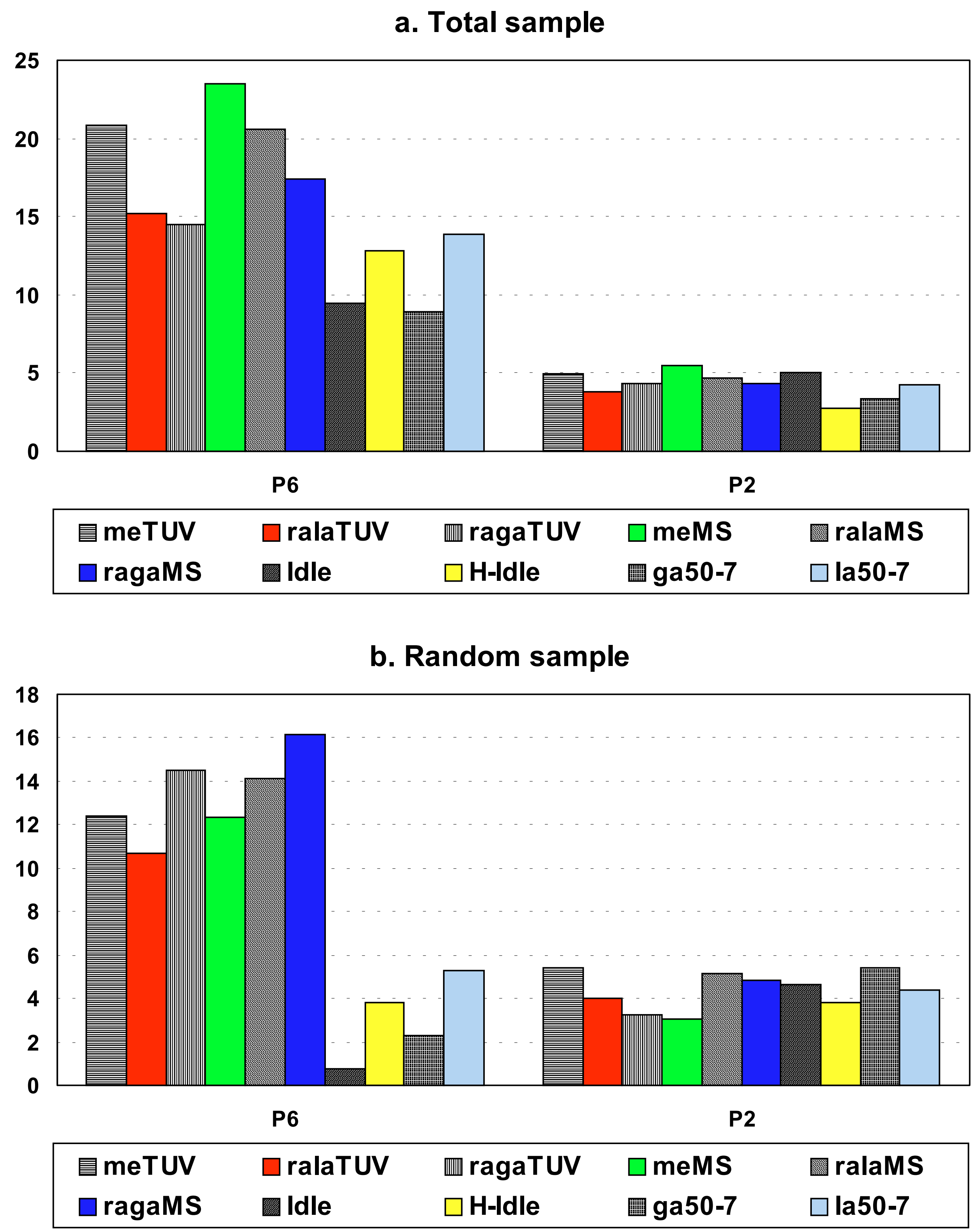

Figure 20 TWC vehicles: P6 and P2 (in %)

5.1.3 Conventional and oxidation catalyst equipped vehicles results

The vehicle sample is neither very large nor homogenous as far as the emission standards are concerned. Therefore, both vehicle technologies are treated as one using the total average emission standard. Figures 21-22 (a and b) show the parameters of each short test both for total and random vehicle sample targeting to the very high polluters (a=50% above standard) with the optimum cut-points which are presented in Table 6.

Table 6 Conventional and oxi-cat vehicles cut-points

Short test	**Total vehicle sample**			**Random vehicle sample**		
	CO	**HC**	**NOx**	**CO**	**HC**	**NOx**
meTÜV	9	3	4	8	3	4
ralaTÜV	1	4000	3000	-	-	-
ragaTÜV	1.5	4000	-	1.5	4000	-
meMS	12	3.5	5	12	3	4
ralaMS	1.1	400	3000	-	-	-
ragaMS	2	4000	-	2	4000	-
Idle	1.5	3000	-	1.5	3000	-
H-Idle	1.5	3000	-	1.5	2500	-
ga50-7	1	3000	-	-	-	-
la50-7	1.5	3000	4500	-	-	-

CO: in % excecpt for mass emissions in g/km

HC: in ppmC1 except for mass emissions in g/km

NOx: in ppm except for mass emissions in g/km

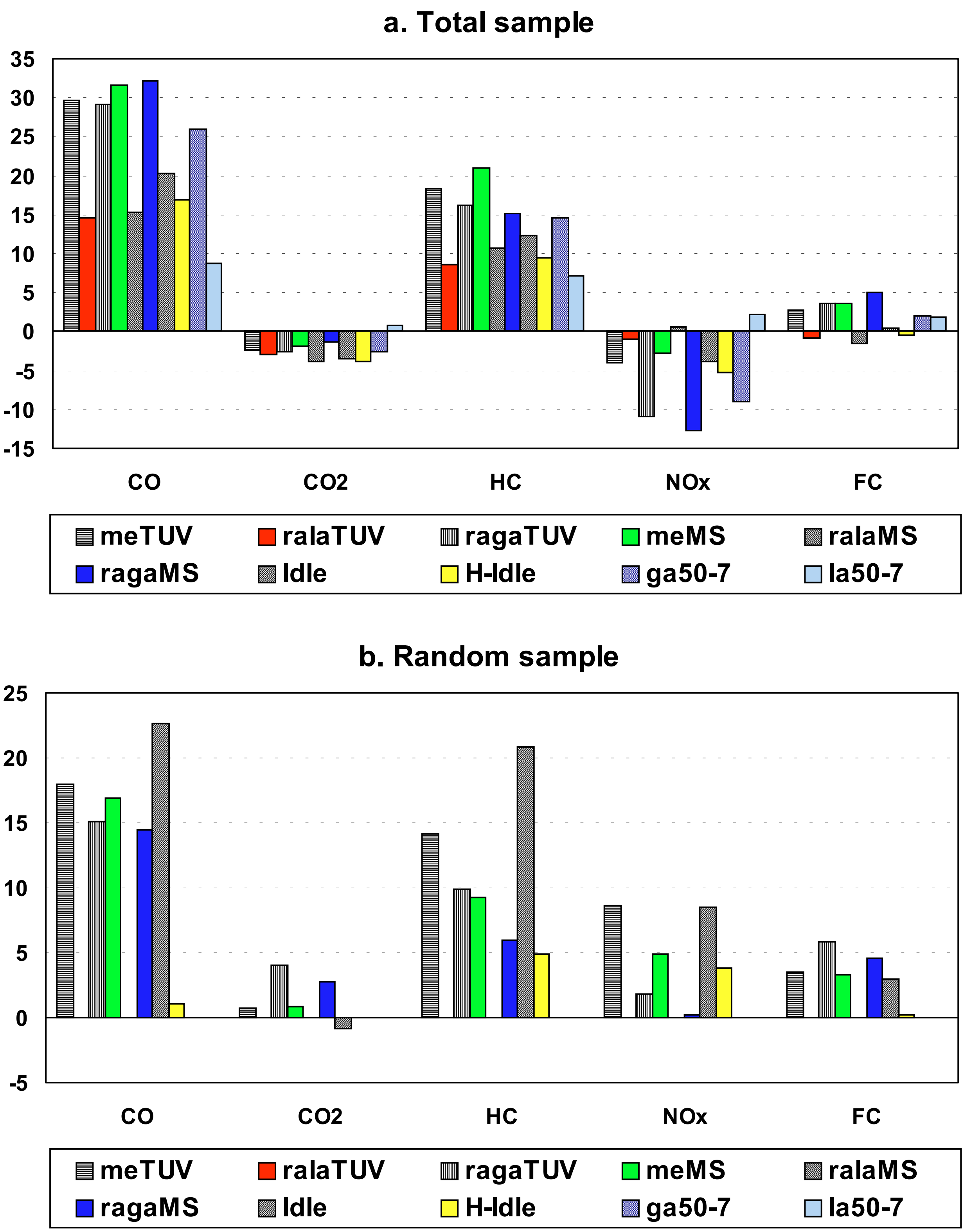

Figure 21 Conventional and oxi-cat vehicles: ERRPs (in %) according to Modem

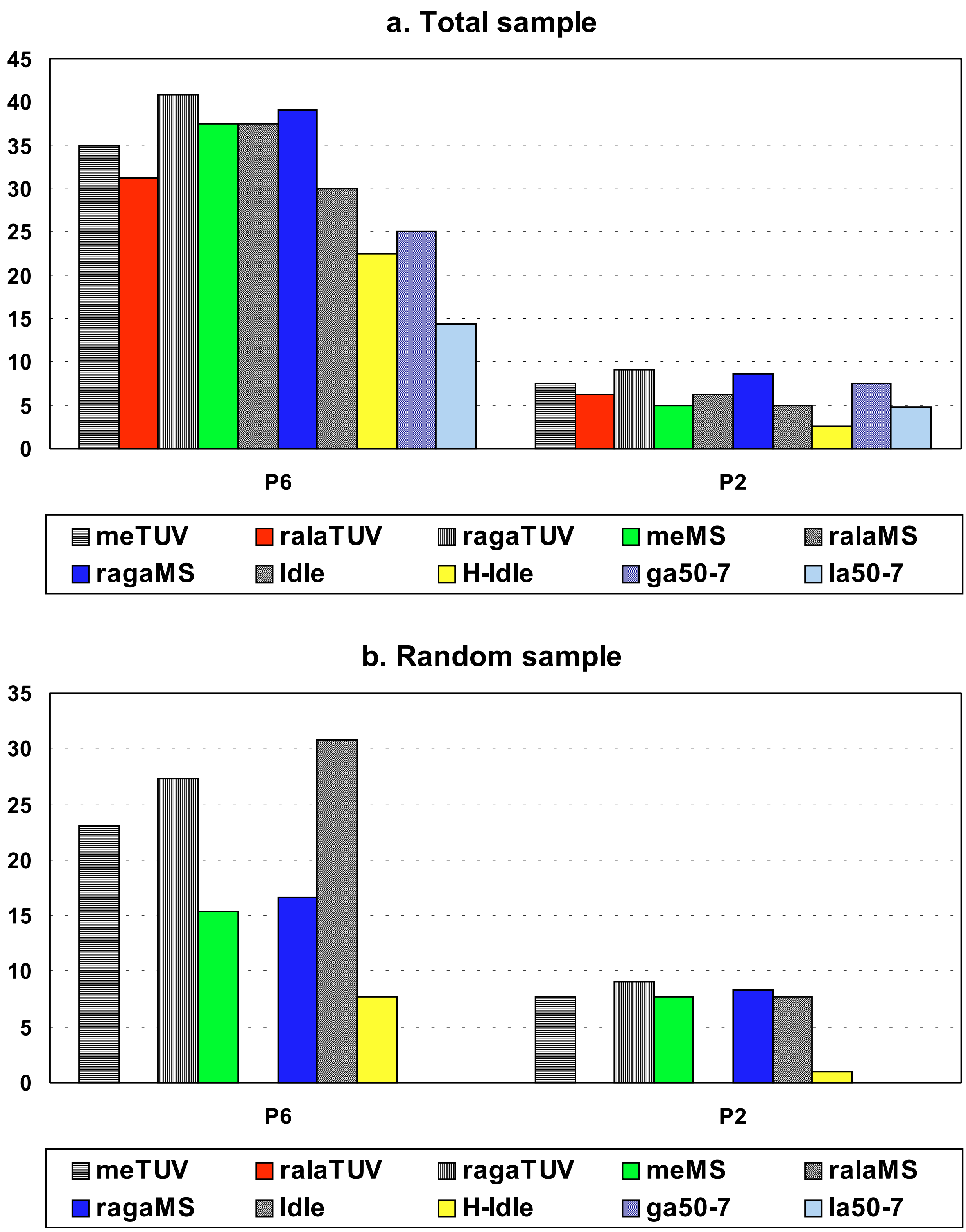

Figure 22 Conventional and oxi-cat vehicles: P6 and P2 (in %)

5.1.4 Diesel vehicles results

A diesel vehicle can be characterised as a high polluter mainly because of the particulate emissions. The other pollutants - CO, HC and probably NOx - are too low and generally they remain unaffected by eventual malfunctions or engine degradation. Therefore, the analysis focuses basically on the measurement of exhaust gas opacity or smoke number. As a result PM becomes the only and guide pollutant in the evaluation.

As far as the short tests measuring opacity are concerned, conclusions can be drawn on the basis of their correlation to NEDC cold cycle. These short tests are instantaneous measurement of opacity over the two short transient short tests, the free acceleration smoke test and the Autonat test. Since only the correlation factor is investigated, all vehicles should be correlated independently of their type approval. Figure 23 (a, b, c and d) shows this correlation.

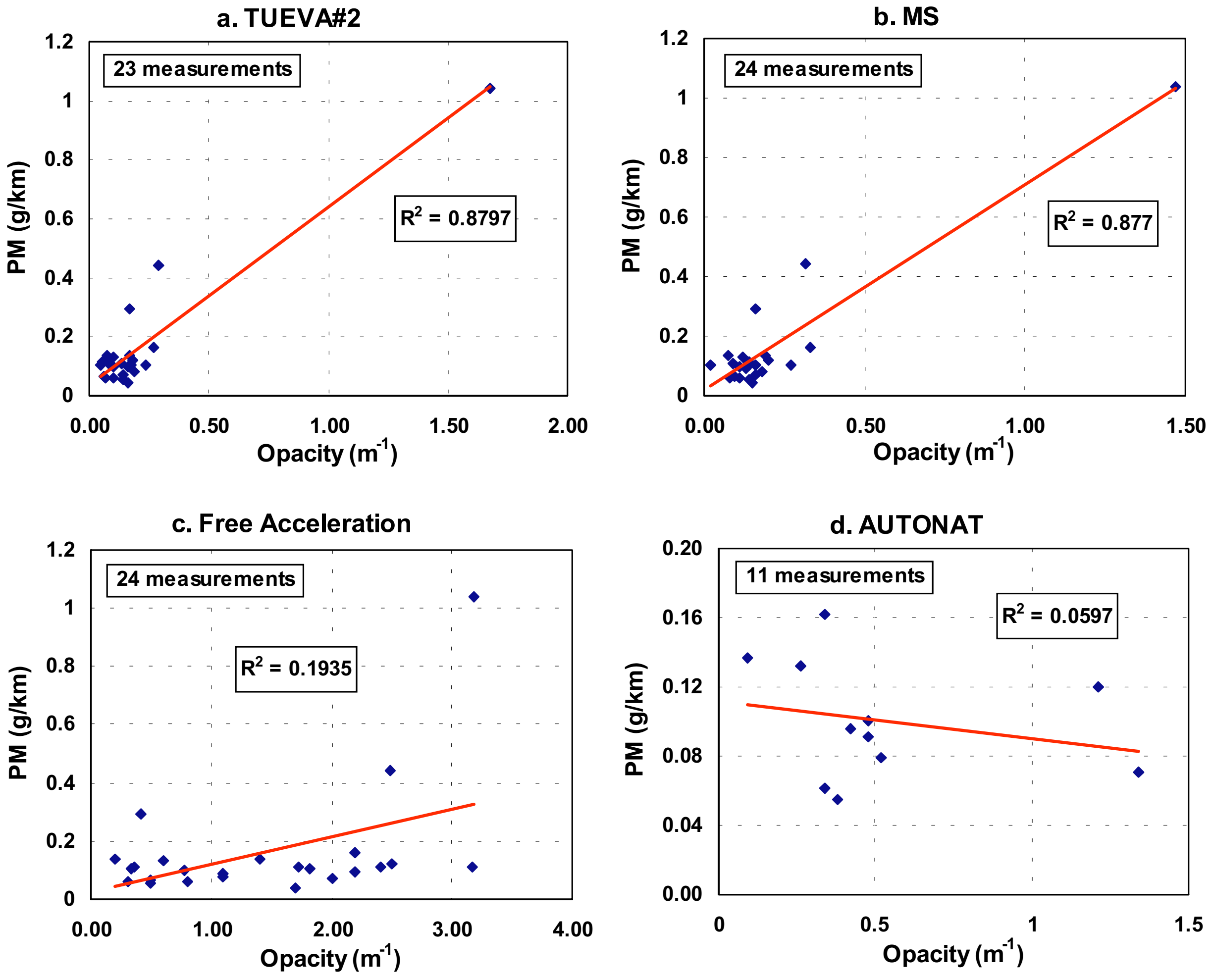

Figure 23 NEDC PM and short tests opacity correlation (diesel vehicles)

From these figures it can be derived that both short transient tests (Figures 23a and 23b) show an increasing tendency for the high polluters with a good correlation factor. The free acceleration test (Figure 23c) also shows such a tendency but not so clearly as the transient tests. According to this chart the very high polluters seem to be indicated but the dispersion is very high (low correlation factor). The Autonat test (Figure 23d) can hardly show such an increasing tendency (the sample is very small since it includes only vehicles from INRETS). However all above correlations deteriorate when a high emitting vehicle (VW bus) is excluded.

Even though the sample is quite small a demonstrative attempt to evaluate the short tests has been carried out. The Autonat test has been excluded from the evaluation because it does not show any correlation to NEDC cold cycle at all.

The PM emission standard has been chosen at 0.18 g/km, which seems to be sufficiently close to real emission results. The cut-points are selected in such a way so that the very high polluters can be detected by all short tests. Table 7 includes all relevant calculations (VW bus has been excluded since it overestimates the ERRPs).

Table 7 Evaluation of short tests for diesel vehicles

Short Test	Group	N	P	NEDC			Modem		
				E	EF	ERRP	E	EF	ERRP
ragaTUVA#2	1	18	86	1.661	0.092		2.333	0.130	
	2	1	5	0.162			0.260		
	4	0	0	0.000			0.000		
	6	1	5	0.443	0.443	14	0.725	0.725	17
	Cutpoint= 0.25 m^{-1}								
	N= 21		78 %						
	E= 2.56						E= 3.53		
ragaMS	1	19	86	1.753	0.092		2.508	0.132	
	2	1	5	0.162			0.260		
	4	0	0	0.000			0.000		
	6	1	5	0.443	0.443	13	0.725	0.725	16
	Cutpoint= 0.3 m^{-1}								
	N= 22		81 %						
	E= 2.65						E= 3.70		
FAS	1	17	77	1.584	0.093		2.250	0.132	
	2	3	14	0.341			0.604		
	4	0	0	0.000			0.000		
	6	1	5	0.443	0.443	13	0.725	0.725	16
	Cutpoint= 2.4 m^{-1}								
	N= 22		81 %						
	E= 2.66						E= 3.79		

As Table 7 shows the free acceleration test seems capable of indicating the very high polluters, but the errors of commission are as expected significantly high too, due to the dispersion of the measurements (very low correlation factor).

5.1.5 Directive 92/55/EEC

The effectiveness of the current Directive 92/55/EEC has been evaluated in the case of TWC vehicles. The partial tests included and the corresponding cut-points are shown in Table 8.

Table 8 Tests and cut-points of Directive 92/55/EEC for TWC cars

Partial tests	Cut-points	
	CO (%)	lambda
Idle	0.5	-
High idle	0.3	1 ± 0.03

As Table 8 shows, there are two cut-points for lambda therefore, the basic chart is somewhat different since there are two groups in the chart defined as groups 2, 4 and 6.

Results have been produced for two cases; total and the random vehicle sample targeting the high polluters (0% above standard). Figures 24-25 (a and b) show the parameters of this short test for both samples.

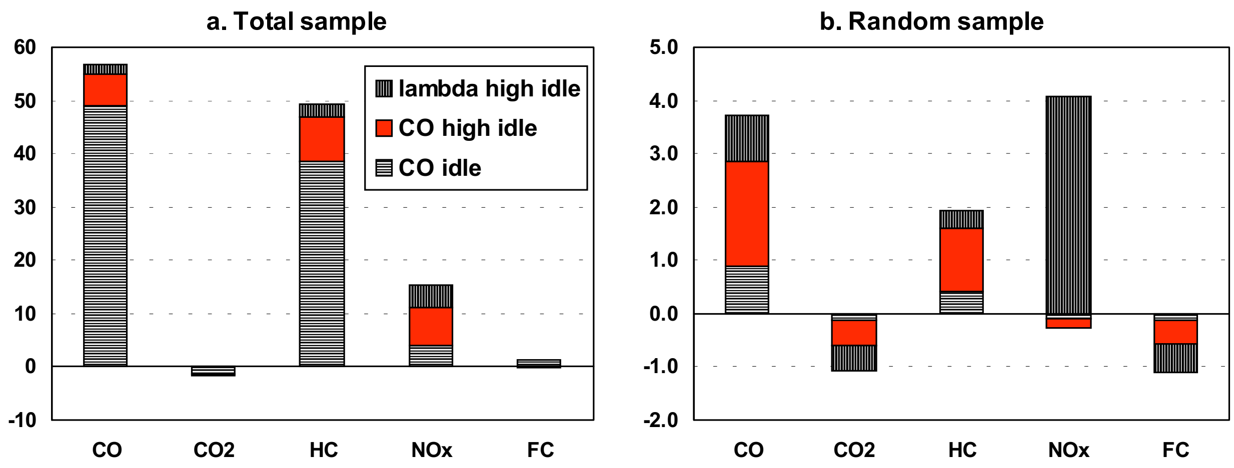

Figure 24 Directive 92/55/EEC: ERRPs (in %) according to Modem for TWC cars

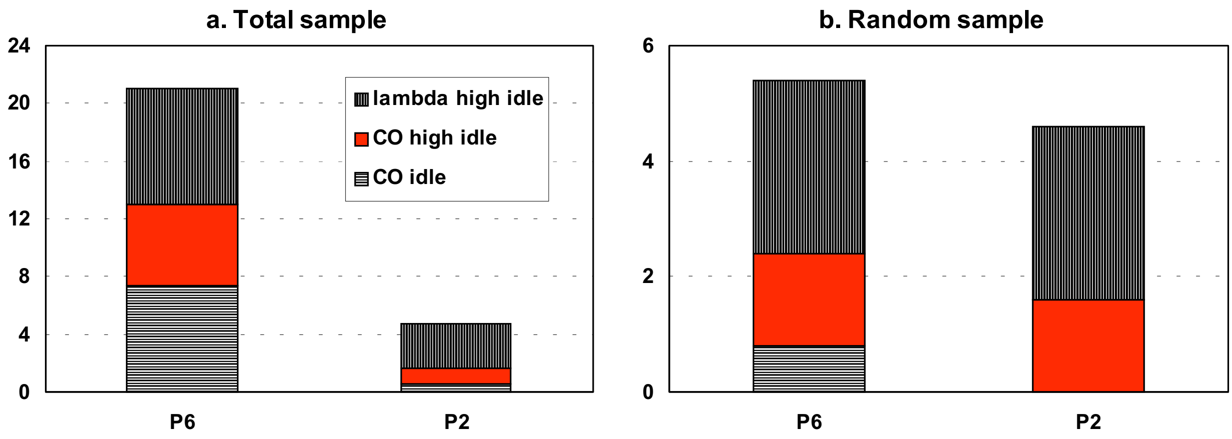

Figure 25 Directive 92/55/EEC: P6 and P2 (in %) for TWC cars

5.2 Remote sensing

5.2.1 Comparison of Remote Sensing with Idle Tests

The vehicles stopped at the roadside were subjected to a standard tailpipe emissions test. Figure 26 shows the comparison of the idle CO emissions measured at the tailpipe using conventional garage equipment with the corresponding remote sensing CO reading. It will be noted that there is a great deal of scatter in this graph. This large amount of scatter is not because of errors in the remote sensing measurement - it is due to the different operating conditions the vehicle was under for the two tests: under some load while passing through the remote sensing device as opposed to being under no load for the idle test.

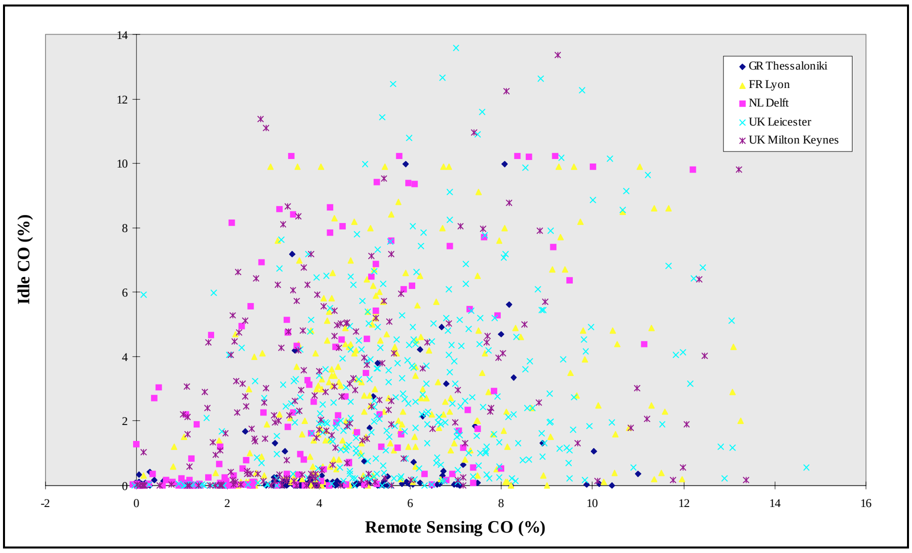

Figure 26 Comparison of idle test results with remote sensing readings: all data

In Figure 27, similar data is used (but this time from the fast idle test), but only the data for catalyst cars under almost steady speed have been plotted (i.e. vehicles undergoing high accelerations or decelerations have been rejected). This shows a better comparison between the two tests. With a remote sensing cut-point of 5% CO (indicated by the vertical line on the graph), ten of the vehicles have high remote sensing and fast idle CO emissions - in comparison to a fast idle limit of 0.3% indicated by the horizontal line. There are, however, seven vehicles with high remote sensing readings and low idle readings (i.e. errors of commission). Some of these vehicles had only travelled a short distance from the start of their journey and may have still been running under cold start conditions when passing through the remote sensing device. There are also a large number of vehicles with high idle emissions and remote sensing readings less that 5% CO. Hence using a cut-point of 5% will result in a number of high polluting vehicles being missed (errors of omission).

Where multiple readings have occurred (i.e. when the same vehicle has passed through the remote sensing site on more than one occasion) the remote sensing readings have been averaged. However, quite a lot of the data is from single readings.

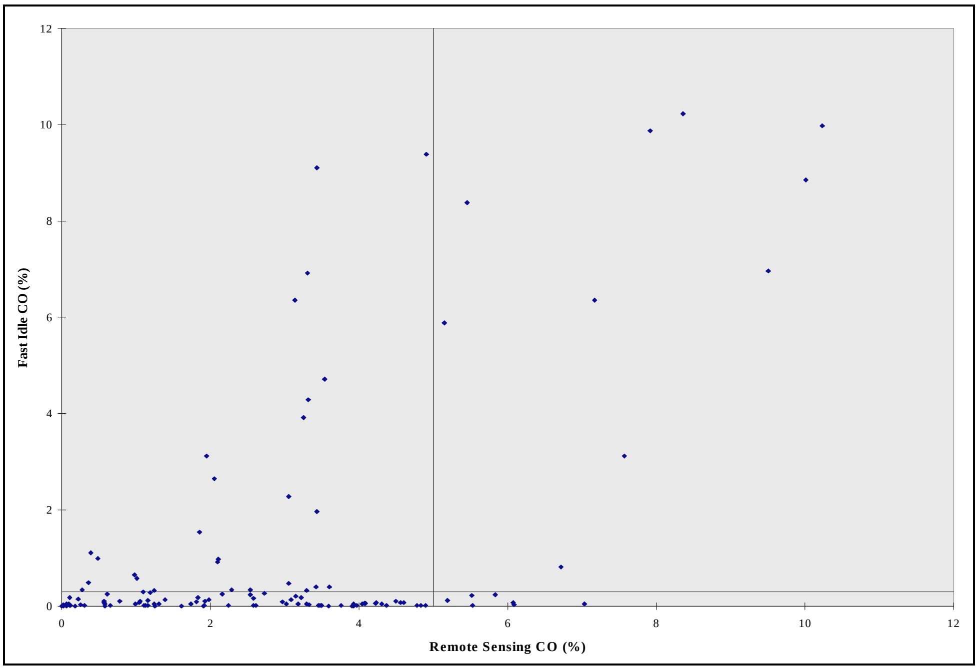

Figure 27 Comparison of fast idle test results with remote sensing: catalyst cars with low accelerations and decelerations

5.2.2 Errors of Commission and Errors of Omission

From the remote sensing and roadside idle/fast idle data the following errors have been calculated:

Errors of Commission: vehicles identified as high emitters by remote sensing but with low idle/fast idle emissions.

Errors of Omission: vehicles with low remote sensing reading but with high idle/fast idle emissions.

(however, it should be noted that the idle/fast idle test has its own errors of commission and errors of commission when compared to a NEDC dynamometer test)

The errors have been calculated according to the vehicle type:

a. all vehicles (catalyst and non-catalyst).

b. catalyst vehicles only.

c. non-catalyst vehicles only.

and according to the remote sensing readings:

1. all data.

2. remote sensing readings that occurred under almost steady state condition (measured acceleration within ±2 mph/s (±0.89 m/s^2) - i.e. all readings that occurred under high acceleration and deceleration have been excluded.

3. as 2 but only for vehicles that have repeat readings (more than one valid reading).

4. all vehicles that have repeat readings (more than one valid reading) regardless of their measured acceleration.

The limits used for determining the errors of commission and the errors of omission are a remote sensing cut-point of either 5% or 7% CO for catalyst and non-catalyst vehicles respectively and the appropriate idle test limits.

For non-catalyst cars, an idle test limit of 3.5% CO has been used. The in-service exhaust emissions test according to the Directive 96/96/EC specifies limits for non-catalyst cars as either 3.5% or 4.5% CO at natural idle depending on the age of the vehicle. As the ages of all these vehicles are not known, the limit of 3.5% has been used, which is applicable to vehicles from 1986 onwards.

The emission limits for cars fitted with catalytic converters has been taken as 0.5% CO at idle and 0.3% CO at fast idle. These are the default limits as specified in Directive 96/96/EC, although in some countries the actual limits used for the natural idle test are vehicle type dependent, relying on information supplied by the vehicle manufacturer. In the calculations of the errors, a catalyst vehicle is considered a pass if both the idle CO is no greater than 0.5% and the fast idle CO is not greater than 0.3%, whereas the vehicle is considered a fail if either the idle or the fast idle exceed these limits.

The resulting errors are shown listed in Table 9 - the errors are shown both as an absolute number and as a percentage of the number of vehicles in each group. Using a remote sensing cut-point of 5% CO for catalyst cars, the errors of commission are 10% and the errors of omission 19% when considering all the data. For the non-catalyst cars, with a remote sensing cut-point of 7%, the errors of commission and omission are 13% and 28% respectively.

Restricting the remote sensing data to only include readings taken under low acceleration and decelerations, although decreasing the absolute numbers, has very little effect on the percentages for either the errors of commission or omission (although, if a large number of vehicles are measured under very high acceleration, then the errors of commission will be effected, due to higher than normal emissions occurring during operating conditions requiring fuel enrichment).

However, restricting the reading to only those vehicles with multiple valid readings significantly effected the errors. For both catalyst and non-catalyst vehicles, the errors of commission reduced significantly (down to 5% for catalyst and 4% for non-catalyst) regardless of whether high accelerations and decelerations were excluded or not. The errors of omission decreased for catalyst cars to 13% whereas for non-catalyst cars they increased to 36%.

Table 9 Errors of Remote Sensing in comparison with idle tests

	All Data	**Low Accels & Decels only**	**.. with Repeat Passes**	**All Data with Repeats**
a. For all Vehicles				
Number of Vehicles	747	601	110	150
Errors Of Commission	91 (12%)	73 (12%)	5 (5%)	7 (5%)
Errors Of Omission	187 (25%)	158 (26%)	32 (29%)	40 (27%)
True Failures	62 (8%)	54 (9%)	9 (8%)	10 (7%)
b. For Catalyst Vehicles only				
Number of Vehicles	253	201	42	61
Errors Of Commission	25 (10%)	20 (10%)	2 (5%)	3 (5%)
Errors Of Omission	47 (19%)	41 (20%)	7 (17%)	8 (13%)
True Failures	18 (7%)	17 (8%)	5 (12%)	5 (8%)
c. For Non-Catalyst Vehicles only				
Number of Vehicles	494	400	68	89
Errors Of Commission	66 (13%)	53 (13%)	3 (4%)	4 (4%)
Errors Of Omission	140 (28%)	117 (29%)	25 (37%)	32 (36%)
True Failures	44 (9%)	37 (9%)	4 (6%)	5 (6%)

Criteria:

EoC: Catalyst	idle CO <=0.5% AND fast idle CO <= 0.3% AND RS CO >5%
EoC: Non-Catalyst	idle CO <=3.5% AND RS CO >7%
EoO: Catalyst	(idle CO >0.5% OR fast idle CO > 0.3%) AND RS CO <=5%
EoO: Non-Catalyst	idle CO >3.5% AND RS CO <=7%

5.2.3 Comparison of Remote Sensing with Dynamometer Tests

A sub-sample of the vehicles stopped for the roadside idle test were submitted to a number of dynamometer based tests. All of these vehicles had passed through the remote sensing site and thus some remote sensing data was available for each vehicle. Most of the vehicles had a least one valid remote sensing CO reading. Some of the vehicles passed through the site on several occasions, resulting in a number of readings.

Figure 28 shows an example of the dynamometer results plotted against the remote sensing values. In this case, the CO emissions from the NEDC cycle are plotted against the corresponding remote sensing CO (the valid remote sensing readings have been averaged for each vehicle to take into account multiple passes). In addition to the data from this project, additional data from the Swedish remote sensing work has been added. The remote sensing data from Sweden were sampled at one site near Stockholm, and most of the data are averages from repeat sensor readings. In the Swedish work, instead of using the European legislative cycle, the vehicles were tested over their own legislative cycle (the USA's FTP cycle). Hence the results from either the NEDC or the FTP are shown plotted against the remote sensing values.

The data plotted in Figure 28 is for both catalyst and non-catalyst cars. As there appears to be a much greater variation in the tailpipe concentrations in a non-catalyst car than from a catalyst car with a closed loop control system, the following analysis will deal exclusively with catalyst vehicles.

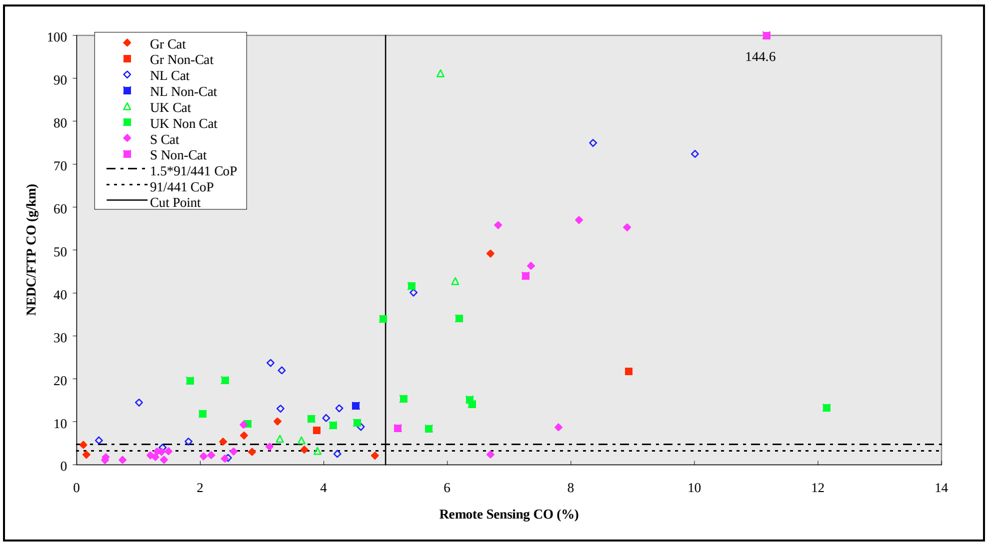

Figure 28 Dynamometer CO plotted against remote sensing CO for all vehicles

Carbon Monoxide (CO)

To allow for the different dynamometer tests that the vehicles from this project and the Swedish project were subjected to, the ratios of the actual emissions relative to their corresponding legislative emissions limits will be used. Figure 29 shows these relative CO emissions plotted against the remote sensing CO readings (again average per vehicle). The two horizontal lines indicate the legislative emissions limits and one and a half times this limit.

This graph shows that some of the vehicles had very high dynamometer CO emissions - some almost 30 times the limit. It is clear from the graph that remote sensing was able to detect these

gross emitters. Setting a cut-point of 5% CO would select 12 vehicles - all of them high emitters apart from one which is only just over the limit (Group 4 category vehicle).

Using this cut-point, there are a number of vehicles that are over the emission limit (ranging from 1.5 to about 7 times the limit) that remote sensing would not select (Group 5 category vehicles). However, some of the remote sensing data are based on just one reading. It is possible that multiple readings may change the situation - moving some of the vehicles from Group 5 into Group 6.

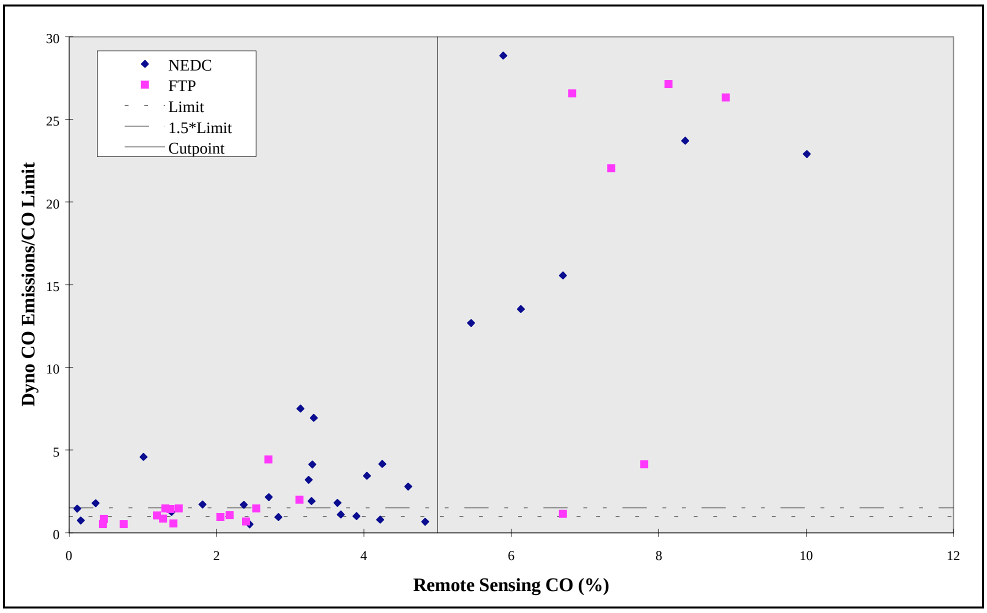

Figure 29 Dynamometer CO plotted against remote sensing CO

Hydrocarbons (HC)

For hydrocarbons, the result is not as good as for CO. Figure 30 shows the HC dynamometer results plotted against the remote sensing HC readings. Again, emission ratios are used for the dynamometer readings (for the NEDC test, the HC limit has been taken as 51% of the legislative HC+NOx limit). The graph shows a large range of remote sensing readings for vehicles with relatively low dynamometer results. It is therefore impractical to set a cut-point for the remote sensing HC readings that will allow vehicles with high HC to be correctly selected, without including a large number of vehicles with low levels of HC.

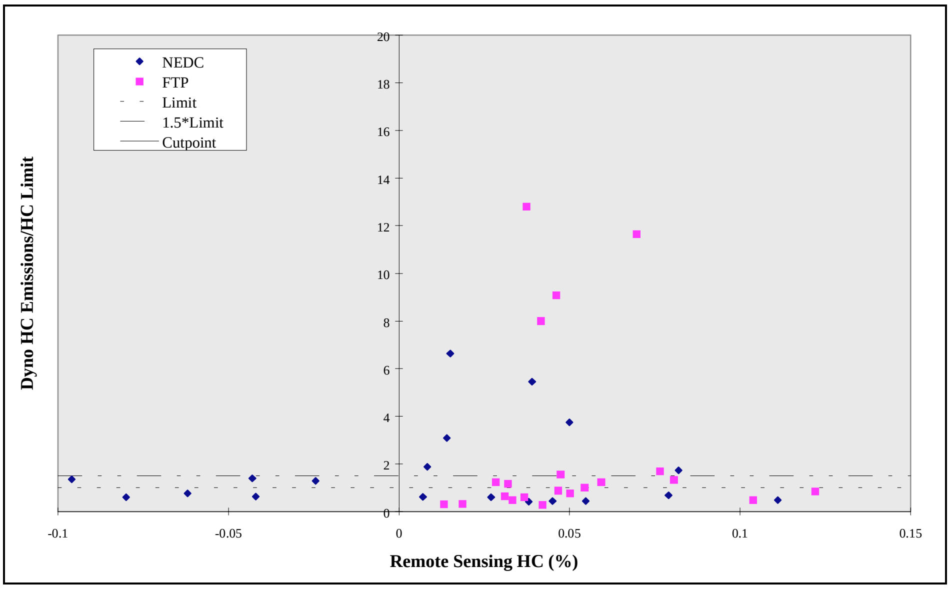

Figure 30 Dynamometer HC plotted against remote sensing HC

However, plotting the same dynamometer HC emission ratios against the CO remote sensing results shows a much better comparison. With the cut-point of 5% CO, in addition to selecting vehicles with high CO emissions, remote sensing would also select most of the vehicles with high HC emissions. It is therefore possible that hydrocarbons do not need to be measured - just targeting vehicles with high CO emissions would also select most of the vehicles with high hydrocarbons (although there will, no doubt, be some exceptions). This has also been found in the short test evaluation carried out by LAT.

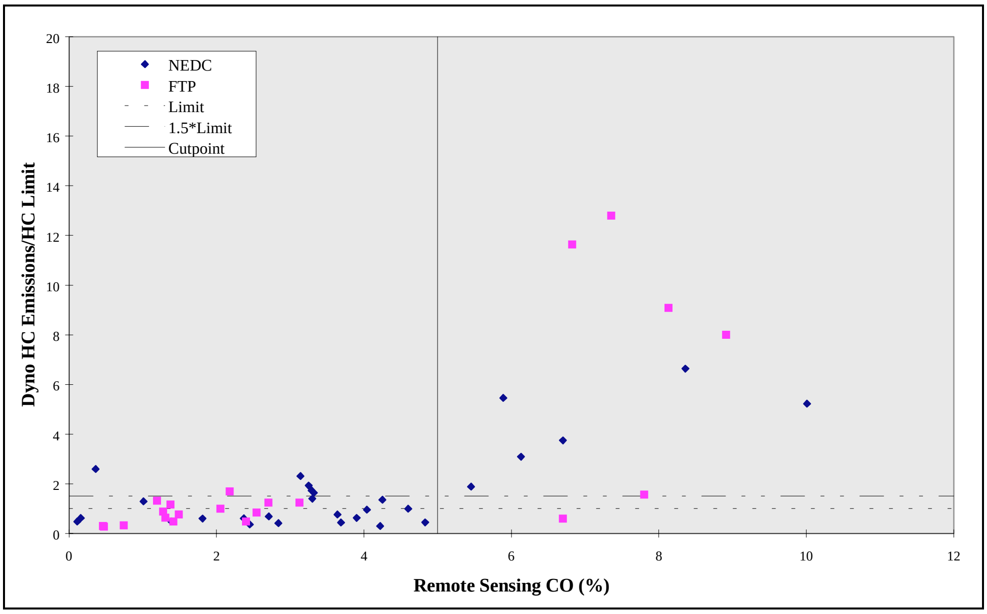

Figure 31 Dynamometer HC plotted against Remote Sensing CO

Oxides of nitrogen (NOx)

Figure 32 similarly shows the dynamometer NOx emission ratios plotted against the remote sensing NO readings. There are a fewer number of points plotted on this graph, because of the lower success rate of the remote sensing device to detect valid NO values. Most of the vehicles subjected to the dynamometer tests were selected on the basis of being high CO emitters. Hence, most of the vehicles have low NOx emissions. There is only one vehicle, which has significantly high NOx emissions - about 4 times the NOx limit. This vehicle also has a high remote sensing reading.

It is therefore possible that setting an NO cut-point of about 1% would allow vehicles with high NOx emissions to be detected. However, this is based on a very limited sample size - further work investigating vehicles with high NOx emissions is needed to evaluate the effectiveness of the NO channel.

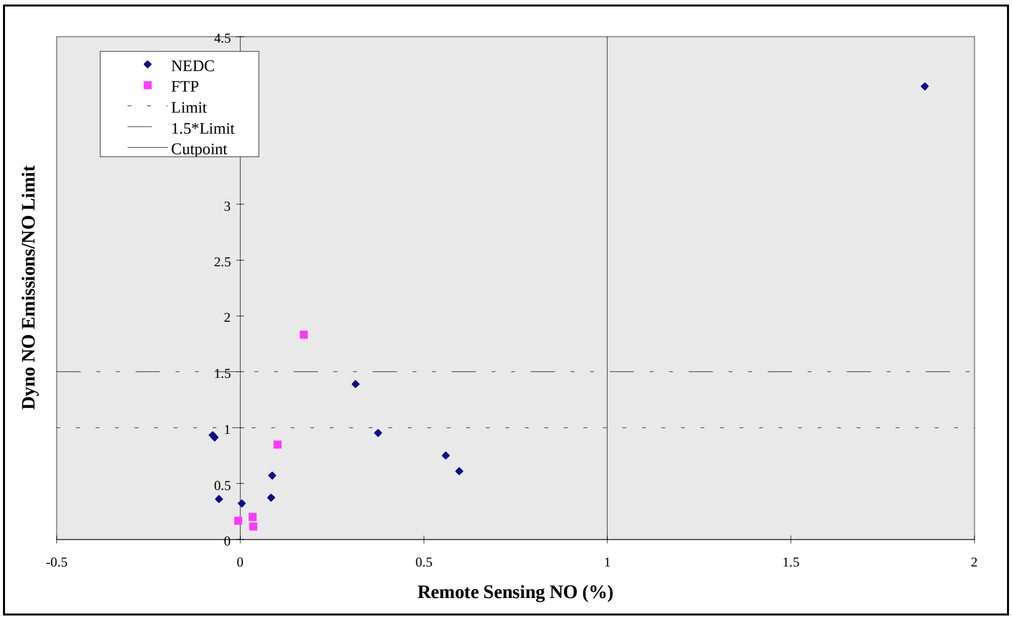

Figure 32 Dynamometer NOx plotted against remote sensing NO

5.2.4 Comparison of Remote Sensing with Dynamometer and Idle tests

Vehicles that have been subject to idle & fast idle and dynamometer tests and which have valid remote sensing readings are listed in Table 10. This table lists the CO emissions for the various tests (the remote sensing values are average values where repeat readings occurred).

Out of a total of 29 vehicles, 15 vehicles have dynamometer CO emissions over 4 g/km. Eleven of the vehicles have idle and/or fast idle CO emissions greater than 1%. Of these 11 vehicles, 10 are correctly identified as high emitters (i.e. there is one error of commission).

Six of the vehicles have high remote sensing CO reading. All six vehicles are correctly identified as high emitters which is confirmed by the idle tests.

These values are also shown graphically in Figure 33. The six vehicles mentioned above (signified by labels 1, 13, 22, 27, 30 & 33 on the graphs) show high dynamometer, idle and

remote sensing results. Vehicles 16, 19 and 20 have high idle and dynamometer results but low remote sensing readings. However, these three vehicles have only one remote sensing reading - repeat readings could alter the comparison.

Table 10 CO Emissions for Vehicles subjected to Remote Sensing, Dynamometer and Idle/Fast Idle Tests

Lab. Ref.	Idle (%)	Fast Idle (%)	NEDC CO (g/km)	Remote Sensing(%)	Graph Label
61	**4.54**	**5.06**	**49.18**	**6.70**	**1**
62	0.15	0.32	**10.11**	3.25	2
63	1.09	0.34	5.36	2.37	3
64	0.02	0.06	**6.83**	2.71	4
66	0.07	0.01	2.36	0.16	6
68	0.01	0.01	3.50	3.69	8
71	0.01	0.14	2.99	2.84	9
72	0.02	0.02	4.62	0.11	10
73	0.11	0.06	2.11	4.83	11
551	**11.30**	**10.10**	**72.47**	**8.36**	**13**
552	0.01	0.42	5.42	1.81	14
553	**2.89**	**10.63**	**13.14**	4.25	15
554	**3.30**	**3.00**	**21.95**	3.32	16
555	0.00	0.00	**14.49**	1.01	17
557	**8.34**	**2.62**	**23.72**	3.14	19
558	0.03	**7.40**	**13.06**	3.30	20
559	0.00	0.00	**10.88**	4.04	21
560	**9.07**	**9.28**	**72.37**	**10.01**	**22**
561	0.40	0.55	5.64	0.36	23
562	0.00	0.04	3.97	1.39	24
563	0.05	0.07	1.61	2.45	25
564	0.00	0.02	2.51	4.22	26
565	**2.90**	**7.20**	**40.09**	**5.45**	**27**
566	0.02	0.02	**8.84**	4.60	28
1	0.92	1.47	**91.18**	**5.89**	**30**
4	**2.49**	0.05	**42.75**	**6.13**	**33**
5	0.40	0.11	5.71	3.64	34
9	0.00	0.01	**6.07**	3.29	38
10	0.00	0.00	3.19	3.90	39

Number of Vehicles	29
High Polluters: NEDC >6g/km	16
High Polluters: Idle and/or Fast Idle >1%	11
Correctly Identified by Idle/Fast Idle	10
High Polluters: RS> 5%	6
Correctly identified by RS	6
Confirmed by Idle	6

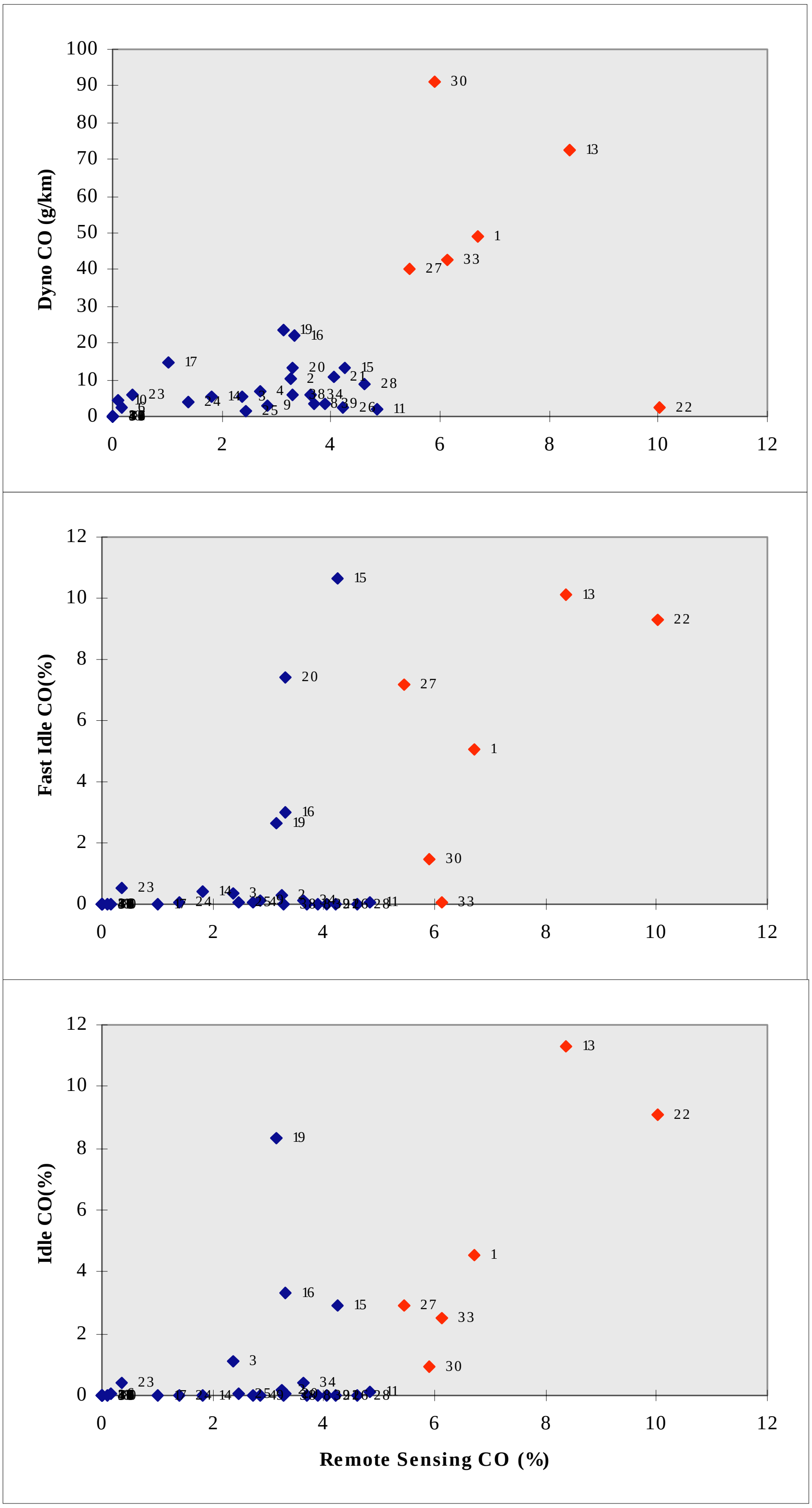

Figure 33 Comparison of Dynamometer, Fast Idle and Idle CO emissions with Remote Sensing CO Emissions

5.2.5 Emission Reduction Rate Potential

To provide consistency in the analytical approach used in the overall project, the approach follows the analysis method described previously for the evaluation of the short tests.

If the remote sensing readings are plotted against their corresponding results from a dynamometer based test (type approval emissions test), the vehicles can be categorised according to the following categories (as explained elsewhere):

Group 1	Vehicles correctly identified as low emitting vehicles
Group 2	Vehicles incorrectly identified as high emitting vehicles - they are in fact low emitting vehicles (errors of commission)
Group 3	Vehicles with slightly high emissions identified as low emitting vehicles
Group 4	Vehicles with slightly high emissions identified as high emitting vehicles
Group 5	Vehicles incorrectly identified as low emitting vehicles whereas they are in fact high emitting vehicles (errors of omission)
Group 6	Vehicles correctly identified as high emitting vehicles

The ideal is to identify all the vehicles with high emissions (vehicles in Group 6) and send them for maintenance so that their emissions are reduced to a normal level (the same as vehicles in Group 1).

Any errors of commission (vehicles in group 2) are vehicles incorrectly identified, and thus their emissions will not change significantly even if they are subjected to maintenance.

For vehicles within group 4, because their emissions are only slightly above the limits, presumably due to a minor problem, then, again, any maintenance is unlikely to have any significant effect on their emissions.

Based on a remote sensing cut-point of 5% CO, then from Figure 29, it can be seen that there are 11 vehicles that fall into the group 6 category. The remote sensing reading and dynamometer test results for these 11 vehicles are listed in Table 11. The remote sensing reading are the average readings obtained - this might be from a number of passes or just a single pass. Because some of the vehicles were tested over the NEDC test cycle and some over the FTP test cycles, the emissions of CO, HC and NOx are shown as ratios with respect to their corresponding limits (because the EC legislation specifies the limits in terms of the sum of HC & NOx, the HC and NOx limits has been approximated as being 51% and 49% of the total limit respectively).

Table 11 Catalyst vehicles falling in group 6 based on CO emissions

Remote Sensing				Dynamometer				
Avg CO (%)	Avg HC (%)	Avg NO (%)	Avg CO2 (%)	CO	HC	NOx	CO_2	FC
				Emissions/Emission Limit			g/km	
10.01			7.70	22.90	5.23	0.61	130.23	79.87
8.91	0.04			26.33	8.00	0.30		
8.36	0.02		8.94	23.71	6.64	1.30	156.34	90.17
8.13	0.05			27.14	9.08	0.17		
7.80	0.05			4.14	1.56	0.73		
7.35	0.04			22.05	12.80	0.87		
6.83	0.07			26.57	11.64	1.55		
6.70	0.05		9.65	15.56	3.75	0.35	137.02	69.67
6.13	0.01	0.31	10.55	13.53	3.09	1.39	175.26	78.16
5.89	0.04	-0.06	10.85	28.86	5.46	0.36	139.92	92.36
5.45	0.01		11.22	12.69	1.89	0.91	140.80	65.29

The Emission Reduction Rate Potentials of a test, as used in the evaluation of the short tests, for the remote sensing tests is as follows:

- the Emission Factor EF_{i6} has been calculated as the average of the values listed in Table 11 (i.e. vehicles with high remote sensing and dynamometer CO) for all the pollutants, not just CO (although for CO, HC and NOx the actual emissions rather than the ratios have been used, the ratios being used just to categorise the vehicles).
- the Emission Factor EF_{i1} has been calculated for all pollutants from the vehicles with low remote sensing and dynamometer CO (again actual emissions rather than ratios have been used).

The resulting Emission Reduction Rate Potential are shown graphically in Figure 34.

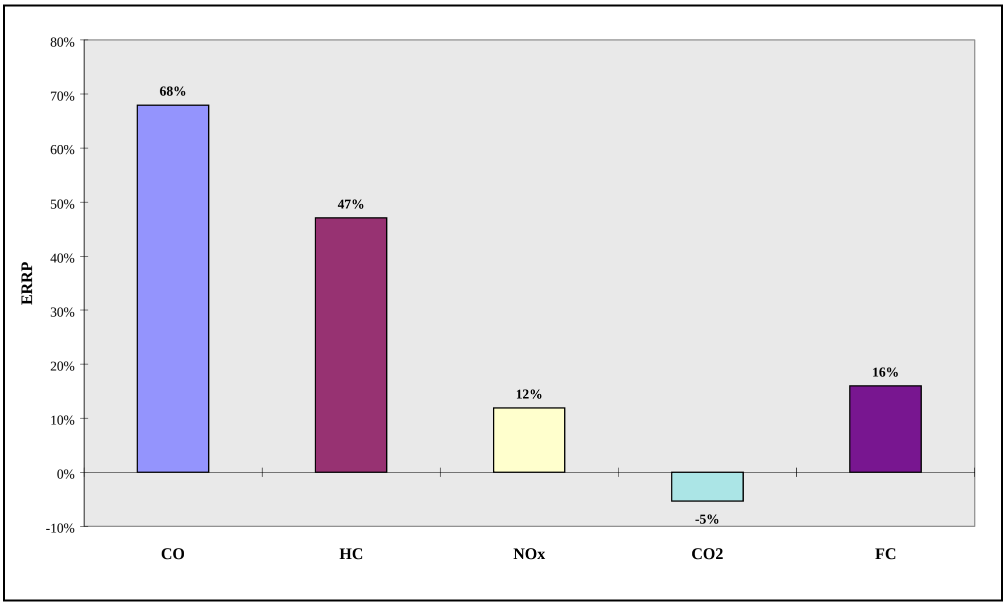

Figure 34 Emission Reduction Rate Potential (ERRP) of remote sensing based on a CO cut-point of 5%

This shows a high reduction rate potential for carbon monoxide and hydrocarbon emissions (68% and 47% respectively), a reduction in oxides of nitrogen emissions and fuel consumption (12% and 16% respectively) and a 5% increase in carbon dioxide emissions. The reason for the increase in the carbon dioxide emissions is that the faults decrease the combustion efficiency of the engine, resulting in fuel wastage, which produces high carbon monoxide and hydrocarbon emissions but lowers the carbon dioxide emissions. When the fault is repaired, the carbon dioxide emissions are restored to normal, with reductions in the carbon monoxide and hydrocarbon emissions.

The above ERRPs are based on just a CO cut-point (5% CO). The inclusion of an NO cut-point (1% ?) would modify these values, possibly increasing the NOx reduction and decreasing the CO and HC values. However, as previously mentioned, there was only one vehicle with significantly high NOx emissions - further information on vehicles with high NOx emissions is required to fully evaluate the potential of a NO cut-point.

It should be remembered that these Emission Reduction Rate Potentials are based on the sample used in the dynamometer tests. These were selected from the remote sensing and roadside tests and are typically high emitting vehicles. This sample is therefore a biased one, with a large number of high emitting vehicles.

To fairly evaluate the emission reduction rate potentials, an unbiased sample is required. In practice, this would require a large number of vehicles from the remote sensing survey selected at random and subjected to dynamometer tests - this would be extremely expensive and time consuming. However, the remote sensing readings from a random selection of vehicles are available - the remote sensing reading of almost all the vehicles that passed through the test sites.

These samples of vehicles are made up of various vehicle types - petrol non-catalyst, petrol catalyst and diesels. As mentioned previously, in some countries it is possible to determine the age of the vehicle from the registration number. Using assumptions about the year of

introductions of catalyst, it is possible to consider just the latest vehicles which will be catalyst-petrol and diesel vehicles.

This has been carried out for the UK and the Greek test sites - after evaluating the average remote sensing reading per vehicle (to take into account repeat passes) the vehicles have been grouped into various years, and the number of vehicles with high emissions have been counted.

Tables 12 and 13 show the results of this analysis for the UK and Greek results respectively. The tables show the total number of vehicles detected by registration index and the number with excessive remote sensing readings - based on cut-points of 5% CO and 1% NO. The latest vehicles, shown at the top of the table, are assumed to be catalyst-petrol or diesel vehicles. All the vehicles with high CO readings are very likely to be catalyst-petrol vehicles - diesel vehicles, due to their lean mixtures, are very unlikely to produce high CO readings. The vehicles with high NO reading could include both catalyst-petrol and diesel vehicles (although in some cases it is possible to identify diesel vehicles).

From these tables it can be seen that there are a relatively small number of vehicles in the UK fleet with high CO emissions - which may be due to their relatively recent introduction. In Greece, there were a higher proportion of high emitting catalyst vehicles. This may be due to the fact that they have been around in Greece a lot longer - and therefore there were more older ones with old technology catalysts - but may also be due to the vehicles being under higher loads due to the incline at this site.

It is therefore possible that out of the total number of catalyst-petrol and diesel vehicles, there will be 3% of catalyst cars with very high CO emissions. Another 2% of the vehicles might also have high NO emissions, some of which (but not all) will be due to faulty catalyst-petrol vehicles. However, some of these vehicles might be operating under cold start conditions, although it is impossible to tell from the data without stopping the vehicle and questioning the driver.

Figure 29 and Table 9 show that the vehicles with high CO emissions range from 4 to almost 30 times the legislative emissions limit. Assuming that the 3% of vehicles with high CO emissions have average emissions of 40 g/km and the remaining 97% of the fleet have an average of 3 g/km, then the ERRP for the whole fleet (rather than the sample that was used above) can be approximated as:

$$\text{ERRP} = [40-3] * 3/[97*3+3*40] * 100\%$$
$$= 27\%$$

However, if only 0.5% of the fleet are gross CO polluters as observed in the UK remote sensing tests, then the calculation becomes:

$$\text{ERRP} = [40-3] * 0.5/[99.5*3+0.5*40] * 100\%$$
$$= 6\%$$

Therefore, for a fleet with 3% gross emitting catalyst cars, remote sensing might be able to reduce the total CO emissions by 27%. However, if only 0.5% of the fleet are gross emitters, then the reduction in CO emissions is only 6%.

Table 12 Number of gross emitting vehicles in the U.K study

Reg. Index	Year	Emberton No. of Vehicles	Leicester No. of Vehicles	Total No. of Vehicles	No. with CO >5%		No. with NO >1%		No. with high CO or NO	
P	**96/97**	449	609	1058	4	0.38%	11	1.04%	15	1.42%
N	**95/96**	811	1067	1878	10	0.53%	38	2.02%	47	2.50%
M	**94/95**	721	1078	1799	7	0.39%	30	1.67%	37	2.06%
L	**93/94**	579	908	1487	9	0.61%	28	1.88%	37	2.49%
Sub-total for 'Catalyst' Cars				*6222*	*30*	*0.48%*	*107*	*1.72%*	*136*	*2.19%*
K	**92/93**	413	781	1194	34	2.85%	33	2.76%	65	5.44%
J	**91/92**	342	684	1026	52	5.07%	33	3.22%	84	8.19%
H	**90/91**	353	722	1075	77	7.16%	37	3.44%	111	10.33%
G	**89/90**	395	955	1350	126	9.33%	47	3.48%	167	12.37%
F	**88/89**	342	916	1258	109	8.66%	50	3.97%	156	12.40%
E	**87/88**	298	889	1187	93	7.83%	36	3.03%	127	10.70%
D	**86/87**	202	796	998	93	9.32%	38	3.81%	129	12.93%
C	**85/86**	182	585	767	87	11.3%	26	3.39%	110	14.34%
B	**84/85**	121	427	548	59	10.8%	26	4.74%	83	15.15%
A	**83/84**	107	465	572	68	11.9%	18	3.15%	81	14.16%

Table 13 Number of gross emitting vehicles in the Greek study

Reg. Index	Year	No. of Vehicles	No. with CO >5%		No. with NO >1%		No. with High CO or NO	
NBZ	**92**	510	18	3.53%	17	3.33%	35	6.86%
NBY	**95/96**	664	16	2.41%	13	1.96%	29	4.37%
NBX	**96**	125	5	4.00%	3	2.40%	7	5.60%
NBT	**95**	635	13	2.05%	22	3.46%	34	5.35%
NBP	**94/95**	639	16	2.50%	15	2.35%	31	4.85%
NBO	**94**	591	13	2.20%	16	2.71%	28	4.74%
NBN	**93/94**	578	23	3.98%	19	3.29%	40	6.92%
NBM	**93**	620	20	3.23%	22	3.55%	41	6.61%
NBK	**93**	589	10	1.70%	19	3.23%	27	4.58%
NBI	**92/93**	590	18	3.05%	13	2.20%	31	5.25%
NBH	**92**	553	23	4.16%	19	3.44%	42	7.59%
NBE	**91/92**	560	25	4.46%	16	2.86%	39	6.96%
"Cat" Sub-total		*6654*	*200*	*3.01%*	*194*	*2.92%*	*384*	*5.77%*
NBB	**91**	561	21	3.74%	16	2.85%	36	6.42%
NBA	**91**	569	18	3.16%	16	2.81%	34	5.98%
NAY	**90**	471	54	11.46%	24	5.10%	75	15.92%
NAX	**90/91**	457	29	6.35%	22	4.81%	50	10.94%
NAT	**89/90**	410	57	13.90%	30	7.32%	82	20.00%
NAP	**89**	376	44	11.70%	33	8.78%	74	19.68%
NAO	**88/89**	389	66	16.97%	40	10.28%	102	26.22%
NAN	**87/88**	286	44	15.38%	24	8.39%	67	23.43%
NAM	**87**	334	40	11.98%	21	6.29%	60	17.96%
NAI	**87**	263	49	18.63%	23	8.75%	66	25.10%
Special Categories								
AMO	**89/90**	21	3	14.29%	4	19.05%	6	28.57%
AMY	**90/91**	25	1	4.00%	1	4.00%	2	8.00%
MOI	**91**	43	4	9.30%	4	9.30%	7	16.28%
PAO	**92/94**	118	3	2.54%	3	2.54%	5	4.24%
PAI	**91/92**	8	1	12.50%	0	0.00%	1	12.50%

6. Cost-Effectiveness

This section describes the methodology used to calculate the cost-effectiveness of the various inspection methods described in the section 5.

6.1 Methodology

6.1.1 General outline

The methodology is outlined in the flowchart of Figure 35. The fixed input consists of the composition of a nation's car fleet and its emission factors (top box column two), as well as the cost of maintenance per vehicle, which is dependent on the cost of labour in the country considered (top box column three). The variable input consists of the type of inspection program chosen and the number of cars subject to the program (column five). This last item depends on the choice of the first year that vehicles are subjected to the program (e.g. after three years from new) and the frequency of the inspection (annually or biannually).

The selectivity of the inspection program and the average effect of maintenance on the vehicles identified as faulty (column one) are taken as the results of this project and are reported in the relevant section. In this section they are treated as fixed input.

The selectivity of the inspection program chosen (column one) together with the actual number of faulty vehicles in the fleet (column two) determines the number of vehicles identified as faulty (column two). This number includes the so-called errors of commission, i.e. the vehicles that the inspection method identifies as faulty, although they are actually low emitters Although the number of faulty vehicles in the fleet will partly depend on the general state of maintenance of the fleet considered, this influence was not varied per country in the calculation examples, since the available data were not sufficient to allow such variation. This means that the boxes 'selectivity of the inspection program' and 'number of faulty vehicles in the fleet' were in actual fact treated as one box, which only varies for the type of vehicle (Otto conventional, Otto catalyst-equipped, diesel, etc.) and not for the nationality of the fleet. Therefore the actual number of vehicles detected as faulty is only a function of the composition of the fleet, and not of its state of maintenance. The number of vehicles detected as faulty, multiplied with the average effect of maintenance results in the total effect of maintenance in kilotons of pollutant avoided (column two). This is the first interim result.

The total cost of inspection is obtained by simply multiplying the cost of inspection per vehicle (see subsection 6.1.4) with the number of vehicles to be inspected (column four). The total cost of maintenance is obtained by multiplying the cost of maintenance per vehicle with the number of vehicles identified by the program as being faulty (column three). Adding the total cost of inspection to the total cost of maintenance results in the overall cost of the I/M program column four/five). This is the second interim result.

When the total cost of the I/M program is divided by the total effect of maintenance one obtains the cost per unit of effect (MECU / kton of pollutant avoided). This is the final result of the calculation (column two/three).

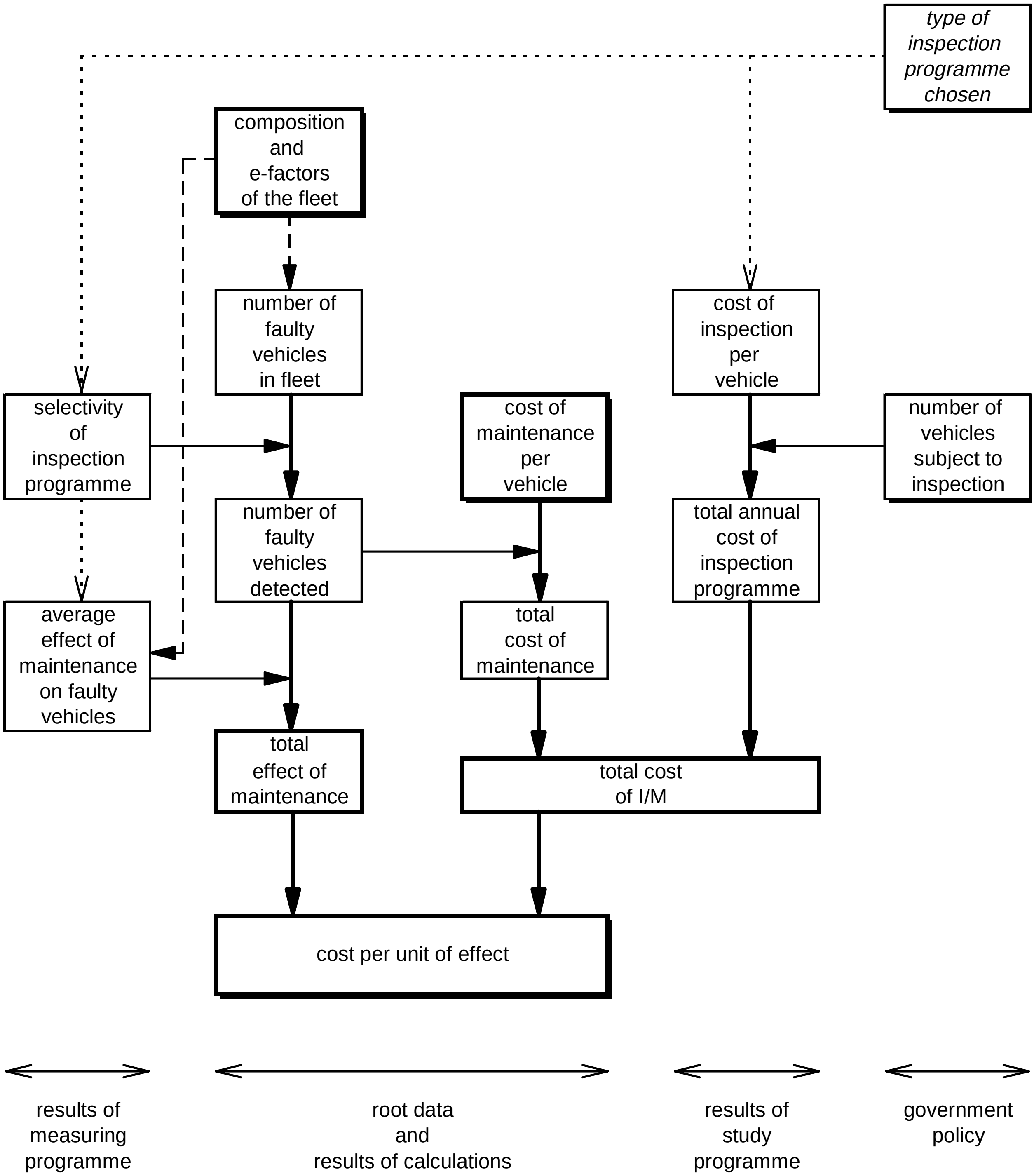

Figure 35 Flow chart of the cost-effectiveness calculation.

6.1.2 Types of inspection program considered

In this section the following types of inspection program are considered:

⇒ Unloaded test. For spark ignition (Otto) engines this test usually consists of an idle test, possibly with the addition of a similar test at a raised idle speed. For compression ignition (diesel) engines it consists of a free acceleration test. In this study the test methodology of EC Directive 92/55/EEC has been used as a baseline for the evaluation of the other methods. In the calculation examples it has been assumed that such a system is based on a decentralised inspection program (garages can test).

⇒ Static loaded test. This test consists of driving the vehicle on a non-adjustable chassis dynamometer. Within the project a fixed load of 7 kW at a fixed speed of 50 km/h was chosen. On the basis of practical considerations it was decided to calculate this option only for a centralised inspection system (separate inspection stations).

⇒ Dynamic loaded test. This test consists of a small driving cycle on a chassis dynamometer with limited adjustability. Two different options were evaluated:

- Emission measurement by monitoring the raw average emission concentrations (‘ra’)
- Emission measurement by monitoring the mass emissions through a sampling system (‘me’)

6.1.3 Selectivity of the program and average emission reduction potential

The selectivity of the inspection programs mentioned above and the emission reduction rate potential (ERRP) have been determined in section 5. The ERRP is representative of the ideal effect of maintenance, occurring when all maintenance is successful. In practice the real effect may be less (see Table 20 in subsection 6.2) . The vehicle samples of some participating partners contained a number of faulty vehicles chosen deliberately and not randomly, so as to test the capability of the short tests to detect faulty vehicles. The selectivity was therefore determined for an adapted sample containing the randomly chosen vehicles only. In some cases this led to rather small samples for certain vehicle types, but this approach was still judged to be more representative of the situation in the field. The selectivity of the inspection programs is given in Table 14.

Table 14 The percentage of vehicles identified as faulty by the various inspection methods. In the case of diesel smoke only two methods are compared.

inspection method	petrol/LPG w/o catalyst	petrol/LPG with catalyst	diesel smoke test
92/55/EEC	54	8.7	26
static	33	8.0	
dynamic ra	75	15	9
dynamic me	50	27	

In the case of diesel engines only the smoke measurement leads to any useful identification of faulty vehicles. The method according to 92/55/EEC is the free acceleration test. The ‘dynamic ra’ test measures the average smoke over a dynamic test. The sharing of the repair over minor maintenance, major maintenance and catalyst replacement has been determined on the basis of the experience with the present program, combined with the experience with the Dutch in-use compliance program. Sensitivity analysis of the sharing over minor and major repair shows that for the year 1995 this influence is only a few percent, due to the low share of major repair needed on non-catalyst vehicles (they are usually just maladjusted). For the year 2005, with a much higher share of catalyst equipped vehicles, for which a much higher share of major repair has been assumed (more replacement of faulty parts) the influence of the assumption of the share of major repair does rise to 10-15% of the total cost of I/M. For diesel vehicles the sensitivity of the assumption of the share of major repair amounts to about 5% for the dynamic test or about 10% for the free acceleration test with its much higher number of errors of commission.

Table 15 Kind of repair assumed necessary

Class of repair	petrol/LPG w/o cat.	petrol/LPG with catalyst		diesel	
		pre Euro I	Euro I/II/III	pre Euro I	Euro I/II/III
minor	90%	80%	65%	90%	80%
major	10%	19%	34%	10%	20%
cat replace		1%	1%		

The ERRPs for the measured sample have been identified on the basis of the evaluation presented in section 5. The ERRPs for Euro III have been calculated on the basis of the assumption that the wrong vehicles on average emit as much as the wrong vehicles of Euro I/II, but that the corrected vehicles have the same emissions as other correct vehicles of Euro III.

The emission of NOx avoided is in most cases purely a come-along effect of a test that as such measures other pollutants and identifies high polluters on that basis. Only in the case of the ‘dynamic me’ has it been assumed that NOx analysers are present in the inspection station. NOx analysers are rather sophisticated equipment that is not available in garage type equipment. This explains the rather high ERRP for NOx in the ‘dynamic me’ test.

The effect of maintenance on fuel consumption has not been quantified. The effect on fuel consumption of 3-way catalyst equipped vehicles is small, in the order of about 2 % maximum. This does seem to minute to calculate a cost-effectiveness. As such it is, of course, a small but advantageous come-along effect. For conventional cars the effect is somewhat bigger, in the order of about 5 % maximum. But even then the cost-effectiveness seems marginal if fuel consumption had to be the main driver.

6.1.4 Costs of inspection and maintenance

The costs of the inspection methods varies with the country, mainly on the basis of the hourly rates of the technicians involved. The costs of investment, amortisation, interest and housing

have been kept constant. By way of example the Dutch case is given in Table 16 (see sub-report 7 for more details). The cost of an inspection according to 92/55/EEC has been supplied by each of the partners of the project. Where necessary this cost has been corrected for the fact that a safety inspection is included. For the Netherlands the resulting cost would amount to 10 ECU per inspection in a decentralised system.

Table 16 Calculation of the cost in ECU/vehicle of an inspection in a centralised system (92/55/EEC in garages)

	92/55/EEC	static	dynamic ra	dynamic me
Investment ECU		30 000	45 000	50 000
vehicles/year		10 000	10 000	8 000
fixed cost/veh. ECU		0.88	1.17	1.58
labour/veh.		10.00	10.00	12.50
administrative/veh		3.00	3.00	3.00
Total/vehicle ECU	10.00	13.88	14.17	17.08

The cost of maintenance was likewise supplied by the partners for minor maintenance and major maintenance. Where necessary this was corrected for the additional cost of replacement parts. The cost of catalyst replacement was set at 500 ECU throughout. For the Netherlands this would come to the costs as set out in Table 17.

Table 17 Cost of maintenance

Minor repair	90 ECU
Major repair	190 ECU
Replacement of catalyst	500 ECU

In the case of catalyst replacement the cost of minor repair has to be added to the cost of the actual replacement catalyst. This brings the actual cost to 590 ECU.

So, if a program indicates 27 % of the catalyst equipped vehicles as faulty ('dynamic me', Table 14), the cost of maintenance is (see also Table 15)

minor repair	0.27 x 0.80 x 90 ECU	= 19.440	MECU/million vehicles
major repair	0.27 x 0.19 x 190 ECU	= 9.747	MECU/million vehicles
cat replacement	0.27 x 0.01 x 590 ECU	= 1.593	MECU/million vehicles
Subtotal cost		30.780	MECU/million vehicles

To this has to be added the cost of a second inspection on the repaired cars:

second inspect.	0.27 x 17.08 ECU	= 4.612	MECU/million vehicles
Total cost		35.392	MECU/million vehicle

6.2 Calculation Example

6.2.1 The emission benefits

By way of example the calculation will be performed for the Dutch case. The inspection set-up has been assumed as follows. Only cars of three years and older are subject to the inspection and the inspection is annually. That means that in 1995 approximately the following numbers would have been due to be inspected:

100 % of Otto conventional (pre 1989)	= 1.710 million
100 % of catalyst tax incentive (1989-1991)	= 0.420 million
0 % of Euro 1 (1992-1995)	= 0 million
approx. 80 % of the LPG vehicles	= 0.528 million
	= 2.658 million Otto vehicles
approx. 80 % of the diesel vehicles	= 0.336 million diesel vehicles

With diesel and LPG no account has been taken of the different legislation steps.

The ERRP for the various components in the various tests is as given in section 5. Applying these figures to e.g. the static test, the following potential reduction in CO can be calculated:

Number of cars x km/yr per car x emission g/km x ERRP = emission avoided/yr

1.710 x 9700 x 11.3 x 0.147 = 27.55 kton/yr	Otto conventional
0.420 x 13600 x 2.8 x 0.031 = 0.50 kton/yr	catalyst tax incentive
0.528 x 22500 x 1.3 x 0.031 = 0.48 kton/yr	LPG (catalyst assumed)
total = 28.53 kton/yr	

In similar way it can be calculated that the total of emissions potentially avoided for all options is as indicated in Table 18.

Table 18 The potential emission avoided in kton of pollutant per year

	CO	HC	NOx	PM
92/55/EEC	30.6	2.66	4.40	0.40
static	28.5	2.43	3.15	
dynamic ra	29.7	2.24	2.20	0.40
dynamic me	36.0	2.48	5.02	

6.2.2 The costs

The cost of the inspection schemes is given in Table 16 The total cost of inspection for 2.658 million Otto vehicles amounts to:

92/55/EEC 2.658 x 10.00 MECU = 26.58 MECU

static 2.658 x 13.88 MECU = 36.89 MECU

dynamic ra 2.658 x 14.17 MECU = 37.66 MECU

dynamic me 2.658 x 17.08 MECU = 45.40 MECU

For diesel vehicles it amounts to;

92/55/EEC 0.336 x 10.00 MECU = 3.36 MECU

dynamic ra 0.336 x 14.17 MECU = 4.76 MECU

The cost of repair was calculated for catalyst equipped vehicles in the dynamic me test as 35.392 MECU/million vehicles (section 6.1.4). In a similar way the cost for the total fleet composition (Otto engines) can be calculated as:

92/55/EEC 112 MECU

static 75 MECU

dynamic ra 165 MECU

dynamic me 133 MECU

For the diesel engines it can be calculated as:

92/55/EEC 9.65 MECU

dynamic ra 3.34 MECU

The lower cost of the diesel dynamic test is a consequence of the fact that less vehicles are (erroneously) indicated as faulty (errors of commission), thereby leading to less unnecessary ‘repair’ cost.

This brings the total cost of the I/M system at the following costs:

92/55/EEC	138 MECU for Otto	and	13.01 MECU for diesel
static	111 MECU for Otto		
dynamic ra	203 MECU for Otto	and	8.10 MECU for diesel
dynamic me	178 MECU for Otto		

6.2.3 The cost-effectiveness

The potential cost effectiveness is obtained by dividing the total cost of inspection and maintenance by the potential amount of pollutant avoided. No attempt has been made to share the costs over the different pollutants, since this would require a weighting of the importance of the different pollutants, which is not available. So in the tables the resulting figure represents the amount of MECU/kton that would apply if the measures were exclusively taken to avoid that particular pollutant, with the following condition: the cost-effectiveness of the abatement of CO, HC and NOx has been exclusively related to the costs of I/M for Otto engined vehicles. The costs of the abatement of PM (particulate matter) has been exclusively related to the I/M costs of diesel engined vehicles. It should be noted, however, that the inspection cost of the diesel vehicle in the dynamic test is based on a high use of that test equipment (10 000 vehicles per year per lane). In practice that would mean that this cost is only realistic if the same equipment is also used for the inspection of Otto engined cars! The resulting cost-effectiveness is given in Table 19.

As stated above these figures relate to the potential effectiveness and therefore represent only a potential cost-effectiveness. In actual fact it should not be assumed that all vehicles are repaired to the point that their emissions represent the average of the non-identified cars. Table 18 below represents the relative real effectiveness of the repairs in the case of 3-way catalyst cars. In order to obtain the real cost-effectiveness the potential cost-effectiveness has to be divided by this factor. As can be seen, in the project it was especially the effect on NOx that lagged behind the real potential. These figures may be more favourable, however, when the standard of repair can be increased. The real effects on CO and HC seem to be close to the potential.

Table 19 The results of the cost-effectiveness calculation for the Netherlands 1995.

the NETHERLANDS 1995	I/M system	kton/yr avoided	MECU/kton inspection	MECU/kton maintenance	MECU/kton insp.+ maint.	percent repaired
CO						
otto only	92/55/EEC	30.63	0.87	3.64	4.51	37.8%
	static	28.53	1.29	2.62	3.91	24.3%
	dyn. ra	29.74	1.27	5.55	6.81	53.7%
	dyn. me	35.99	1.26	3.70	4.96	41.6%
HC						
otto only	92/55/EEC	2.66	9.98	41.89	51.87	37.8%
	static	2.43	15.19	30.73	45.92	24.3%
	dyn. ra	2.24	16.78	73.50	90.28	53.7%
	dyn. me	2.48	18.27	53.54	71.81	41.6%
NOx						
otto only	92/55/EEC	4.40	6.04	25.37	31.41	37.8%
	static	3.15	11.70	23.67	35.37	24.3%
	dyn. ra	2.20	17.08	74.85	91.94	53.7%
	dyn. me	5.02	9.05	26.53	35.58	41.6%
PM						
diesel only	92/55/EEC	0.40	8.4	24.06	32.44	26.1%
	dyn. ra	0.40	11.8	8.26	20.03	8.7%

Table 20 The actual effect of maintenance as a percentage of the potential effect

Type of inspection	CO %	HC %	NOx %
unloaded	94	92	36
static	93	91	56
dynamic ra	91	88	51
dynamic me	88	85	49

The calculated amount of pollutants avoided is shown in Figure 36, whereas the cost-effectiveness is shown in Figure 37. By way of comparison the cost-effectiveness of a south-European country is shown in Figure 38. Figure 36 shows clearly that the baseline method is more or less equal the more advanced inspection methods in 1995, when there are still many conventional vehicles, but starts to become inferior in the future when there are more catalyst vehicles. Figure 37 shows that the cost-effectiveness of the more advanced inspection methods does tend to remain at the same level in future years, whereas that of the baseline method deteriorates. In Greece, with a continuing high share of conventional vehicles the baseline method remains the most cost-effective, even in future years (Figure 38).

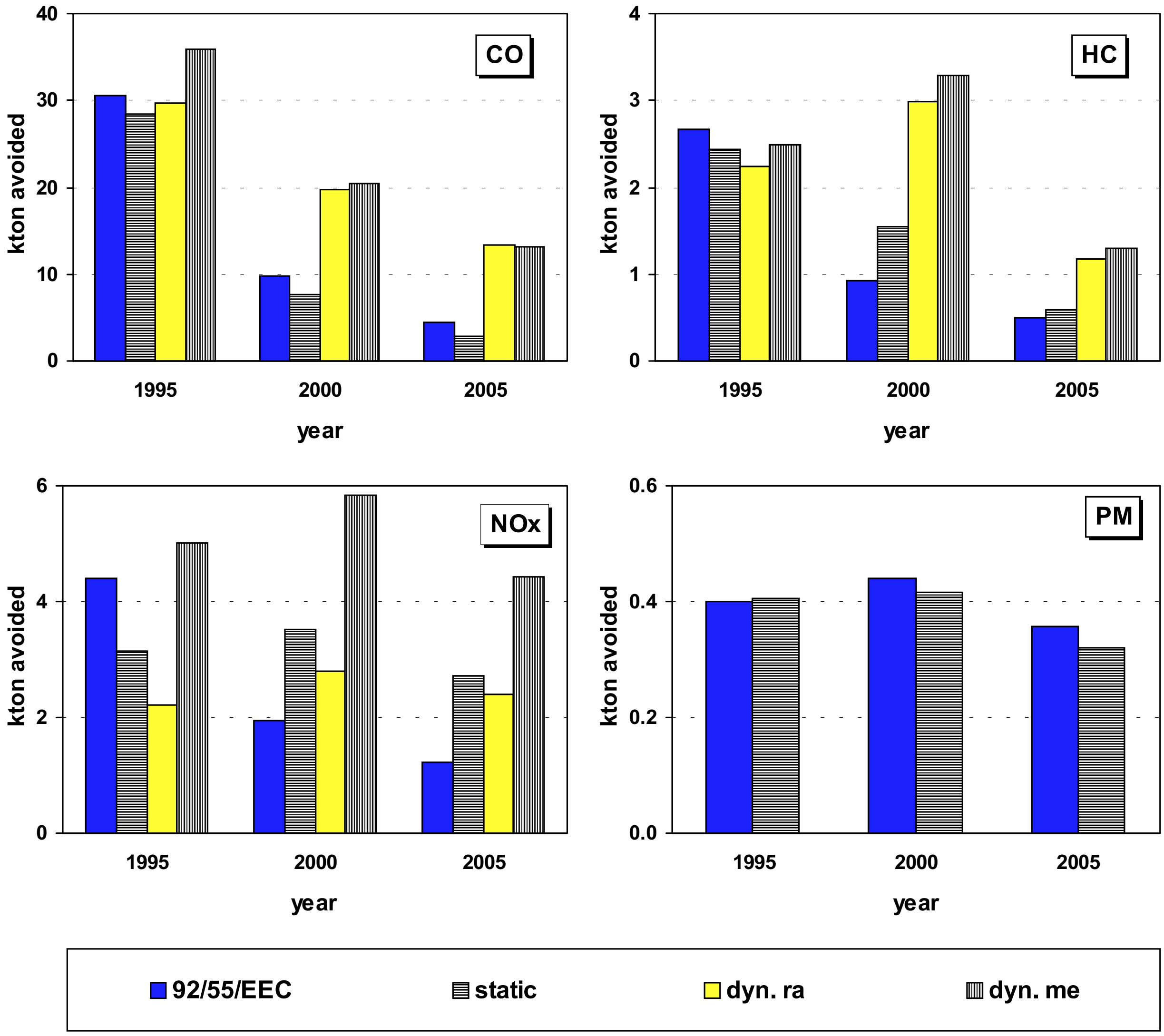

Figure 36 The trends in the amounts of pollutants avoided; the Netherlands

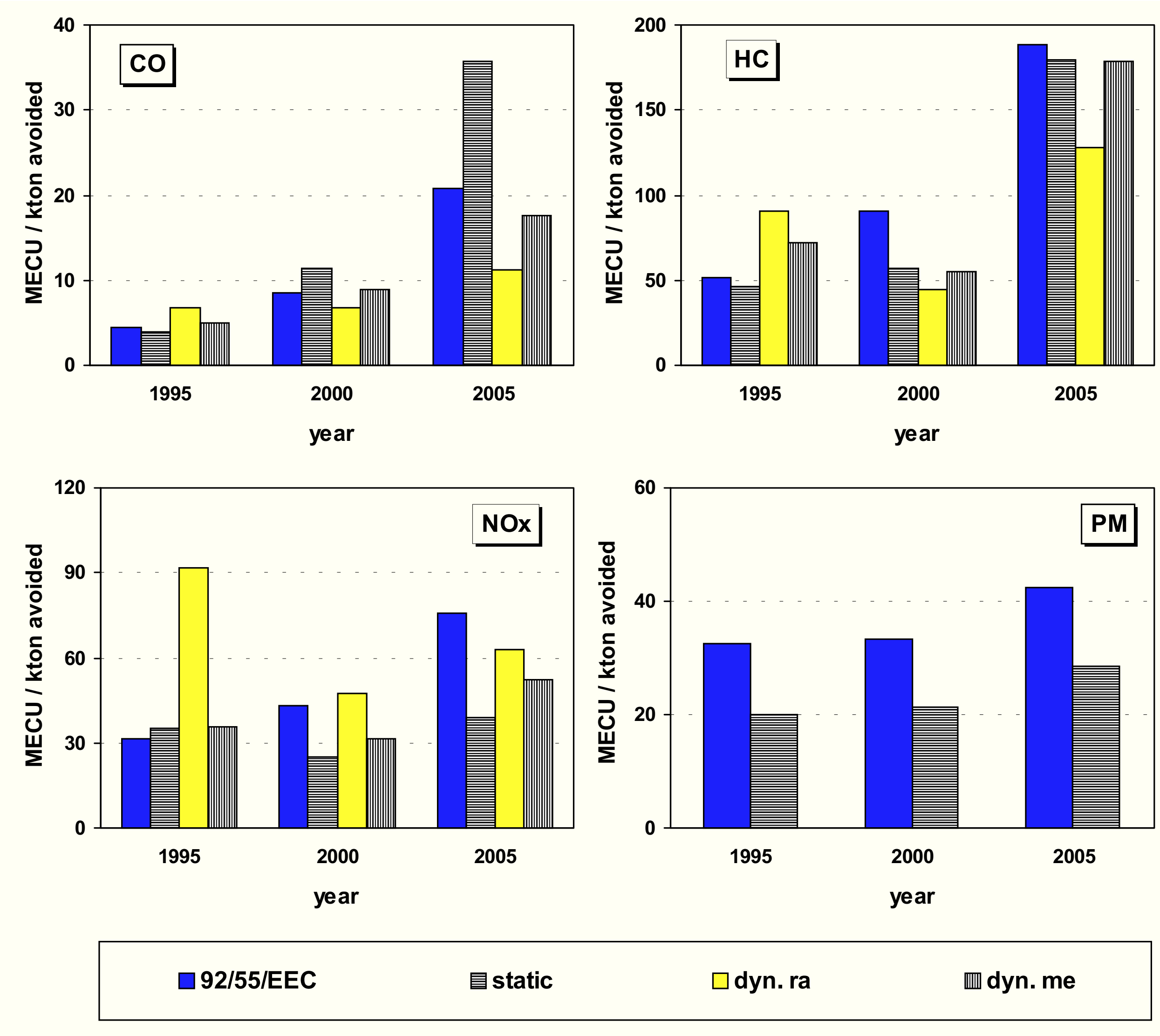

Figure 37 The trends in cost-effectiveness; the Netherlands

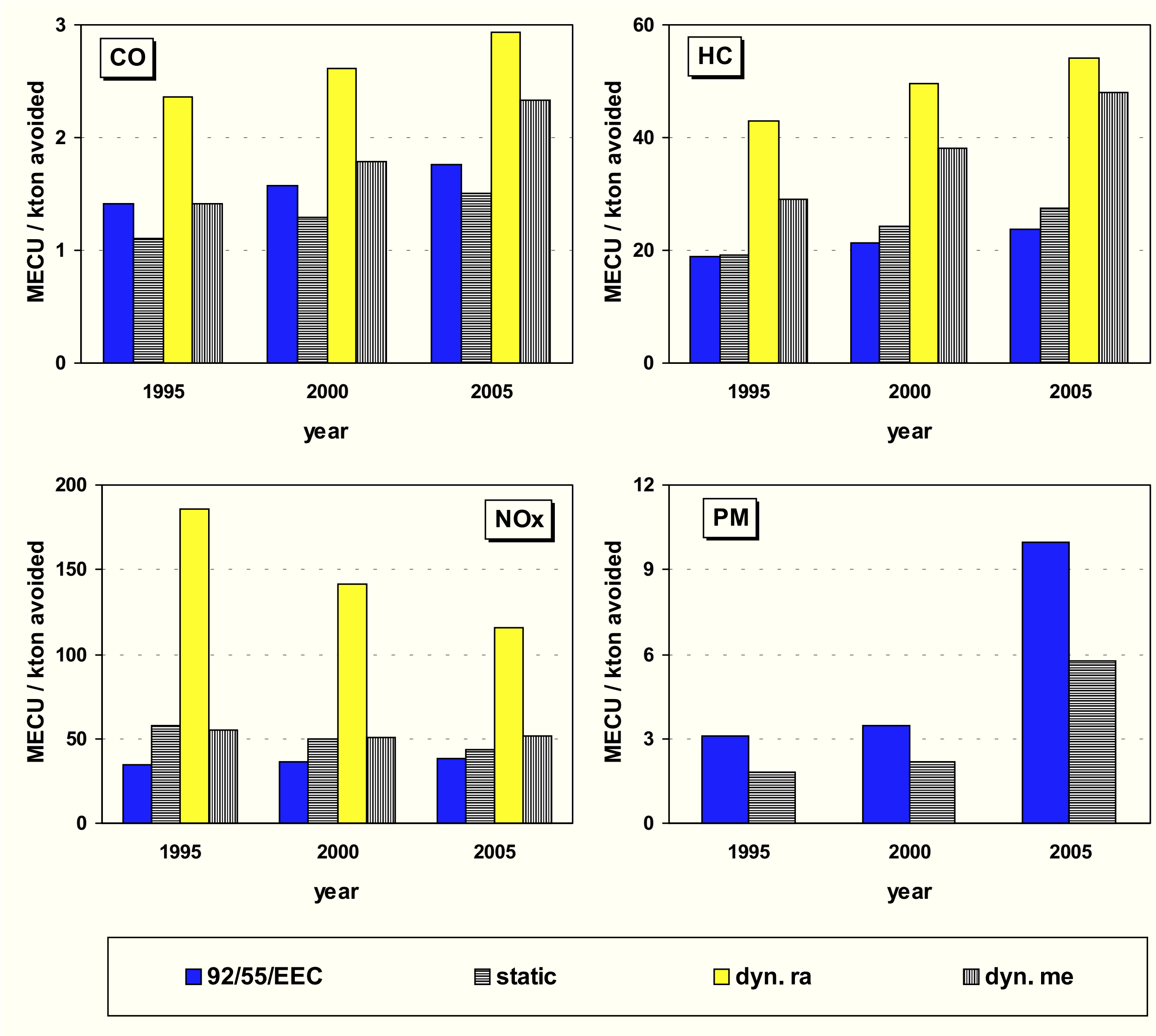

Figure 38 The trends in cost-effectiveness; Greece

6.3 Remote sensing

In general, at present it is hard to ensure realistic cost-effectiveness estimates of remote sensing for I/M-purposes, mainly due to the fact that - in contrast to conventional I/M-schemes based on e.g. mandatory annual idle emission testing in a centralised network - there is a lack of experience of large scale uses of remote sensing for enforcement purposes, e.g.: what are the costs for routinely operating a remote sensor within an I/M-scheme (instrument amortisation and maintenance costs, staff operation costs, site installation and relocation costs, etc.); how many days a year and how many hours a day can a remote sensor be operated on average (this will certainly vary between countries); how many cars a day can be measured on average, etc.? In addition, although the data collected within the EU I/M-project give some indications, we do not yet have very good statistics to estimate the actual potential of the remote sensing technique to correctly detect high and low polluters. This potential is also likely to be site dependent.

Based on approximating calculations, however, it may be noted that remote sensing identification of only the very high polluters is about 3 times more cost-effective compared to when all high polluters are detected. The figures turn out to be (optimistic to pessimistic assumptions):

	very high polluters only	all high polluters
CO (MECU/ktonnes)	0.8 - 5.5	2.4 -14.2
HC (MECU/ktonnes)	17 - 120	50 - 300

The calculated cost-effectiveness for the conventional I/M-schemes for Sweden for 1995 (4.0-8.1 MECU/ktonnes CO and 65-156 MECU/ktonnes HC) falls within this range set by the optimistic and pessimistic estimates for the cost-effectiveness of remote sensing. The calculations show that the emissions avoided by detection of the very high polluters account for the majority of the emissions avoided when all high polluters are detected. Nevertheless, it is likely that the average emissions and perhaps also the emission reduction potential of cars within the high polluter category (not including the very high polluters) are somewhat underestimated in our calculations. The fraction of the high polluter remote sensing identification costs of the overall costs range from 10% to more than 50%. Trying to detect all high polluters, rather than the very high polluters only is likely to increase the percentage of errors of commission. The possibility of including also remote sensing NOx and opacity measurements needs also to be considered. Similar calculations of cost-effectiveness can be made for e.g. the use of remote sensing in roadside inspections.

7. Outlook

In this section a discussion is provided on a number of elements which are very closely related to the results of the project but also with the activities at European Union level regarding the overall issue of controlling the emissions of in use cars. Therefore three specific items are addressed in the following:

(i) Further improvements necessary for and possibilities offered by an enhanced remote sensing system.

(ii) The On Board Diagnostics and its relation with the I/M schemes.

(iii) Short tests for the diesel engine, in view of both the immediate needs but also the emission standards proposed by the Auto Oil I Programme.

7.1 Remote sensing

Previous studies have been restricted to a few days testing, with a number of vehicles pulled for testing during the course of the work. This results in some repeat readings on the vehicles stopped for testing, but not for all vehicles. It may be more interesting to visit a single site for a few weeks, analyse the data to identify vehicles with a large number of repeat readings and high emissions and then try to locate those vehicles for further tests (this could be done by trying to spot and stop the vehicle at the test site - if they have passed through the site several times previously, then they will probably continue to use the same route, perhaps even at the same time of day - or by tracing the vehicle through the appropriate vehicle licensing offices).

One of the problems with the collected data is the analysis of the video images of the vehicles. This could be automated by the use of a registration number recognition system, integrated with the remote sensing software to allow live number recognition, or used after the test to analyse the collected images.

Another problem with the current system is the use of standard videotapes. These tapes run continuously, independent of the traffic flow, and need replacing every 3 hours. During analysis, the tapes have to be constantly played, paused, rewound, fast-forwarded to find the next vehicle on the tape. With the current developments in mass storage devices for PCs, an alternative storage media could be used (e.g. CDROM, DVD etc.). This would reduce the amount of wasted space (as currently occurs on the videotape when there is a large gap between vehicles), which would make the video image analysis easier and may allow longer time until the storage media is full.

With on-line registration number recognition it would be possible to do away with the need for video image storage - more precise vehicle details could be obtained from a vehicle registration database. Or the video image storage could be selective - only storing the images of vehicles that repeatedly have high emissions.

A further problem with the current system is its high visibility - the source and detector are placed either side of the road surrounded by cones to protect them and a large van is parked at the side of the road. Vehicles often slow down while passing through the site, resulting in invalid

readings. The presence of police officers further up the road also causes vehicles to slow down, thinking they are approaching a speed check area. It is possible that the system could be hidden away within normal street 'furniture' and be fully automated and secured so that no manning is required.

It is therefore recommended that:

- Remote sensing should be carried out at a site over a few weeks. Modern vehicles with a high number of repeat readings and a high average should be further investigated (initially using a cut-point of 5% CO, but this could be modified according to the site location and the condition of the local traffic - investigations could be carried out on 5% of the traffic with the highest emissions).
- Further investigation could also be carried out on vehicles that produce high NO readings.
- Registration number recognition software needs to either be built into the remote sensing device or used to analyse the video images, in order to remove the large burden of visually analysing the video images.
- To provide further information about the vehicles and to categorise them according to vehicle technology, a vehicle registration database is needed.
- Speed and acceleration needs to be taken into account with the remote sensing readings - if large accelerations or decelerations are detected, then the remote sensing readings should be rejected as they will be unrepresentative of normal driving.
- After a large amount of remote sensing data has been collected, it might be possible to derive model specific cut-points. This would prevent specific models that produce high tailpipe concentrations under certain conditions (e.g. low-powered vehicles that occasionally have to operate under wide-open throttle conditions) from being incorrectly identified as high emitters.
- Development of the remote sensing system should allow the device to be hidden within normal street 'furniture', where it can operate unmanned.

In the above usage of remote sensing, the exhaust emissions would be measured without any interference with the traffic flow (unlike the current study, which stopped some of the vehicles for a roadside test). There would be no need to carry out an immediate roadside check of the vehicles. Any vehicles over the period that repeatedly exhibit high exhaust emissions could be contacted and advised to have their vehicles checked (as the vehicle registration numbers are known, the owners' details could be obtained from a vehicle registration database).

There may be reasons why a suspect vehicle has high remote sensing readings - e.g. cold start or high load fuel enrichment (although speed and acceleration measurement should account for the latter case). A follow-up test according to the I/M test procedures would therefore be required (and would also allow the repair garages to check that the vehicle has been repaired properly).

The follow-up could be carried out in a number of ways such as:

- The vehicle owner is *instructed* to submit his vehicle for an emission test at a local test centre within a certain time limit.
- The vehicle owner is *advised* that his vehicle has high exhaust emissions and that it should be repaired as soon as possible.

Alternatively, remote sensing could be used in conjunction with roadside tests. A number of countries currently carry our random roadside checks on exhaust emissions. By selecting vehicles that look in a poor condition and vehicles that are know to have high exhaust emissions, a 'hit' rate of 25-35% can be achieved. However, these vehicles with high emissions are predominantly old vehicles without catalysts. Remote sensing could assist these existing roadside checks by selecting modern vehicles with catalysts that appear to be gross emitters (these vehicles are much more important than the old ones as they are likely to cover a much higher annual mileage).

Remote sensing could also be used as a "clean-screen" device before a loaded transient test - in order to reduce the burden of the loaded transient test lanes, vehicles which exhibit low remote sensing readings can be given an immediate pass, while all other vehicles have to be tested over the transient cycle. Pilot studies have been carried out quite successfully within the Ontario IM240 I/M programme, eliminating about one third of the vehicles for IM240 testing while preserving 88% of the emission reduction potential of a full IM240 programme (Petherick 1996)

Another use for remote sensing might be to provide an independent means of evaluating the effectiveness of Inspection and Maintenance programmes. Examples of this application with positive results are available for both the US (Stedman et al. 1997) and Sweden (Sjödin et al. 1997). This could also serve as a means of evaluating other road vehicle emission control strategies e.g. new car emission standards (in-use compliance and penetration of new standards into the fleet), new fuels etc.

7.2 On Board Diagnostics

In relation to the future the question needs to be considered if an I/M scheme still pays off in years after 2000, when OBD (on board diagnostics) begins to play an important role in new vehicles. The Common Position regarding the emission Directive stage III (2000 and beyond) specifies OBD for Otto engined vehicles as from 01-01-2000 and for diesel engined vehicles as from 01-01-2005. According to the Common Position the OBD is subject to the following requirements and exemptions. Basically the OBD system is required to signal emission related defects that are likely to cause the emissions to exceed the so-called OBD threshold. This threshold lies considerably above the emission limit value for the type testing.

Furthermore the manufacturer has the right to temporarily disable the system under circumstances where he judges that reliable monitoring is not possible. Also the system is required to function properly over 80,000 km. At higher mileage it is still required to operate, but not necessarily in accordance with the original threshold values.

In summary it may be said that OBD has the potential to monitor the proper functioning of emission systems, but it will be some time before it will make I/M completely superfluous, especially for older cars.

7.3 Short tests for diesel cars

The particular experience gained in the framework of this project but also the general experience of the partners point out to two main questions which have not been tackled:

- In view of the unsatisfactory results of the currently in force free acceleration test and of the high costs associated with the introduction of a transient loaded test specifically for diesel smoke, is there any other alternative, at least for cars of current or slightly older technologies?
- In view of the very stringent PM emission standards proposed for the years 2000 and 2005, and in connection with the discussion on the necessity of focusing specifically on size distribution and/or number of particulates emitted, will opacity measurement be adequate for emission testing of future in use diesel vehicles irrespective of the type of short test?

In order to provide a very first input to the discussion, some preliminary testing was performed, the results of which are presented in the following paragraphs.

7.3.1 Acceleration on a free roller set with an external flywheel

The bad correlation of the free acceleration test with the emissions in any of the full cycles is largely related to the extreme and indeed unrealistically high transient character of the free acceleration smoke test. It is felt that the correlation might improve if a test could be devised that is still transient, but in a less extreme way. A simple test that would be less transient and more realistic than the free acceleration test would have to simulate at least part of the vehicle inertia in addition to the internal inertia of the engine. Such a concept could be imagined e.g. as a chassis dynamometer that contains a (fixed) flywheel but no power measurement. Such equipment does indeed exist at garage level for the determination of engine power.

As a demonstration of such a test is presented, performed by two partners (TÜV Rheinland and LAT/AUTH) on two diesel vehicles.

7.3.2 Test description

The test starts with a warmed up engine at idle. The engine of the vehicle is accelerated up to the 3rd gear. In the 3rd gear the engine is accelerated up to an engine speed above the rated speed by pressing the gas pedal to the bottom (full load position). At maximum speed the clutch of the vehicle is released after some seconds so that the engine speed drops down to low idle speed. During the test the engine speed and the exhaust gas opacity are measured continuously. The test is repeated at least three times.

7.3.3 Test performance

The above described test has been performed with

- A Volvo diesel car equipped with a naturally aspirated engine. The chassis dynamometer of TÜV Rheinland has been used as a free roller set with an equivalent inertia weight of 680 kg. For opacity measurements the Bosch Smokemeter RTT 110 was used. It is the same instrument as used in German AU.
- A Renault Trafic, 2.6 t gross vehicle weight light duty vehicle, equipped with a 2.5l naturally aspirated engine. The chassis dynamometer of LAT/AUTH has been used as a free roller set with an equivalent inertia weight of 770 kg. For opacity measurements the Siemens Opacimat EU was used.

The curves of engine speed and opacity as recorded during the tests are shown in Figures 38 and 39 for the Volvo and the Renault vehicles respectively.

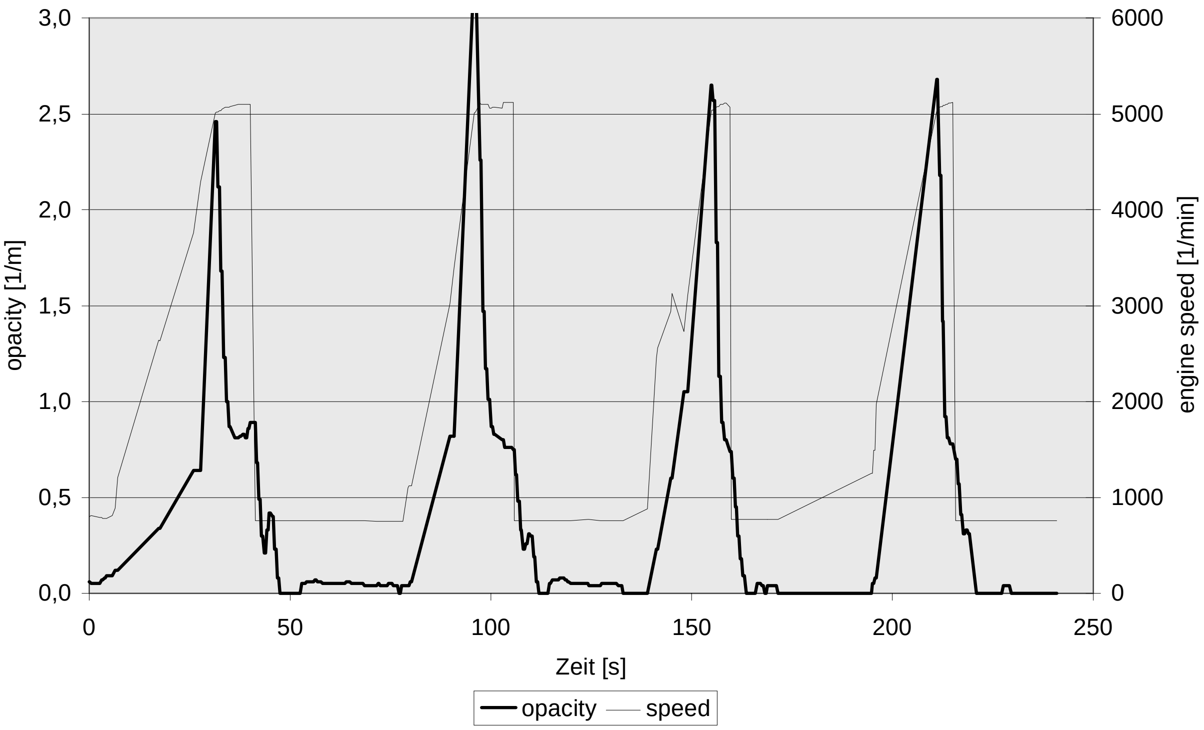

Figure 39 Continuously recorded opacity and engine speed of a Volvo diesel vehicle driven at maximum fuel injection on a free roller set (equivalent inertia weight of 680 kg)

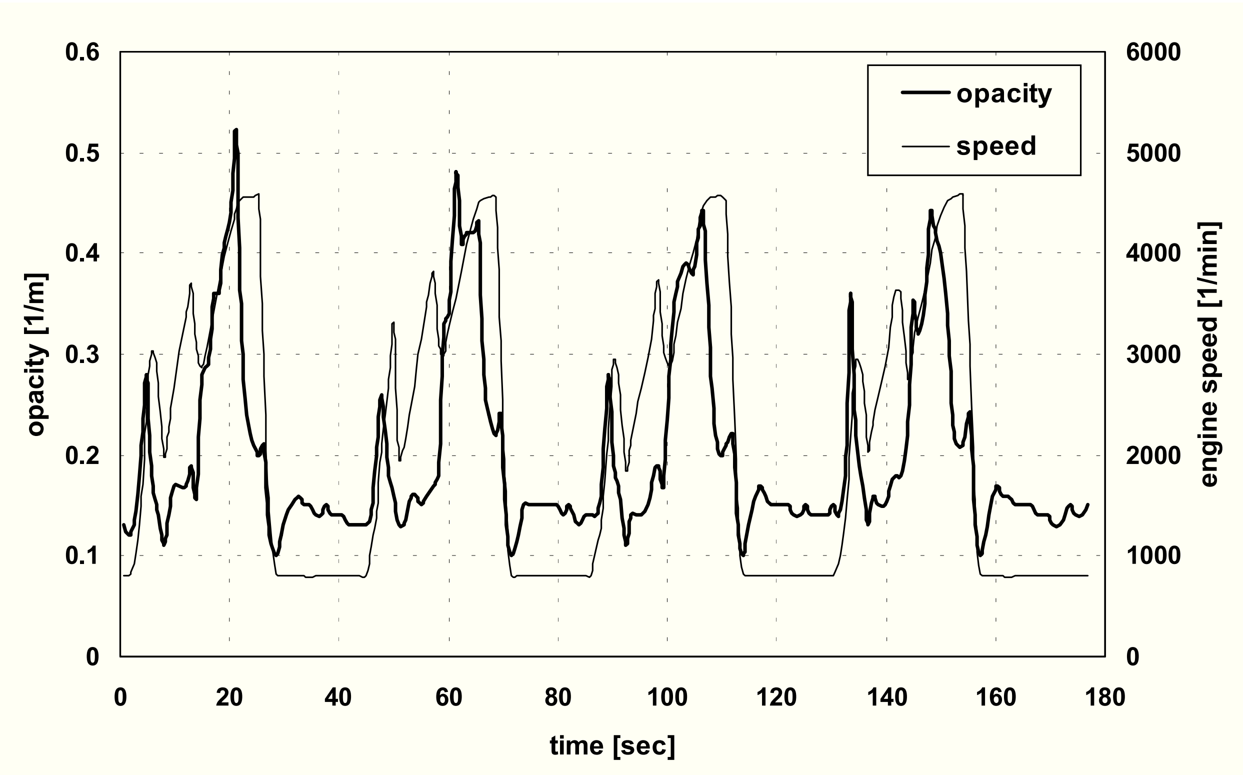

Figure 40 Continuously recorded opacity and engine speed of a Renault diesel vehicle driven at maximum fuel injection on a free roller set (equivalent inertia weight of 770 kg)

As can be seen in these figures the duration of one acceleration mode is lower than 50 s. The maximum opacity peak occurs just before maximum engine speed is achieved. As already been mentioned the maximum speed is a bit higher than rated speed. In the case of the Volvo car the rated speed is 4800 rpm and the maximum speed is a bit higher than 5000 rpm. The maximum opacity peak seems suitable for the evaluation of the particulate emission behaviour of the vehicle.

The main difference between an acceleration mode on a free roller set and the free acceleration smoke test is the acceleration time of the engine. The acceleration time of the free acceleration test is a bit more than one second and covers the speed range from low idle to maximum engine speed. The acceleration mode on the free roller set begins in the 3^{rd} gear at a speed above 1000 rpm and ends after approximately 15 seconds at a speed between rated speed and maximum speed. During the whole speed range the gas pedal of the vehicle is in the full load position. In comparison to the free acceleration test the acceleration mode on the free roller set simulates to a certain extent a real traffic load situation when a vehicle tries to achieve travel speed with max. possible acceleration.

Because of lack of experience no preconditioning procedure necessary for the reproducibility of the test results can be given. It has to be tested if the repetition of several acceleration modes is sufficient to guarantee the reproducibility of the results.

7.3.4 Opacity measurement on a vehicle equipped a diesel particulate trap

As already mentioned, it is possible that opacity measurement may be completely ineffective in the short run (at least with the opacimeters of current technology). Near future development in emission standards indicate that visible smoke may completely disappear from diesel vehicle, i.e. with the use of after-treatment devices (see for example Pattas et al. 1996, 1997).

In order to demonstrate this, the Renault Trafic diesel light duty vehicle of LAT/AUTH mentioned above was tested on the chassis dynamometer over the UDC at its standard configuration and equipped with a cellular ceramic diesel particulate trap (Corning EX80, 5.66” x 6”). Figures 40 and 41 present the recordings of opacity and vehicle speed measured continuously over the cycle without and with the trap respectively. It can be clearly seen that the opacimeter in the with trap condition is operated outside its sensitivity limits.

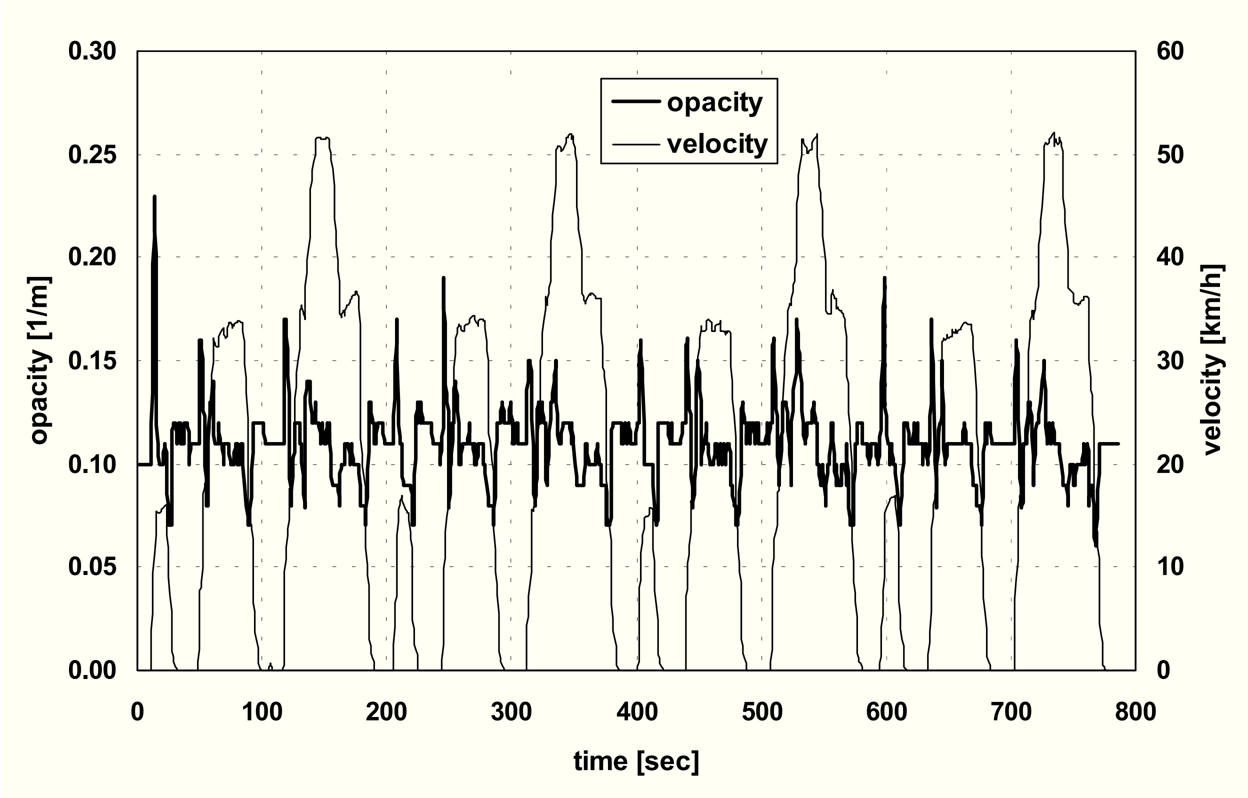

Figure 41 Continuously measured opacity over UDC without trap

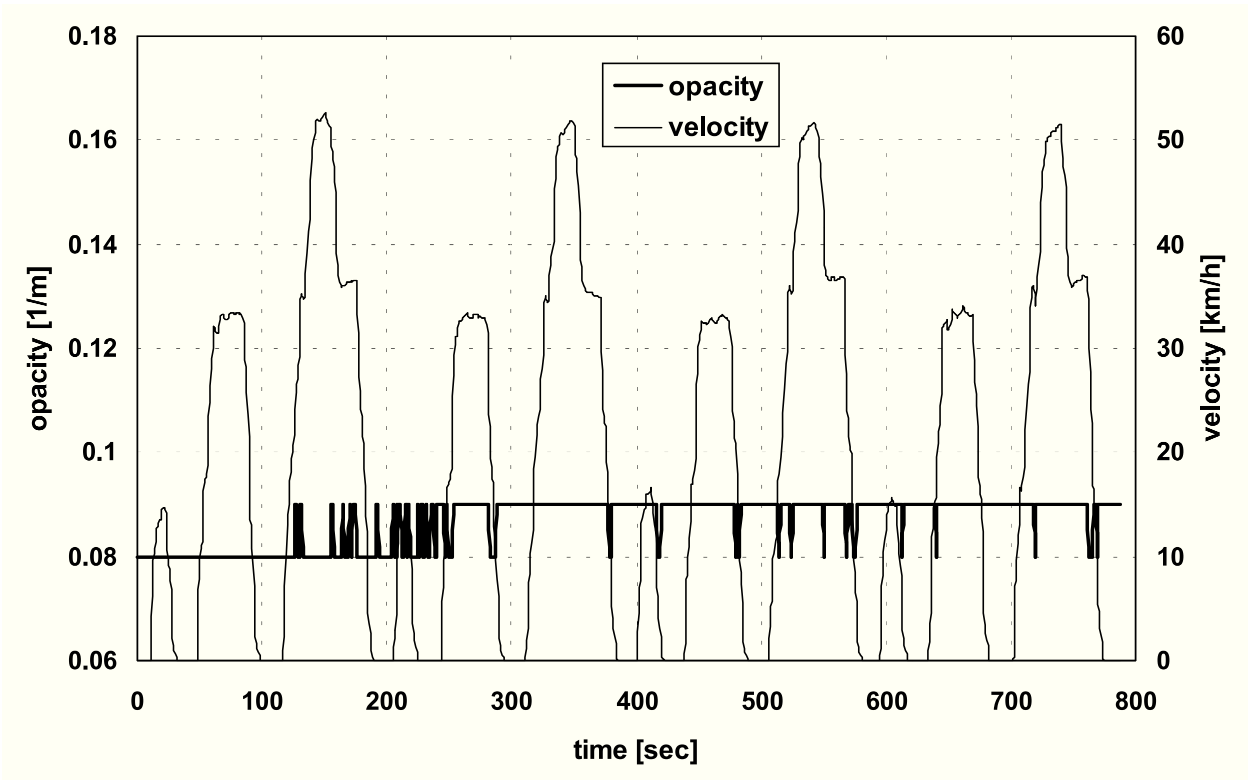

Figure 42 Continuously measured opacity over UDC with a diesel particulate trap

8. Conclusions

8.1 General

In the framework of the project a relatively large sample of passenger cars was tested which comprised:

- 192 TWC equipped cars complying with the emission standards of 91/441/EEC including 17 LPG powered cars
- 41 conventional and oxidation catalyst equipped cars, complying with ECE 15/04 emission standards (34 cars) and with intermediate emission standards (7 oxi-cat equipped cars)
- 28 diesel cars complying with a large number of emission standards (from ECE 15/04 to 91/441/EEC)

The above vehicle sample consisted mainly of a number of randomly chosen vehicles (in general representative of the car fleets of the countries involved), but also of a number of gross polluters which were specifically selected for the tests. In the case of TWC cars 135 cars constituted the so called randomly chosen sample, while 57 gross polluters were also added, identified either via remote sensing or using the TÜV test lanes. In addition a number of the vehicles (exceeding by 100% the emission standards as a general rule) were sent to maintenance and re-tested.

The test protocol used comprised, apart of the certification cycle (NEDC), a real world cycle (Modem cycle), two short transient tests (TÜV and Modem short), one steady state loaded test (7 kW at 50 km/h) and no-load tests (idle and high idle for gasoline cars and free acceleration tests for diesel cars). The tests involved bag-based emissions and continuous measurement of raw exhaust concentrations, usage of garage and laboratory analysers and checks of the effects of simplified inertia weights.

In parallel and in connection to the above, remote sensing was conducted in a number of cities involved in the experiments, where more than 80 000 cars were checked. In conjunction to the remote sensing, idle tests were performed on a number of cars identified as gross polluters. In addition, dynamometer testing was performed on a smaller number of these cars. The latter results were complemented with Swedish data collected in the same manner in the framework of another project, which was running in parallel and followed the same general approach.

Using the emission test results an evaluation of the short tests was conducted and complemented with a cost effectiveness analysis which focused on the years 1995, 2000 and 2005 for the countries Austria, France, Germany, Greece, the Netherlands, Sweden and the United Kingdom.

On the basis of the above the following conclusions and recommendations can be drawn per vehicle category

8.2 TWC equipped vehicles

- On the basis of the test results of the randomly chosen sample 20% of the vehicle fleet is responsible for 45% of total CO emissions, 45% of total NOx emissions, and 35% of total HC emissions, using the NEDC test data. If Modem is used then 20% of the car sample is responsible for about 45% of total emissions of all pollutants.
- No vehicles have been found emitting high levels of HC only (i.e. being low emitters in CO and NOx) or both HC and NOx (i.e. being low emitters in CO). This means that those vehicles, which are HC gross polluters, emit high CO also and thus they may be captured via this pollutant.
- On the basis of the test results of the randomly chosen sample, the short test legislated by the 92/55/EEC was found to be completely ineffective. It can identify only 15% of the high polluters, while the environmental benefit from it (ERRP) does not exceed 4% reduction in any of the pollutants involved. Especially as regards the lambda test, it was found to add in the direction of NOx emitters identification, having the drawback of increasing the errors of commission. It is of importance to note that that there is virtually no improvement at all if to the current CO measurement at idle and high idle, HC measurement is added to these points.
- However, the efficiency of this test clearly increases with increasing share of gross polluters in the fleet. This is demonstrated in the case of the whole sample, where the 92/55/EEC test was found able to identify about 50% of the high polluters.
- Of all the short tests used, the transient short cycles were found to have the greatest potential in terms of environmental benefit. They can identify practically all gross polluters (i.e. vehicles emitting more than 50% above the emission standards) and offer an emission reduction potential of the order of 15 to 20% for all pollutants CO, HC and NOx on the basis of the random vehicle sample.
- Most gross polluters and consequently the major part of emission reduction potentials are identified with the CO measurement. The added value of HC measurement is practically zero, while it adds to errors of commission. The added value of NOx measurement is concentrated almost exclusively in NOx emissions themselves: via NOx measurement 40% of the total NOx emission reduction potential is achieved. It adds about 5% in CO and HC emissions reduction potential. However, NOx measurement may add from 15 to 80% to total errors of commission.
- The effect of all types of short tests on fuel consumption and CO_2 emissions was found insignificant. It ranges from a small reduction to a small increase of the order of ± 2%, depending on the character of the sample.
- The cost-effectiveness analysis has shown that, as soon as there is a high share of catalyst equipped cars in the fleet, dynamic testing over a short driving cycle turns out to be a cost-effective perspective, provided that such testing can be organised in centralised inspection stations with a high throughput per testing lane.
- The two short transient cycles used in the program were found to be equivalent in both high emitter identification and high emission identification. The transient test can be performed
    - either with a CVS and bag system in order to measure mass emissions,
    - or with continuous measurement of the raw exhaust gas concentrations.

- In addition a simplified inertia system seems to be adequate in order to reduce system costs.

A preconditioning of the vehicle is necessary by running one short cycle prior to the official measurement. As the measurement of the emissions is performed under hot conditions of the engine and the pollution control system of the car, the effect of ambient temperature on the test results is practically negligible.

- In the framework of the test program no evaporation losses were measured. Based on a literature survey, the tests adopted in the US can be adopted in Europe too. However, such tests can not be proposed in a decentralised system; they can only be seen as a viable possibility in the framework of the above mentioned centralised scheme.

8.3 Conventional and oxidation catalyst equipped vehicles

- In the case of these cars the idle test was found to be very effective. However, the following improvements seem to be necessary: (a) reduce the CO cut-point from the current 3.5% to 1.5% and (b) introduce an additional HC cut-point of 3000 ppm C_1 (i.e. 500 ppm hexane equivalent), since with the existing 3.5% cut-point very few high emitters can be detected. It should be noted that these results are based on a very small random sample.
- Moreover, it was also found that adding a high idle test to the current low idle does not add in high emitter identification.
- NOx emissions were found to decrease in the case of randomly chosen cars, while an increase was identified in the case of all vehicles, as in the latter case ë was found to be in the rich area.
- An improvement of fuel consumption of the order 5% was measured in all cases.
- The cost-effectiveness analysis has shown that for 1995 the current procedure according to 92/55/EEC with the adaptations discussed above proves to be a very cost-effective procedure. Moreover, for countries with a continuing high share of non-catalyst cars this situation continues to be valid during the coming years.

8.4 Diesel vehicles

- As expected the diesel cars were found to be high polluters only in the case of particulate emissions. CO, HC and NOx emissions were always found to be well below the emission standards.
- Due to the small number of the sample the comparison was made using such cut-points for each test which were able to identify all the gross polluters of the sample, which led to an emission reduction potential of about 25% in PM for all short tests. In this case the free acceleration test of the 92/55/EEC was found to be associated with a high number of errors of commission.
- The above finding is evidently related to the fact that the free acceleration test does not correlate well with any long or short driving cycle, irrespective of its nature (more or less transient); this is particularly true in the case of the NEDC, where no correlation at all was found. In addition, the fact that - on the basis of the experience of the partners - there is a

strong influence of car preconditioning on free acceleration readings makes the results of the free acceleration test even less reliable.

- In contrast to the above, the use of a transient cycle with continuous opacity measurement was found to be very promising, as the average over the cycle opacity values correlate well with the NEDC PM emissions in g/km.
- As a consequence, the cost-effectiveness analysis has shown that for diesel cars the present test and a dynamic test do have approximately the same effectiveness. However, due to a high number of errors of commission (vehicles wrongly identified as faulty) the additional cost of unnecessary repair makes the present free acceleration method much more costly and therefore less cost-effective. This presupposes, however that the diesel cars can be tested on well equipped dynamic testing lanes, which would practically mean that the same lanes are also used for dynamic testing of Otto engined cars.
- The bad correlation of the free acceleration test with the emissions in any of the full cycles is largely related to the extreme and indeed unrealistically high transient character of the free acceleration smoke test. It is felt that the correlation might improve if a test could be devised that is still transient, but in a less extreme way. In fact the much better correlation of the smoke in the transient vehicle cycle with the actual PM emission already points in this direction. A simple test that would be less transient and more realistic than the free acceleration test would have to simulate at least part of the vehicle inertia in addition to the internal inertia of the engine. Such a concept could be imagined e.g. as a chassis dynamometer that contains a (fixed) flywheel but no power measurement. Such equipment does indeed exist at garage level for the determination of engine power. A small but dedicated follow-up project is suggested that does look further into this possibility.
- However, it has to be emphasised that opacity measurement may be completely ineffective in the short run, as near future development in emission standards indicate that visible smoke may completely disappear from diesel vehicle (i.e. with the use of after-treatment devices). Moreover, the increasing concern regarding the health effects of nanoparticles introduce new parameters into the overall picture of diesel emissions testing, which may render all the above completely obsolete.

8.5 Remote sensing

Remote sensing has a number of advantages over conventional test methods:

- it can measure the emissions from a very large number of vehicles
- measurement can be made without any inconvenience to the vehicle driver
- a fully automated system would allow measurement to be made with little man-power effort

The one problem with remote sensing is the variation in a vehicle’s exhaust emissions with driving parameters. Previous studies, based on fleets comprising almost entirely of non-catalyst vehicles have identified this problem as making remote sensing ineffective. However, the introduction of closed loop control on catalyst equipped cars reduces the amount of variation that occurs.

The variation on the vehicles exhaust emissions can mean that vehicles are detected with high CO emissions, whereas under a standard idle test the CO emissions are reasonable. However, the work in this study has shown that catalyst petrol vehicles with very high CO emissions can be detected with remote sensing. Nevertheless, remote sensing cannot detect vehicles with CO emissions just over the emissions limits, without including a large number of errors of commission; it can detect the gross emitters.

It is possible that the system could be ‘tuned’ to take into account the particular road layout, the speed and acceleration of the vehicle passing and perhaps even the make and model of the vehicle to provide an even better detection rate. Certain vehicles may characteristically produce high emissions under certain conditions (e.g. low powered vehicles will operate under wide open throttle conditions more often than high powered vehicles, which is likely to require open loop, fuel enrichment, operating conditions).

Based on just a remote sensing CO cut-point of 5%, the sample subjected to dynamometer test produces very high Emission Reduction Rate Potentials of 68% and 47% for carbon monoxide and hydrocarbons respectively. It should be noted, however, that the sample was biased in that it contains a large number of dirty vehicles. There is also some reduction in the oxides of nitrogen emissions and fuel consumption, with a small increase in the carbon dioxide emissions.

Using just a CO cut-point, the detected vehicles will also include a number of vehicles with high HC emissions (most of the vehicles with high HC emissions will also have high CO emissions). A few vehicles with high NOx emissions will also be detected.

Vehicles running lean with high NOx emissions might go unnoticed with just a CO cut-point. It may therefore be necessary to include a NO cut-point. However, in our test sample, only one vehicle dynamometer tested exhibited very high NOx emissions - further study in this are is required.

The sample selected for dynamometer testing was biased towards high emitting vehicles. Analysis of the remote sensing data shows that high emitting catalyst vehicles could account for 3% of the fleet in Greece and 0.5% of the fleet in the UK where catalysts have only recently been introduced. Although this sounds like a small number, the gross emitting vehicles detected in the sample had CO emission rates up to 30 times the legislative emissions limit and HC emission rates up to 14 times the limit.

Assuming that 3% of the catalyst-petrol fleet have average CO emissions of 40 g/km and the remaining 97% have average CO emissions of 3 g/km, then this produces an ERRP of 27% for the whole fleet. Clearly this 3% produce a significant contribution to the total emissions and targeting just them could significantly reduce total emissions. However, if only 0.5% of the fleet are high emitters, with CO emissions of 40 g/km, then the ERRP is only 6%.

It should also be noted that the remote sensing tests were carried out in countries which already have an established I/M test procedure. The number of dirty vehicles detected shows the importance of carrying out tests in addition to the annual/biannual I/M test.

8.6 Cost-effectiveness

- For 1995 the current procedure according to 92/55/EEC proves to be a very cost-effective procedure.
- For countries with a continuing high share of non-catalyst cars this situation continues to be valid during the coming years.
- As soon as there is a high share of catalyst equipped cars in the fleet dynamic testing over a short driving cycle turns out to be more cost-effective, provided that such testing can be organised in a system with centralised inspection stations with a high throughput per testing lane.
- For diesel cars the present test and a dynamic test do have approximately the same effectiveness. However, due to a high number of errors of commission (vehicles wrongly identified as faulty) the additional cost of unnecessary repair makes the present free acceleration method more costly and therefore less cost-effective. This presupposes, however that the diesel cars can be tested on well occupied dynamic testing lanes, which would practically mean that the same lanes are also used for dynamic testing of Otto engined cars.
- OBD is not likely to constitute a cost-effective alternative on the short or middle term, for the following reasons:
    - OBD will not be common for Otto engines before 2005 and not be universal before 2010, with diesel engines trailing 5 years behind.
    - OBD does only monitor exceeding of the OBD thresholds, which may be considerably higher than the certification limits.
    - Under the present description OBD thresholds may start to slip after 80,000 km.
    - Under the present description OBD may be temporarily disabled under various circumstances.
- If remote sensing is used with a high cut-point (detecting only very high emitters) and vehicle selection is done on the basis of multiple detection (the vehicle is detected on more than one pass), the effectiveness per vehicle detected can be high. Depending on the state of maintenance of the fleet, even the absolute effectiveness can be high.
- Using a low cut-point, in order to detect all high polluters, may lead to lower cost-effectiveness by a factor of three, as well as an increased number of errors of commission.
- Detailed calculations of the cost-effectiveness are not yet possible, but a rough calculation seems to indicate that under the conditions mentioned above the cost-effectiveness may be of the same order of magnitude as that of a regular periodical inspection.

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