Working Group 4: “Inspection and Maintenance (I&M)”

1.Background

The aim of the roadworthiness test for vehicle emissions[1] is to identify motor vehicles that are gross polluters, i.e. pollute at levels significantly in excess of prescribed limits. The current regulated roadworthiness test comprises a test for the carbon monoxide content of the exhaust gases from petrol driven vehicles and smoke opacity measurement for diesels.

Whilst the test procedures are far simpler than those used for type approval testing, the aim of I&M is nonetheless that vehicles identified as gross polluters should not be able subsequently to pass a type approval test (i.e. the in-service test should minimise the risk of errors of commission). Also, vehicles that pass the test should be at least close to passing any subsequent type approval tests (i.e. minimising the in-errors of omission). Errors of commission and omission are present with current in-service inspection methods.

2.0 Working Group 4

The aim of Working Group 4 (a role adopted by the existing “Technical Adaptation Committee on Roadworthiness Testing”) was to examine the potential of periodic I&M programmes to reduce, in a cost-effective manner, pollutant emissions. The work done for the Commission Services team (Joint Commission Services (JCS) study on In-Use Vehicle Emissions—LAT et al 1998) formed the main basis for WG4’s analysis.

The focus of the study was on catalyst equipped cars built to the Euro 1 standard (i.e. in conformity with Directive 91/441/EEC). Nevertheless, conventional spark-ignition and diesel cars were also covered by the study. Work on other motor vehicles, in particular heavy commercial vehicles in relation to their smoke opacity and particulate emissions was done in parallel with the JCS Study and has already led to legislative adaptation; this work is on going.

The working group addressed the following subjects:

- the potential for ambient pollution reduction through roadworthiness testing;

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[1] Directive 91/338/EEC first introduced the requirement to test passenger cars for their ‘roadworthiness’. Before then compulsory roadworthiness testing at the level of the Community had only concerned commercial vehicles (and ambulances). Light goods vehicles were included within the scope of the Directive by Directive 88/449/EEC. The minimum roadworthiness inspection frequency for light goods vehicles and passenger cars is every two years once the vehicle is four years old but most Member States test more frequently. Heavy commercial vehicles are tested annually. Directive 92/55/EEC introduced emission testing, applicable to pre-TWC petrol vehicles from 1996, TWC vehicles from 1997 and diesels from 1998. Directive 96/96/EC consolidates all regulated roadworthiness testing Directives. This has subsequently been adapted by Directive 99/52/EC.

- the correlation between in-service inspection and real world emissions (i.e. diesel smoke opacity at engine transient/no load Vs full load particulate emissions);
- the potential for fine tuning the current standards (i.e. by including OBD monitoring);
- the cost/benefit of radical enhancement of the current standards (i.e. testing in the engine loaded condition);
- the nature and importance of testing against type approval reference values;
- the variance in test equipment accuracy;
- the added benefit of supplementing the roadworthiness test with road-side controls (and the potential for using remote sensing to select potential gross polluters);

2.1 Participation

- Member State's and their inspection organisations who are active in the R&D of Roadworthiness emission standards;
- both the CITA and the EGEA emission working groups;
- touring clubs represented by the FIA;
- industry, i.e. the ACEA, EUROPIA, CLEPA and CECRA (representing garages);
- prominent environmental groups that have expertise in in-service emission standards;

3.0 Roadworthiness Emission Testing in the European Union

3.1 Background

The Roadworthiness framework Directive (77/143/EEC) goes back some twenty years and originally only included trucks, buses, taxis and ambulances within its scope. The Directive included a list of items to be tested and inspected such as brakes and emissions but did not specify how these should be tested, nor the pass/failure criterion. Nevertheless, at the time, this Directive established new ground for several Member States: for others it merely re-affirmed long established testing procedures.

Since 1977, the directive has been modified many times and now includes the inspection of cars and light vans within its scope and it also gives detailed requirements for the testing of vehicle brakes and exhaust emissions (Directive 92/55/EEC). The framework Directive and all its amendments are now consolidated within Directive 96/96/EC.

3.2 Passenger-cars and light goods vehicles

Passenger-car roadworthiness testing was introduced through Directive 91/338/EEC. The requirement to test passenger cars, the vast majority of which are privately owned, established the precedent that the community, in pursuing policies to improve the safety and environmental performance of vehicles on its roads, also needed to take account of privately owned vehicles. Up until this provision, compulsory roadworthiness testing at the level of the Community had only concerned commercial vehicles (and ambulances). Light goods vehicles were included within the scope of the Directive by Directive 88/449/EEC.

The minimum roadworthiness inspection frequency for light goods vehicles and passenger cars is every two years once the vehicle is four years old but most Member States test more frequently. France, Ireland, Denmark, Portugal and Italy were given a dispensation allowing them to commence passenger car testing from 1 January 1998.

3.3 The Scope of the Current Vehicle Emission Test Requirements—I&M Testing

Directive 92/55/EEC requires ‘conventional’ petrol engined vehicles (and that includes open loop catalyst equipped cars) to be tested for the carbon monoxide content of their exhaust gases with limit values of either 3.5% or 4.5% , dependent on the vehicle’s age or against more stringent reference values supplied by the industry.

Petrol vehicles with three-way, lambda-controlled catalytic converters (TWC) were, from 1 January 1997, required to undergo a test for carbon monoxide content of the exhaust. The limit value, at 0.3% vol. CO (or the more stringent manufacturers’ reference values) is an order of magnitude more severe than for conventional petrol engined vehicles. Air/fuel ratio is also tested.

Diesel vehicles need to be tested for the opacity of the generated exhaust smoke during a transient, ‘free acceleration’ engine test where the engine is accelerated against its own inertia. The test became mandatory from 1 Jan 1996.

3.4 Random Roadside inspections

The proposed Directive (COM 1998, 117 final) requires Member States to supplement the annual roadworthiness test for heavy commercial vehicles with targeted, unannounced roadside inspections of both the vehicle’s safety and environmental performance. Vehicles that are unroadworthy as a result of a random inspection, wherever they are registered may be prohibited from free circulation. The diesel smoke opacity check of Directive 96/96/EC is used as the standard for the inspection’s environmental performance. This proposal results from the first Auto-Oil programme.

4.0 Joint Commission services (JCS) study

The principal focus of the joint study was on the testing of catalyst equipped cars built to the Euro 1 standard (i.e. in conformity with Directive 91/441/EEC). Whilst conventional spark-ignition and diesel cars were also covered by the study, work on other motor vehicles, in particular heavy commercial vehicles, was conducted in parallel and has already led to legislative action.

The joint study reviewed all short tests, including from outside Europe, that have been used for in-use passenger car testing. The performance of these short tests was evaluated in terms of their ability to identify high emitting cars (i.e. vehicles emitting more than 50% above the emission standards) and the results compared with emission levels measured according to both European legislated and real-world driving cycles.

The study examined whether emission measurements under load were better at identifying high emitting cars than measurements at idle speed for petrol engined cars, especially those with a three way catalyst (TWC), or via the free acceleration test (FAS) for diesels. For each particular solution, its cost (covering installation and operation) and effectiveness in reducing actual and future emissions of the fleet were quantified.

In addition, the possibility of using remote sensing techniques to identify high emitters was also investigated as a potential supplement to the existing I&M regime.

Conclusions from the joint study on I&M

Three-way Catalyst (TWC) equipped vehicles

The currently regulated short test was found to identify only 15% of high polluters and to result in a reduction of just 5% in polluting emissions compared with no I&M. Of all the short tests used, the transient short cycles were found to have the greatest potential to identify gross polluters. A properly operating I&M programme for TWC cars using transient short test cycles could have the potential to reduce emissions in the order of 35% for CO, 25% for HC and 5% for NOx.

Non-catalyst and oxidation catalyst equipped vehicles

For these cars the test requirements of the current Directive were found to be very effective with, for example, the potential to achieve a 15% reduction in CO emissions. However, reducing the CO cut-point from the currently legislated 3.5% to 1.5% (or alternatively testing against manufacturers' reference values) should bring further gains.

Diesel vehicles

The present regulated FAS test and the dynamic tests had approximately the same environmental effectiveness, i.e. emission reduction potential of about 25% in PM for all short tests (the study team subsequently considered this figure to be an overestimation because of the sample's bias towards higher emitting cars; AOPII assumes a 10% reduction).

However, due to a high number of errors of commission (vehicles wrongly identified as faulty) the additional cost of unnecessary repair made the FAS test method much more costly and therefore less cost-effective. Furthermore, assuming that attention increasingly focuses on ultra-fine particles and that the introduction of after-treatment devices eliminate visible smoke, opacity measurement may become obsolete. Work being done by the International Motor Vehicle Inspection Committee (CITA), on behalf of DG Transport will establish testing techniques and measurement methods for low emission diesel engines, i.e. in order to measure PM.

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, measurements can be made without any inconvenience to the vehicle driver, and a fully automated system would allow measurements to be performed with little man-power effort.

Based on fleet data from the UK and Greece, the use of remote sensing with a CO cut-point of 5% vol. CO could achieve emission reductions of roughly between 5% and

25% of passing vehicles.

4.1 Assessment of potential I&M scenarios

The JCS study demonstrated the shortcomings of the present, legislative system of I&M inspection within the EU. Clearly, dynamic/loaded testing for both petrol and diesel light vehicles produced more realistic results. For TWC vehicles dynamic testing offered far greater environmental accuracy. For diesels, dynamic testing produced less ‘errors of commission’ and therefore could be more efficient.

However, the number of TWC vehicles identified as very excessive polluters by way of remote sensing showed that the regulated biannual (annual in some Member states) was not sufficient to ensure that vehicle would not significantly deteriorate between tests. Consequently, supplementing the regulated test by screening the fleet through remote sensing offers a way of reducing to a minimum the effect of poor maintenance and/or vehicle deterioration on air quality.

4.2 I&M effectiveness, a UK study

A study on the effectiveness of the UK’s I&M programme by the National Audit Office concluded the following.
The level of emissions directly avoided by testing and associated maintenance over the period 1995 to 2005 will fall significantly due largely to improvements in engine technology. This means that more modern vehicles, especially those fitted with catalysts, generate far less emissions, so there are less emissions to be avoided by testing and repair.

The amount of emissions avoided as a result of roadworthiness inspections for the UK for 1995, 1998 and estimated for 2005 are as follows:

Tonnes of emissions avoided (Units: thousand tonnes)

Pollutant emitted	1995	1998	2005
Carbon monoxide	670	297	34
Nitrogen oxides	53	32	8
Hydrocarbons	51	24	4
Particulates	6	7	4

If adopted, dynamic loaded tests should avoid around 0.085m tonnes of carbon monoxide by 2005, compared to the 0.034m tonnes avoided using current testing techniques. A loaded test has the advantage of being the only method by which emissions of nitrogen oxides can be meaningfully measured.

A dynamic test of diesel vehicles would produce the same reduction in particulate emissions as provided by current test techniques.

This work comes to similar conclusions as does the JCS study.

4.3 Technical adaptation

Diesel Vehicles

A recent amendment to the directive specifies some improvements to the current FAS test for diesel engines[2]. This was developed from a proposal by CITA using information from some research by AEA Technology[3].

Up until now, it had been assumed that the opacity of the exhaust smoke generated during the static FAS could identify the maintenance condition of the vehicle. There would be little if any relevance in measuring noxious emissions (CO, HC, NOX and micro particles) produced from this relatively simple test. This is because the quantities of CO and HC are very low from the diesel engine and the engine is not put under the types of heavy service loads that would generate NOX or high quantities of fine particle emissions.

However, it is the emissions of NOX together with the level of micro particulates (less than PM10) that need to be controlled.

Most diesel smoke is emitted during the transient, acceleration phase, more so than in the type approval test. At the time of the Commission study, methods of measurement were not standardised and it was demonstrated that test procedures, especially vehicle pre-conditioning can have a very significant effect on the results.

Also, there can be significant variability in the test results depending on the way the test is carried out in practice. If the accelerator is pressed too slowly, the maximum amount of smoke emitted can be reduced by a factor of five. Also, engine pre-conditioning is a vital component in the validity of diesel testing. Directive 99/52/EC modifies Directive 99/52/EC by taking these issues on board.

5.0 Outline of proposed research

1. If the potential further reductions in emissions from current technology vehicles (those without catalysts and with catalysts without closed loop control) are to be realised, the current test procedures in the directive will need to be amended. A working group is currently looking at whether introducing type specific emission limits could realise some of these reductions. A subsequent study will try to realise more of the potential reductions by producing a specification for a ‘best practice’ test procedure. This will be synthesised from the procedures currently used in the European Union.
2. Directive 96/96/EC does not cover motor cycles and there are no procedures specified for testing the exhaust emissions (or noise) from such vehicles.

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[2] Commission directive 1999/52/EC OJ L142 p. 26

[3] “Diesel smoke test procedures and meter specification”, J.O.W.Norris, J.R.Donald, October 1997.

Earlier proposals to extend the directive to include motorcycles did not meet with much support from the member states, particularly those that had only just introduced passenger car testing. However, more recently there is increasing concern about the contribution of motor cycle emissions to air quality standards and about motorcycle noise, particularly related to the use of non-original equipment replacements and owner modifications. A second study will aim at developing a proper understanding of the parameters that should be controlled on motorcycles and at proposing specifications for procedures and equipment that should be used. The study will also seek to quantify the benefits that would be achieved by the introduction of periodic inspection of motorcycle exhaust emissions (and noise).

3. For the low emission vehicles now coming into use, two studies will be conducted. One is to consider how the OBD systems, that are required by directive 98/69/EC to be fitted to petrol vehicles from 2000 and diesel vehicles from 2003, could be used to increase the effectiveness of periodic and other inspections of vehicles in use. The practicality of obtaining data from OBD systems using current ‘scan tools’ will also be assessed.

   If the study shows that there is benefit in this approach, proposals will be made which can be used as the basis for discussions on the introduction of harmonised procedures in directive 96/96/EC.

4. The research mentioned earlier[2] has already shown that existing test procedures are inadequate for the latest technology vehicles and that a short cycle test on a chassis dynamometer would be better. A study on testing low emission vehicles will aim at developing a specification for the procedures and equipment for such a test. This work will lead to a proposal for test procedures and equipment specifications for a short cycle test on a simple chassis dynamometer to be used as the basis for discussions on the introduction of **optional** harmonised procedures in directive 96/96/EC.
5. Finally, a feasibility study will be undertaken into the need and benefits of a large-scale data gathering exercise of the emissions produced by vehicles in use during a short cycle test. The data from such an exercise would enable the benefits of introducing a short cycle test using a chassis dynamometer to be evaluated more precisely. This is essential information for any proper evaluation of the cost-benefit of introducing short cycle tests. It would also provide information that would help refine the emission factors used in air quality modelling programmes such as MEET[4] and its successors. It would also provide information on whether there would be any benefits from changing the frequency of periodic statutory emission tests.

5.1 Participants

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[4] MEET- Methodology for calculating transport emissions and energy consumption, Final report published by the Office of Official Publications of the European Communities 1999, ISBN 92-828-6785-4.

The following CITA members and other organisations have indicated a willingness to participate in elements of these studies -

(a) VdTÜV/DEKRA, Germany
(b) GOCA asbi, Belgium
(c) AB Svensk Bilprovning, Sweden
(d) AECA-ITV, Spain
(e) Vehicle Inspectorate, Great Britain
(f) EGEA, Belgium
(g) BIVV, Belgium
(h) AEA Technology, Great Britain

6.0 Conclusion— improving testing effectiveness and expanding the roadworthiness scheme.

The potential impact of roadworthiness testing on ambient pollution reduction is set to decline rapidly as newer vehicles produce lower levels of pollutants and are likely to have a more stable emissions performance.

Work is to be undertaken that aims to devise new forms of emission testing for the evolving fleet. The work will assess the potential impact of testing on ambient pollution reduction.

An option for the immediate future will be to amend the roadworthiness Directives (both regulated and roadside inspections) to make use of OBD systems as and when they are adopted. For diesels, as with petrol vehicles, OBD will offer considerable advantages for in-use inspection and control.

A fundamental question today and for the near future is whether the enhancement of the roadworthiness inspection for vehicle emissions by way of chassis dynamometer testing is worthwhile given that OBD will be a reality for new types of petrol cars from year 2000 and for diesels from 2003.

Dynamic testing is probably not feasible for heavy commercial vehicles within an I&M programme. Consequently, the major advance in I&M testing for these vehicles will probably come about through the introduction of the OBD and perhaps the development of remote sensing techniques for diesel vehicles (i.e. by measurement of Nox and particulate emissions).

The work done under the Auto-Oil 2 programme umbrella will be continued within the Technical Adaptation Committee. This work will include:

- Establishing the ‘added value’ of testing against manufacturers emission reference values (both gaseous and diesel particulates)

- Developing measuring equipment and test procedures that can test to ultra-low levels of gaseous and particulate emissions so as to enable testing against manufacturers’ reference values;

- Including OBD monitoring within I&M testing requirements and establishing what level of additional testing is necessary;

- Through the Artemis programme, determining the emission factors for post Euro2 vehicles and therefore the added benefit for I&M control brought about by OBD (post Euro3);

- Through Artemis, understanding the added benefit of increasing the minimum test frequency of cars and light commercial vehicles to annual testing;

- Testing motor cycle emissions. This should now be possible given the existence of comparable type approval standards. A testing technique is to be developed by CITA. The Artemis programme is to develop emission factors for motor cycles and this should indicate the added value of I&M testing;

- Gain experiences with remote sensing and encourage its application;

- Implementation of random roadside inspections (COM(1998) 117) will improve the roadworthiness performance of the heavy commercial fleet. Extending roadside inspections to include light vehicles will be assessed. With the introduction of OBD, such a system should become less costly for the authorities and less intrusive for the public.

In-Use Vehicle Emission Controls:

An Outline of the 1994-1998 Joint Commission Services Study

ABSTRACT

The paper provides an overview and the main results of a project aiming at the evaluation of current and alternative Inspection and Maintenance (I/M) programmes in Europe. For this purpose, a large number of in-use passenger cars from five countries (Greece, Germany, France, the Netherlands and the United Kingdom) was tested according to a common test protocol that included a wide variety of legislated tests as well as procedures that reflect real-world driving conditions. Remote sensing measurements were performed as well, in order to explore the potential of this technique as an alternative or complementary I/M procedure I/M test procedures . Evaluation of all test results was conducted with the objective to define cost-effective and examine the potential of periodic I/M programmes to reduce pollutant emissions and improve fuel economy of in-use cars. The implications for the future legislative steps in the European Union are discussed.

Although European exhaust emission regulations for new cars have become increasingly stringent in the last two decades, real-world emission levels of the average car have remained higher than anticipated. This has to be attributed mainly to the sensitivity of the complex electronic systems of modern vehicles, along with poor maintenance of in-use cars. The problem of in-use deterioration of a car’s engine and emission control system has been well known in the United States for more than a decade and has been demonstrated through the discrepancies between emission model calculations and real-world measurements with the aid of roadside vehicle inspections, tunnel studies and remote sensing observations. As regards periodic I/M programmes, in European Union countries Directive 92/55/EC is in force, which foresees measurement of concentrations of carbon monoxide (CO) in a car's exhaust under no-load operating conditions; other countries of Central and Western Europe have implemented similar regulations. However, defects in modern engine management and emission control systems are difficult to diagnose with old inspection methods; on the other hand, such defects can cause drastic increases in a vehicle's emissions under real-world operation, which may render new emissions regulations ineffective.

The objective of the four-year European study (LAT et al. 1998) was to investigate and develop a series of alternative technically advanced and cost-effective solutions for the periodic inspection of passenger cars in order to achieve low real-world emissions and fuel consumption. Especially in the case of three way catalyst (TWC) and diesel vehicles it was considered necessary to investigate procedures that in theory have a larger potential in detecting wrong engine and/or catalyst settings and eventual defective components. In this respect it was examined whether emission measurements under load was 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 a legislative measure, but merely as a means of tracing the results of an enacted I/M system.

More specifically, the following issues were addressed:

- All short tests that have been used for in-use passenger cars worldwide have been reviewed. On the basis of this review and of additional tests that were designed by the study team, extensive exhaust emission measurements were performed for a number of selected short tests according to a common test protocol that was used by all laboratories participating in the study.

- The performance of these short tests was evaluated in terms of identification possibilities of high emitting cars, and the results were compared to the emission levels as measured according to both European legislated and real-world driving cycles. The likely impact of vehicle maintenance on the emissions of car fleets across Europe was examined and the ability of the short tests to verify the effectiveness of maintenance was quantified.

- Furthermore, the costs associated with each examined test procedure were considered. On the basis of these estimates, the cost-effectiveness of each short test was assessed.

- Finally, the performance of one remote sensing technique, especially when this is coupled to periodic short tests, was investigated.

The focus of the study was on catalyst equipped cars built to the Euro1 standard (i.e. inconformity with Directive 91/441/EEC). Nevertheless, conventional spark-ignition and diesel cars were also covered (to a lesser extent) by the study.

2. Framework of the Study

The study was funded by the European Commission – Directorates General for Transport (VII), Environment (XI) and Energy (XVII). The following institutions participated in the experimental and evaluation phase of the project: Laboratory of Applied Thermodynamics, Aristotle University of Thessaloniki (GR), who acted as coordinator; Institut National de Recherche sur le Transport et leur Sécurité – INRETS (FR); Technischer Überwachungsverein (TÜV) Rheinland (D); Netherlands Organisation for Applied Scientific Research – TNO (NL); Transport Research Laboratory – TRL (UK). Moreover, three more institutes collaborated with the consortium on the basis of nationally sponsored projects: Motortestcenter – MTC (S); Institute of Environmental Research – IVL (S); and the Laboratory of Internal Combustion Engines and Thermodynamics of the Technical University of Graz – VKM-Thd (A).

3. Experimental

In the framework of the project a relatively large sample of in-use passenger cars has undergone laboratory tests; the sample comprised:

- 192 TWC equipped cars complying with the emission standards of 91/441/EC, including 17 liquefied petroleum gas (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 oxidation catalyst equipped cars)
- 28 diesel cars complying with a large number of emission standards (from ECE 15-04 to 91/441/EC)

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 that were specifically selected for the tests. In the case of TWC cars, 135 vehicles constituted the randomly chosen sample, while 57 gross polluters were also added; these were identified either via remote sensing or through the periodic inspections that TÜV Rheinland carries out in Germany. In addition a number of the vehicles (as a rule, those cars exceeding the emission standards by at least 100%) were sent to maintenance and retested.

The laboratory test protocol comprised: 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, use of garage and laboratory analysers and checks of the effects of simplified inertia.

In parallel, remote sensing was conducted in a number of European cities, 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. Dynamometer testing was also 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 that was running in parallel and was following the same general approach.

With the aid of the collected experimental data, an evaluation of the short tests was conducted and complemented with a cost effectiveness analysis that focused on the years 1995, 2000 and 2005 for the countries Austria, France, Germany, Greece, the Netherlands, Sweden and the United Kingdom.

4. General Conclusions

The results of the study are presented in detail in the following papers of this issue. In this chapter the general conclusions of the project are given:

i)Three-way Catalyst (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 nitrogen oxides (NOx) emissions, and 35% of total HC emissions, using the certification cycle (NEDC) test data. If the real-world driving cycle ‘Modem’ is used, then 20% of the car sample is responsible for about 45% of total emissions of all three 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 HC gross polluters emit high CO as well.

For TWC petrol engined cars, the short test legislated in the European Union by Directive 92/55/EC was found to be completely ineffective in environmental terms. 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. As regards the lambda test, it was found to add value in the direction of NOx emitter identification but 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, i.e. by including non TWC cars. In the case of the whole car sample, the 92/55/EC 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. However, NOx measurement may add from 15 to 80% to total errors of commission.

Concerning fuel consumption and CO_2 emissions, the effect of any short test is insignificant: it ranges from a small reduction to a small increase of the order of ± 2%, depending on the character of the sample.

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 constant volume sampling (CVS) and bag system in order to measure mass emissions, or with continuous measurement of the raw exhaust gas concentrations. 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 United States 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.

ii) Non-catalyst 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 cutpoint from the currently legislated 3.5% to 1.5% and *(b)* introduce an additional HC cutpoint of 3000 ppm, since with the existing 3.5% cutpoint very few high emitters can be detected. Adding a high idle test to the current low idle one does not improve high emitter identification. It should be kept in mind, though, that these results are based on a very small random sample.

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 the air/fuel ratio was found to be in the rich area. As regards fuel consumption, an improvement of the order of 5% was measured in all cases.

iii) Diesel vehicles

As expected, diesel cars were found to be high polluters only in the case of particulate (PM) 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 cutpoints for each test that 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 legislated free acceleration test of Directive 92/55/EC was found to be associated with high errors of commission.

This 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. Conversely, 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.

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 flywheel but no power measurement. Such equipment does indeed exist at garage level for the determination of engine power. CITA, on behalf of DG Transport will be assessing the potential for such equipment.

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.

iv) 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, measurements can be made without any inconvenience to the vehicle driver, and a fully automated system would allow measurements to be performed with little man-power effort.

The main 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. However, the introduction of closed loop control on catalyst equipped cars reduces the amount of variation that occurs.

Because of the variation in a vehicle’s exhaust emissions, cars may be detected with high CO emissions, whereas under a standard idle test the CO emissions might be reasonable. However, the work in this study has shown that catalyst gasoline vehicles with very high CO emissions can be detected with remote sensing. Nevertheless, cars with CO emissions just over the emission limits cannot be detected without including a large number of errors of commission. 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 cutpoint of 5%, the sample subjected to dynamometer test produces very high Emission Reduction Rate Potentials (ERRP) of 68% and 47% for CO and HC respectively. It should be noted, however, that the sample was biased in that it contained a large number of dirty vehicles. There is also some reduction in NOx emissions and fuel consumption, with a small increase in carbon dioxide (CO_2) emissions.

Using just a CO cutpoint, 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). On the other hand, most cars running lean with high NOx emissions might go unnoticed with just a CO cutpoint. It may therefore be necessary to include a NO cut-point.

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. 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 TWC car fleet have average CO emissions of 40 g/km and the remaining 97% have average CO emissions of 1.3 g/km, this produces an ERRP of 27% for the whole fleet. Clearly this 3% contributes significantly 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%.

v) Cost-effectiveness

Up till recently (i.e. with the testing of TWC cars) the currently legislated procedure in the European Union (according to Directive 92/55/EC) was a very cost-effective procedure. For countries with a continuing high share of non-catalyst cars this situation will continue to be valid during the coming years. Conversely, as soon as there is a high share of TWC cars in the fleet, dynamic testing over a short driving cycle becomes more cost-effective, provided that such testing can be organised in a system with centralised inspection stations and a high throughput per testing lane.

For diesel cars the present test and a dynamic test 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 renders the present free acceleration method more costly and therefore less cost-effective. This presupposes, however, that diesel cars can be tested on well utilised dynamic testing lanes, which would practically mean that the same lanes are also used for dynamic testing of gasoline cars.

On-Board Diagnostic (OBD) systems are not likely to constitute a cost-effective alternative on the short or middle term, for the following reasons:

- In Europe, OBD will not be common for gasoline engines before 2005 and not be universal before 2010, with diesel engines trailing 5 years behind.
- OBD does only monitor exceedances of specific thresholds, which may be considerably higher than the certification limits.
- Under the present description, OBD thresholds may start to slip after 80 000 km and the system may be temporarily disabled under various circumstances.

If remote sensing is used with a high cutpoint (detecting only very high emitters) and vehicle selection is done on the basis of multiple detection (i.e. 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 car fleet, even the absolute effectiveness can be high. Using a low cutpoint, 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.

2. Test Scenarios

The New European Driving Cycle (NEDC), depicted in Figure 2, was performed under cold-start conditions, i.e. according to the legislation, in order to obtain the reference emissions of the vehicle at the as-received conditions. The cycle was 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 in real-world test lanes will be performed under hot operation conditions.

In addition to the legislated cycle, a real-world 'actual' cycle was also performed in order to be used for the further evaluation of the overall effectiveness of I/M schemes. The cycle used is shown in Figure 3. It was developed on the basis of large scale driving behaviour measurements in three European countries (France, Germany and the United Kingdom) in the framework of the DRIVE – 'Modelling of emissions and consumption in urban areas – Modem' project. As can be seen in Figure 3, the cycle consists of four parts: a 'slow urban' fraction (speeds hardly exceeding 30 km/h), a 'road' part (with speeds up to 100 km/h), a 'free-flow urban' portion (with speeds up to 60 km/h) and a 'motorway' part (with speeds exceeding 120 km/h).

Following the long cycles, two transient short tests, developed in the framework of this project, were performed. These were:

- A short transient cycle taking into account the kinematic 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 × acceleration) of the type approval test, as it is also known that acceleration and deceleration influence the emission behaviour as well. Thus the short cycle, displayed in Figure 4, 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 was performed twice, the first repetition considered as pre-conditioning.

- A ‘real-world’ short cycle that was constructed in order to simulate the long Modem cycle. This is displayed in Figure 5, while Table 1 provides a summary of the characteristics of the above driving cycles.
- The short cycles were followed by a no-load test at idle and fats idle (2500-3000 engine rpm) and finally by a steady-state loaded test, at 50km/hr and 7kW power absorption.

3. The Test Sample

In principle the selection of vehicles was random and differed in each country, in order to account for the particular characteristics of the in-use vehicle stock per country and the future trends. However, since there is strong evidence from the United States 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 minimum share of high emitters (exceeding the standards) was also necessary. This was achieved mainly by selecting a number of vehicles from groups where high emitters can be expected, e.g. high mileage vehicles and national inspection programmes. Despite the fact that this creates a conflict with the requirement to have a representative test sample, 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. Vehicles that were chosen as a priori high emitters came from national programmes (i.e. the German ‘Abgasuntersuchung’ and the Dutch in-use compliance programmes). 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).

In order to quantify the likely effects of maintenance on exhaust emissions, the vehicles that were identified as gross polluters (emitting more than 50% over the emission standard) were maintained and then retested. Maintenance was conducted either at garages of 'average level'or at authorised auto dealers who in principle can ensure high quality repair.

Table 2 gives an overview of the measurements carried out by all collaborating institutes. In total 342 tests were performed on 261 cars, as 81 cars were retested after they had undergone maintenance. The test sample included 41 conventional (non-catalyst) gasoline cars, 192 vehicles equipped with three-way catalytic converters (TWC), including some liquefied petroleum gas powered cars, and 28 diesel cars.

Focusing on the TWC cars, Figure 6 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 United Kingdom (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 about 1 000 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.

4. Results for TWC cars

Average Emissions of the Test Sample

The identity of the sample of catalyst equipped cars in terms of their emissions behaviour over the NEDC is depicted in Figure 7 for the total and the random vehicle sample (there are no randomly chosen vehicles from TRL since all vehicles from this laboratory have been selected on the basis of remote sensing). Of particular interest to stress that on average the car sample has emission levels that are below the emission standards of Directive 91/441/EC as regards hydrocarbons (HC) and nitrogen oxides (NOx) (1.13 g/km composite standard for HC+NOx); only the carbon monoxide (CO) average figure is about double as much as the conformity of production emission standard (3.16 g/km). This finding is also confirmed by the experience (common to all partners) that cars of current TWC 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.

Figure 8 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 times 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, and 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.

Effect of Maintenance

The effect of maintenance on car emissions is illustrated in the case of TWC cars in Figures 11 to 13. Figures 11 and 12 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 American studies are reproduced: 10% of the cars emit 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 25-40% 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 overall emissions.

The potential of maintenance is illustrated in Figure 13. 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:

- The sample should not be considered as representative of the in-use vehicle fleets in Europe because the share of gross emitters is higher than what should be expected in the actual fleets.
- The selectivity of this scheme is maximum as the NEDC was used for the identification of high emitters.
- 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.

In view of the above, the results in Figure 13 should be considered as rather optimistic. This is also supported by the findings of other European projects (e.g. VROM 1994), which assess that the potential of a realistic I/M programme should be close to 10% for CO, 5% for HC and 0-5% for NOx. Finally it is worth stressing that a negligible overall effect on CO_2 is expected after maintenance.

5. Conclusions

- In-use TWC cars in Europe have been found to have on average lower emissions than the legislated emission standards, even in the case of the ‘biased’ total sample of the study. Moreover, it was found that catalysts can exceed the 80 000 km durability requirements and live much longer; the causes of high emissions are confined to engine operation problems rather than the catalyst itself.
- The problem of high emitters seems to be less pronounced in Europe than in the United States: observing the random test sample, 20% of the vehicles accounts for not more than 45% of CO and NOx emissions and less in HC emissions. Identification of high emitters can be achieved through CO measurement and in some cases through NOx measurement; there are no HC-only gross polluters.

- The two transient short tests examined seem to be equivalent for all emissions and fuel consumption, with HC emissions being a partial exception.
- High emission events are under-represented in the NEDC, therefore this cycle underestimates real-life emissions.
- The potential in terms of emissions reduction of a properly operating I/M programme for TWC cars has been estimated on the basis of the test results to be in the order of 35% for CO, 25% for HC and 5% for NOx. However, because of the somewhat ‘biased’ total sample, in real-world conditions this potential should be lower, probably less than half of the above.

Tables

Table 1: Kinematic characteristics of the driving cycles used in the study.

Name	*duration (s)*	*distance (m)*	*speed (km/h)*	*Standard deviation of acceleration (m/s^2)*	*Fraction of 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 slow urban	428	1 705	14.3	0.583	17.4
Modem free-flow urban	355	2 248	22.8	0.702	40.5
Modem road	712	8 485	42.9	0.685	12.4
Modem motorway	452	12 683	101.1	0.418	29.7
Modem weighted			49.22		
TÜV short	200	1 969	35.4	0.535	
Modem 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 slow urban	134	20.9	42.3
Modem free-flow urban	71	28.5	62.3
Modem road	96	49.6	109.2

Modem motorway	11	103.5	128.7
Modem weighted			
TÜV-A short	51	47.6	90.0
Modem short	51	39.6	69.7

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

	Maintenance	*Random Selection*	*From German AU (TÜV)*	*From High emitters (TNO)*	*From Remote sensing tests*	*Total*
Conventional	before	14	-	-	27	41
Gasoline	after	7	-	-	15	22
Gasoline	before	135	16	12	29	192
TWC	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**

List of Figures

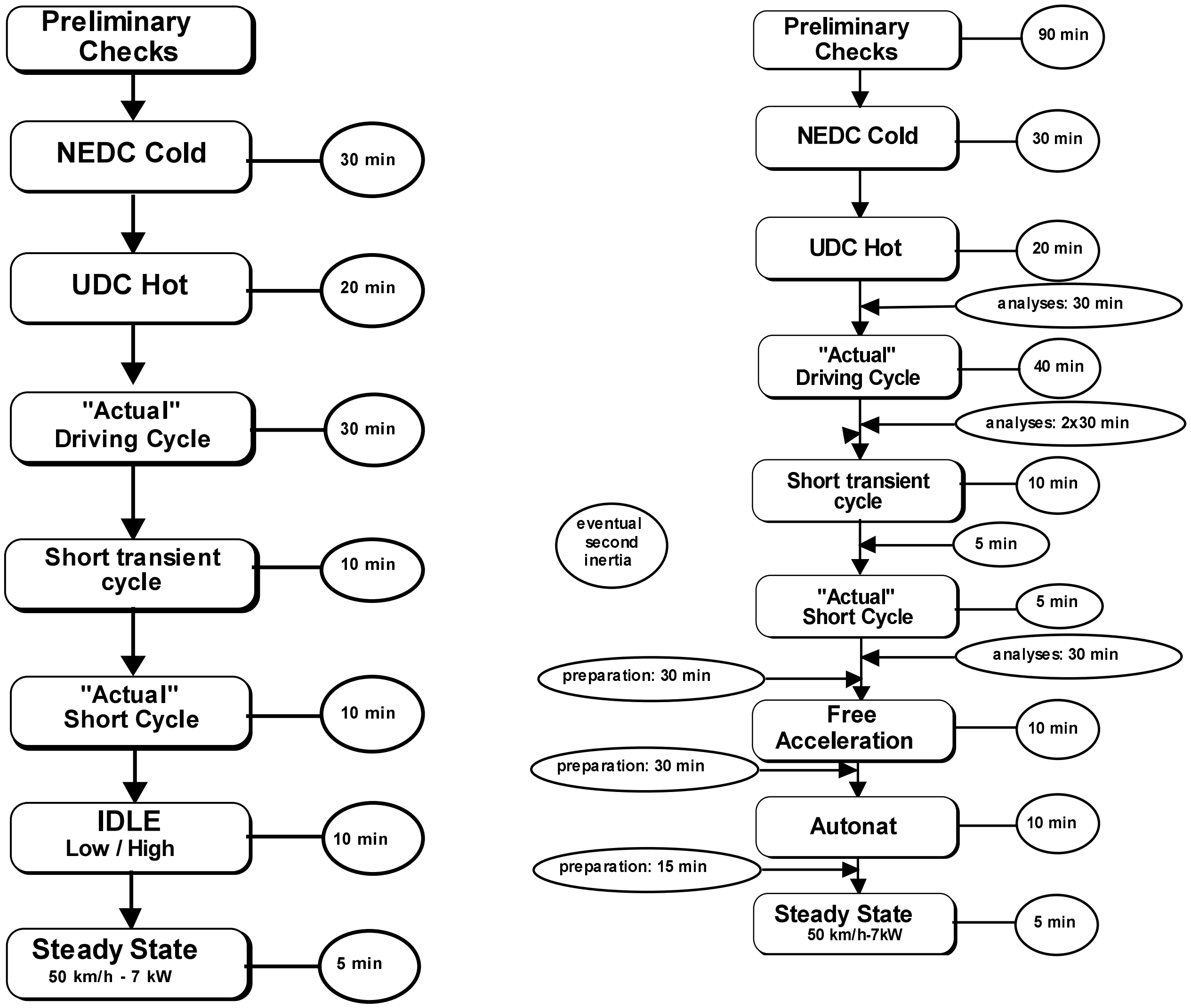
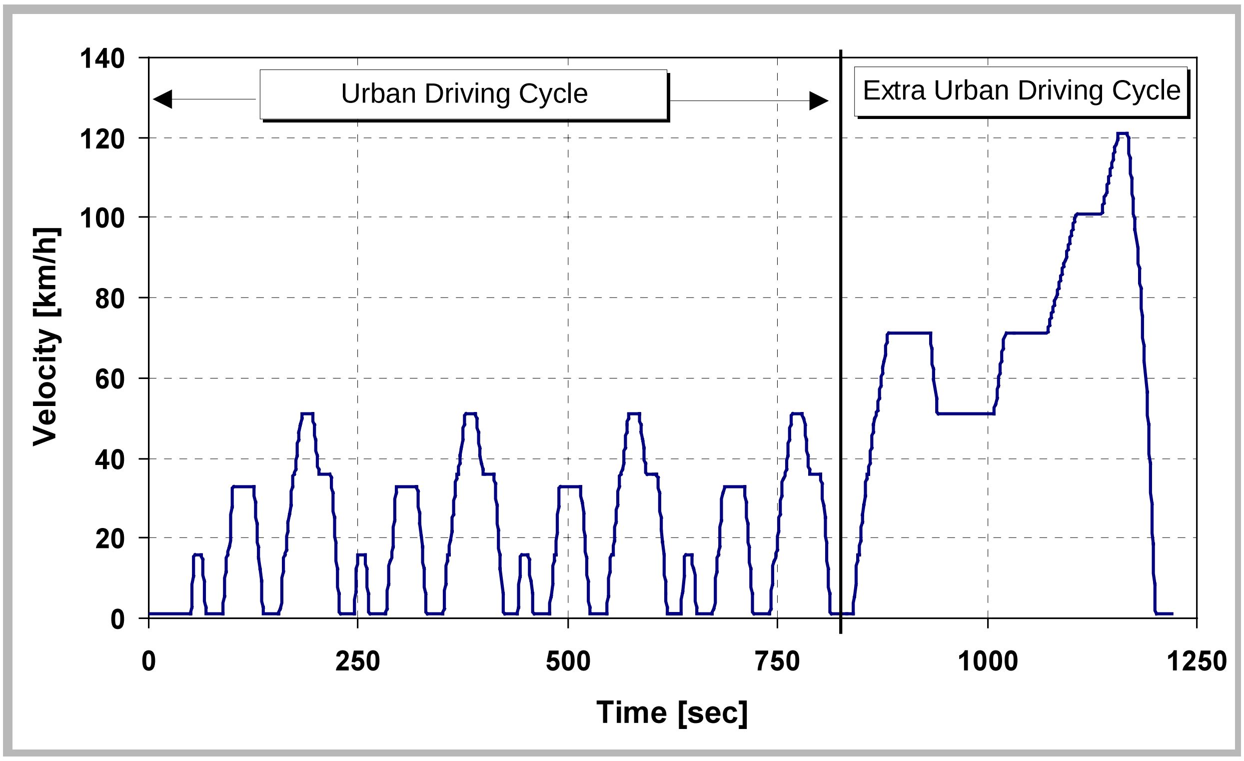

Preliminary Checks
NEDC Cold
30 min
UDC Hot
20 min
"Actual" Driving Cycle
30 min
Short transient cycle
10 min
"Actual" Short Cycle
10 min
IDLE
Low / High
10 min
Steady State
50 km/h - 7 kW
5 min
Preliminary Checks
90 min
NEDC Cold
30 min
UDC Hot
20 min
analyses: 30 min
"Actual" Driving Cycle
40 min
analyses: 2x30 min
Short transient cycle
10 min
eventual second inertia
5 min
"Actual" Short Cycle
5 min
analyses: 30 min
preparation: 30 min
Free Acceleration
10 min
preparation: 30 min
Autonat
10 min
preparation: 15 min
Steady State
50 km/h-7kW
5 min

Figure 1



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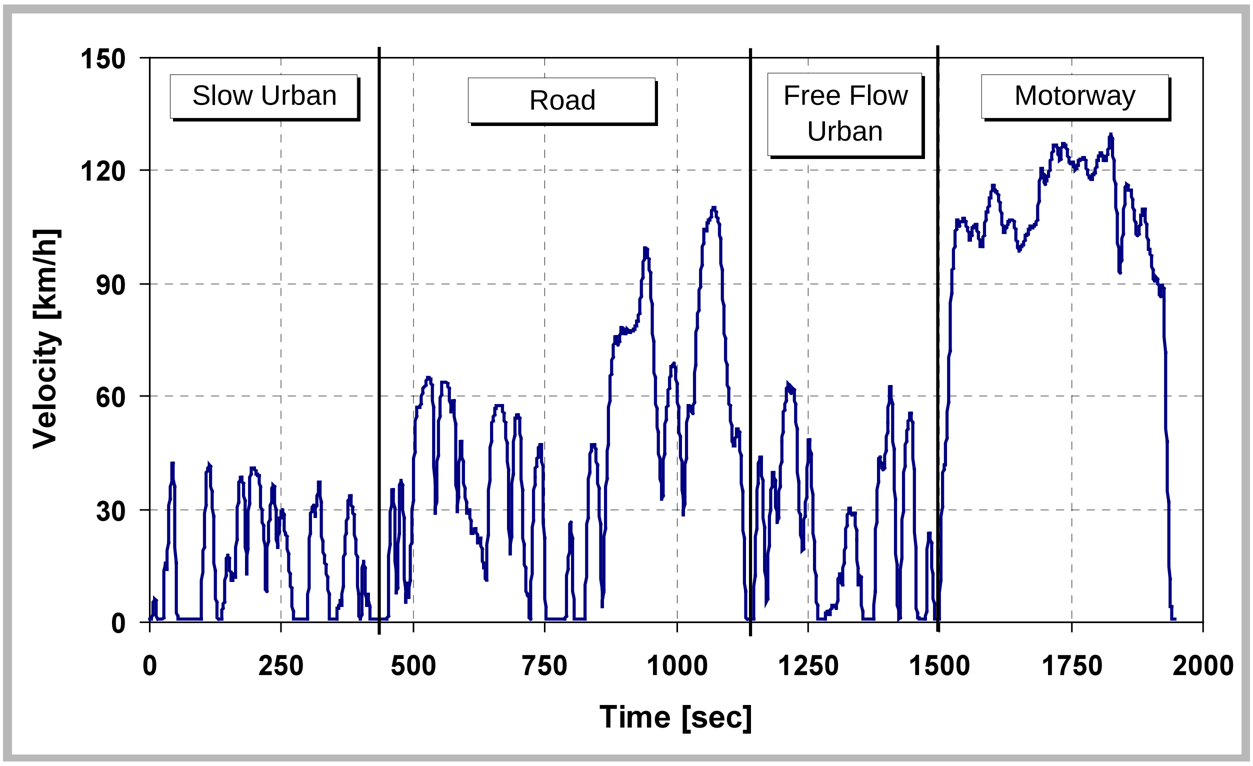

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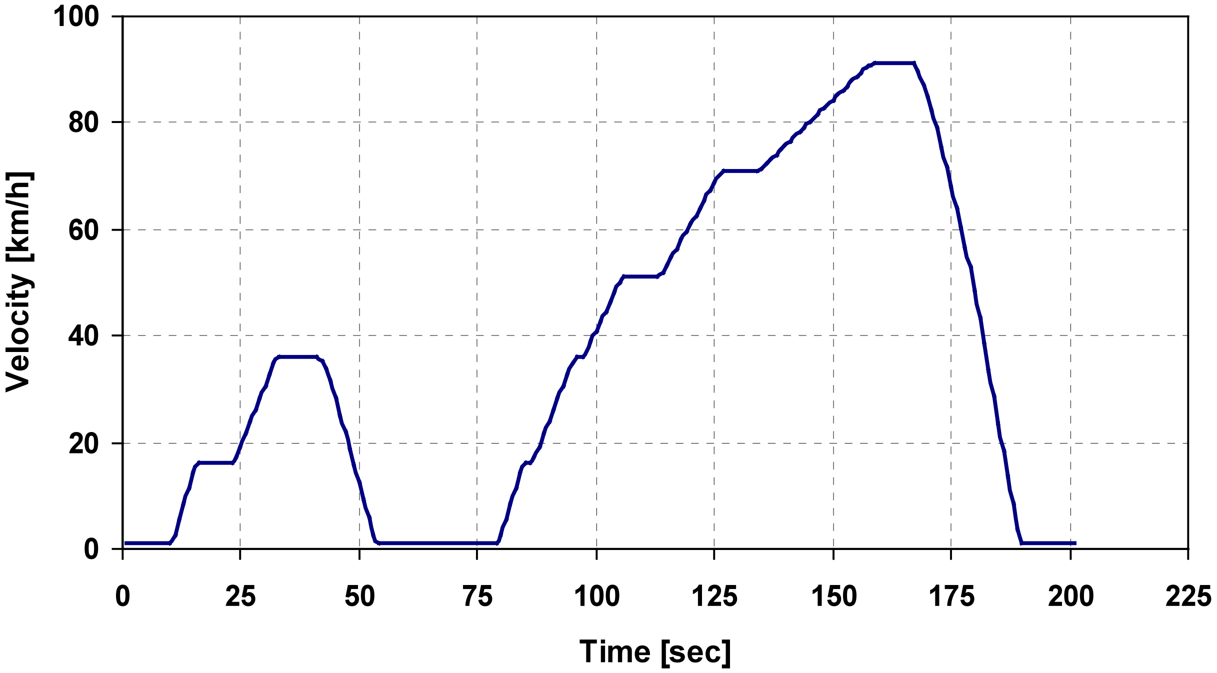


Figure 4

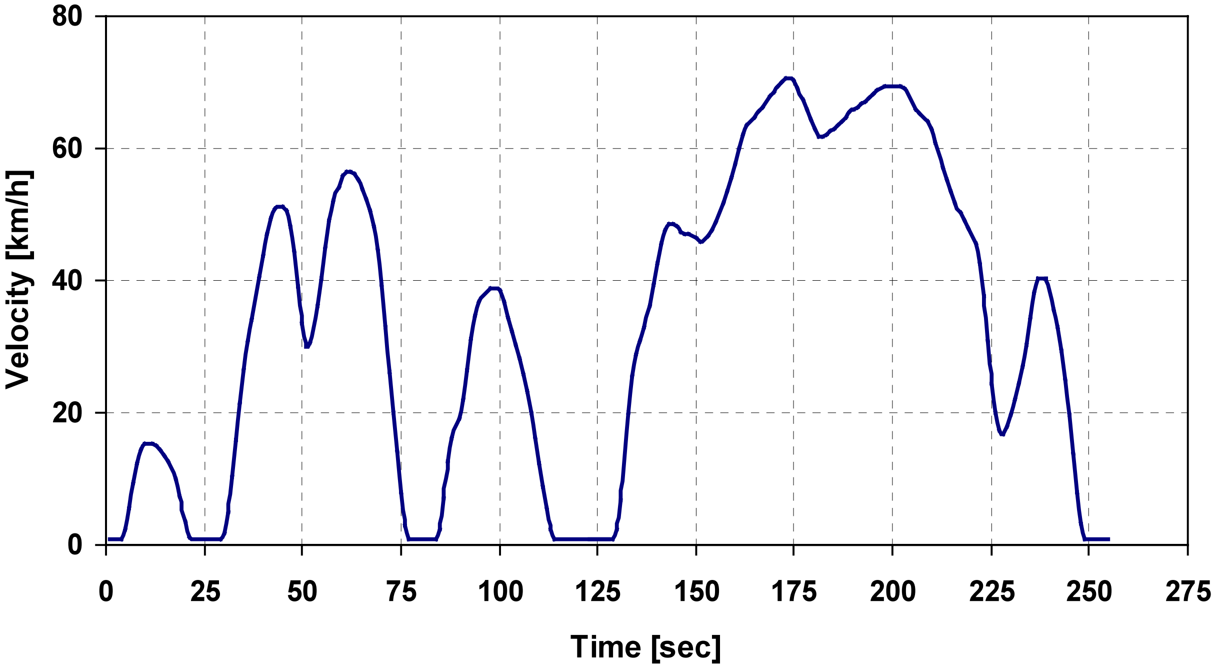


Figure 5

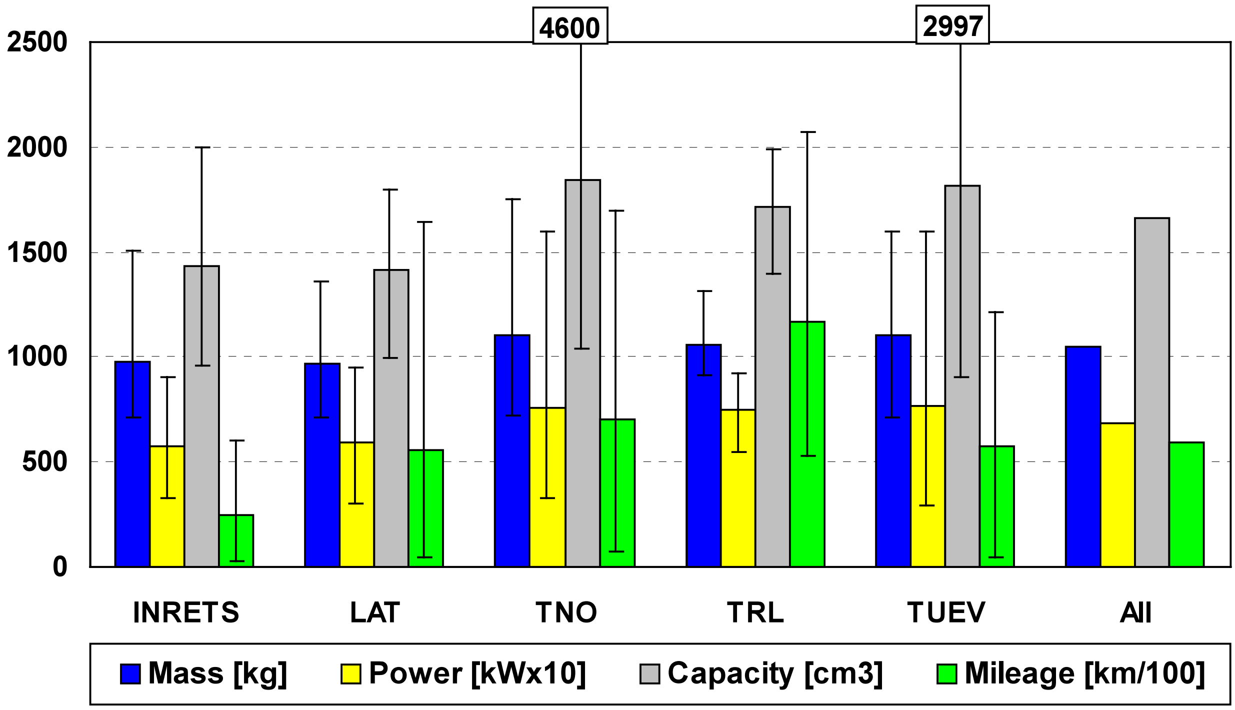

4600
2997
2500
2000
1500
1000
500
0
INRETS
LAT
TNO
TRL
TUEV
All
Mass [kg]
Power [kWx10]
Capacity [cm3]
Mileage [km/100]

Figure 6

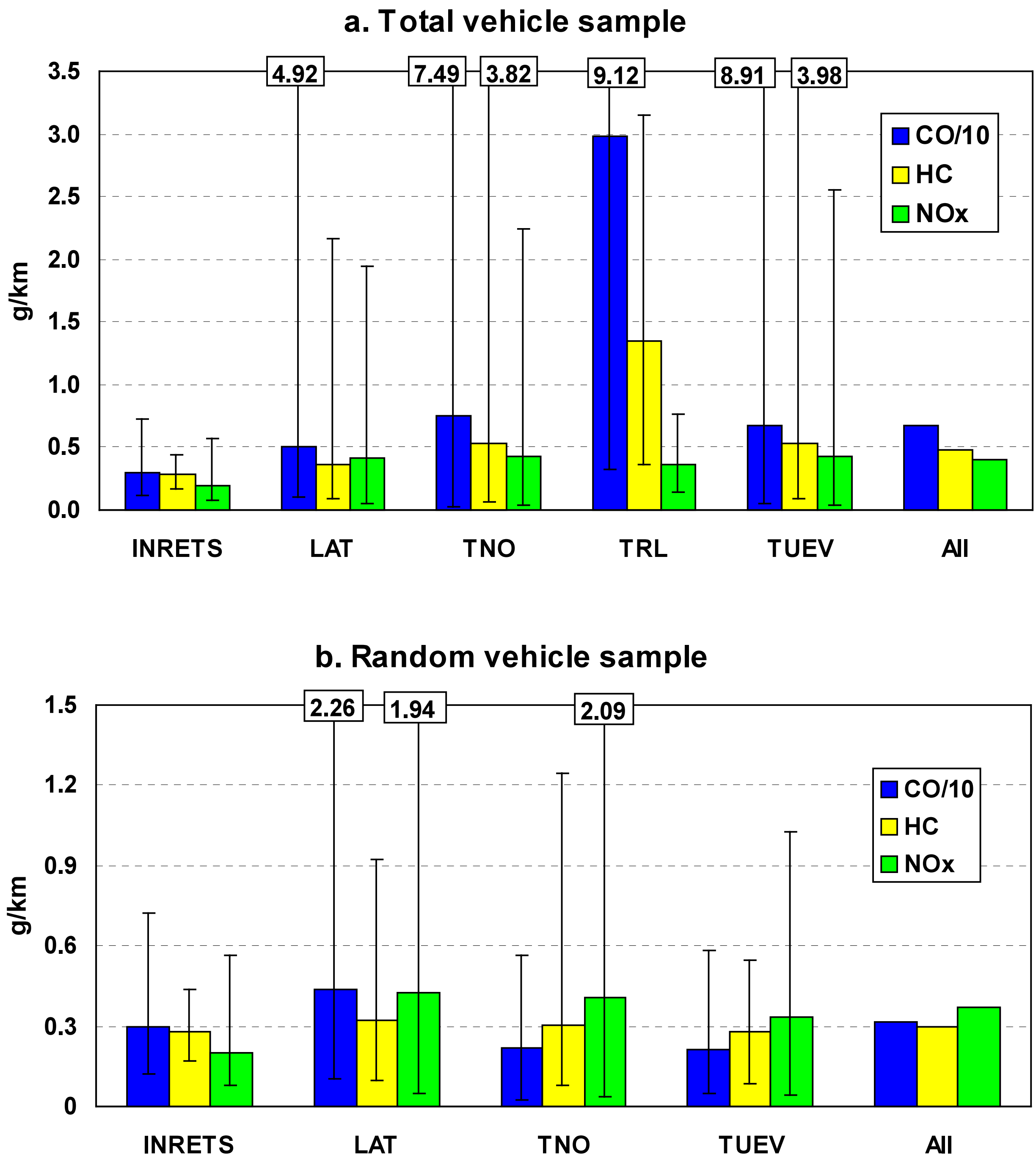

a. Total vehicle sample
g/km
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4.92
7.49
3.82
9.12
8.91
3.98
🟦 CO/10
🟨 HC
🟩 NOx
INRETS
LAT
TNO
TRL
TUEV
All
b. Random vehicle sample
g/km
1.5
1.2
0.9
0.6
0.3
0
2.26
1.94
2.09
🟦 CO/10
🟨 HC
🟩 NOx
INRETS
LAT
TNO
TUEV
All

Figure 7

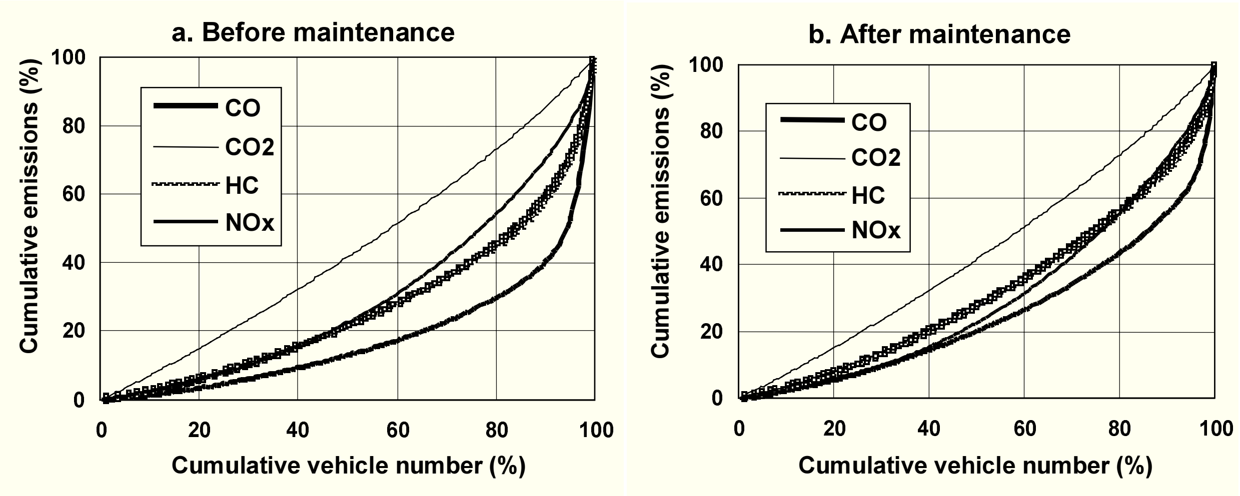


Figure 11

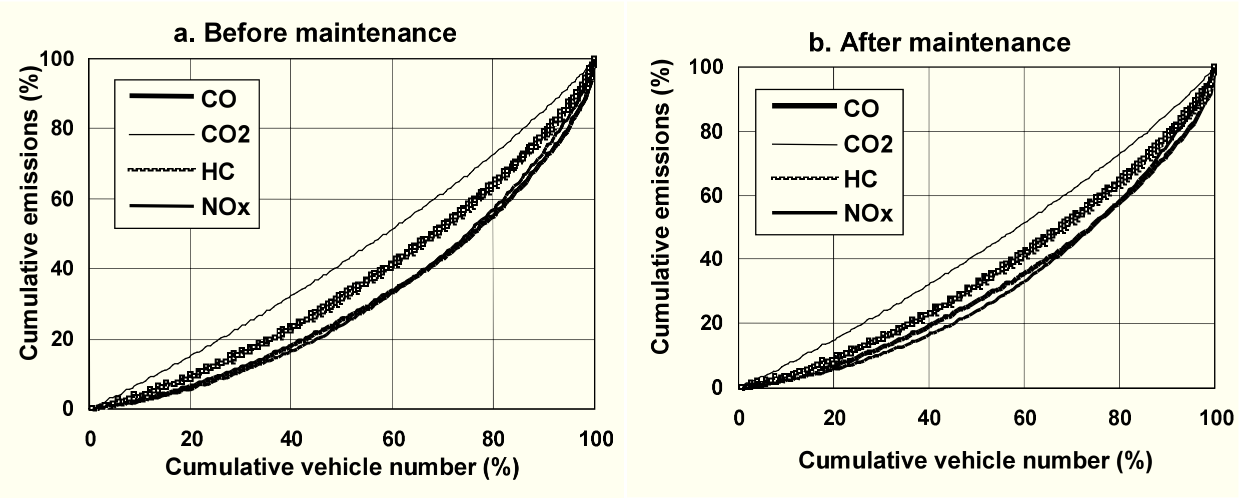


Figure 12

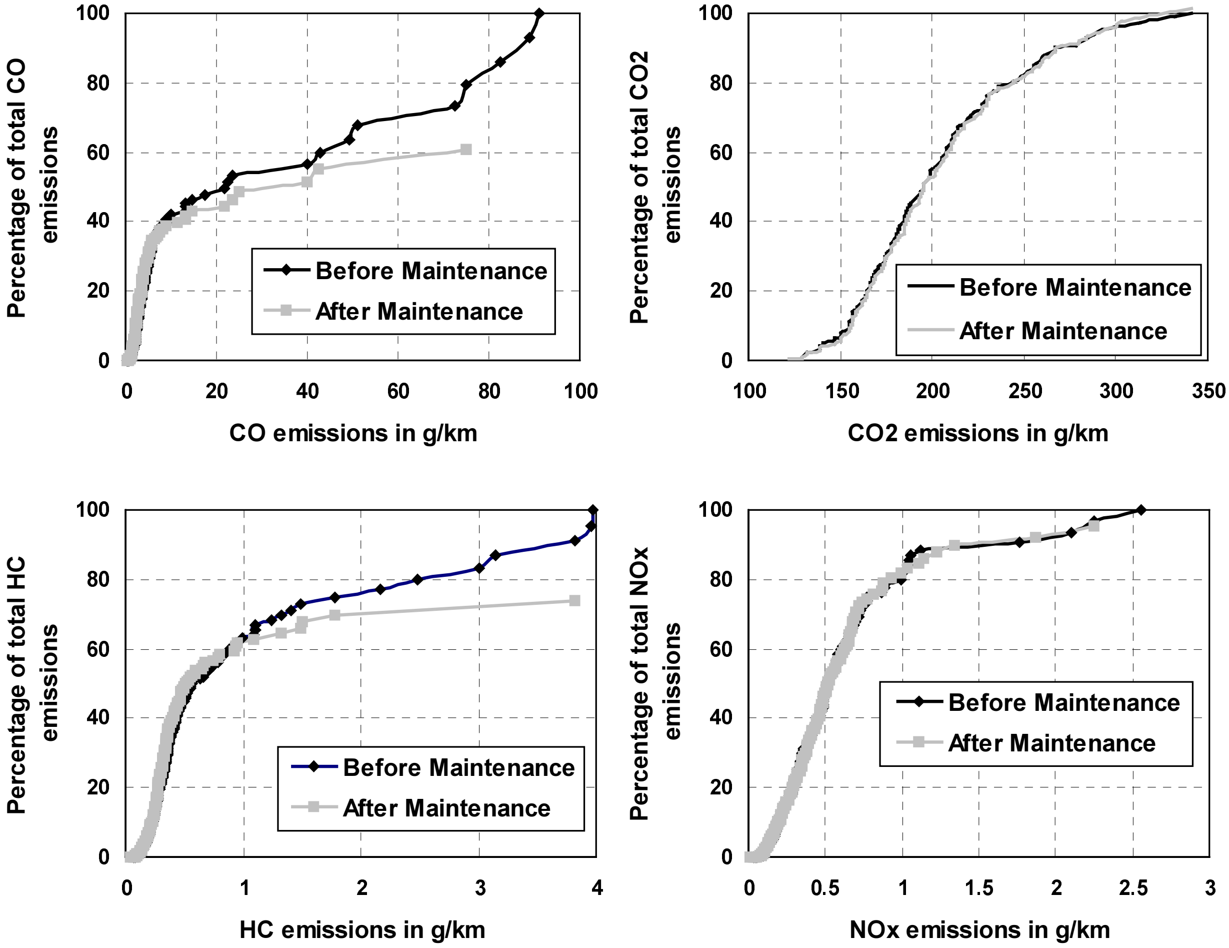


Figure 13

2.0 Evaluation of Alternative Short Tests

2.1 Outline

A short test can be considered effective only when it yields an acceptable correlation to the type approval cycle or a cycle which is representative of the actual driving conditions. Figure 1 presents such a correlation chart where the emissions of a particular pollutant over a short test (horizontal axis) are correlated to the corresponding emission levels over the type approval cycle (vertical axis). By plotting in this chart the emission levels of a sufficient vehicle sample after being tested both over the certification cycle and the short test, an indication of correlation may be obtained.

Figure 1 distinguishes six vehicle groups with the aid of three lines that play a major role in the analysis. The first horizontal line corresponds to the vehicle emission standard for the legislative pollutants. The second horizontal line has been drawn a percentage *alpha* above the emission standard aiming to distinguish the high (groups 3 and 4) and the very high or gross polluters (groups 5 and 6) according to their emissions over the type approval cycle. The vertical line corresponds to the short test cut-point, i.e. the limit for approving or not, vehicles according to the short test. The exact position of this line is to be determined in such way so that the short test is proved to be as effective as possible.

The vehicles belonging to group 1 are referred to as "low polluters" since they emit below the standard and also pass the short test. The vehicles in group 6 are referred to as "needing repair" since they are actually high polluters and fail the short test. The higher the number of vehicles laying in these two groups, the more effective the short test is proved to be, since there is an indication of high correlation between the short test and the type approval cycle. The low polluters in group 2 are wrongly detected by the short test and therefore they are called "errors of commission". The very high polluters in group 5 are called "errors of omission", since these vehicles fail to be detected by the short test.

In most cases the short tests measure more than one pollutants and therefore there are as many correlation charts as the number of pollutants measured. This makes the distribution of vehicles into the six groups more difficult, since an "overlap" among vehicles' pollutants is likely to occur. A particular vehicle could be placed in different groups for different pollutants. Actually, when a vehicle is tested there are two groups; those passing (groups 1, 3 and 5) and those failing the test (groups 2, 4 and 6). This means that when emissions exceed the cut-point at least in one pollutant, the vehicle is sent to maintenance. Thus, a vehicle is referred to

- as needing repair when at least one pollutant lays in group 6
- as an error of commission when at least one pollutant lies in group 2, but none in group 6
- as an error of omission when it passes the short test even though it has excessive emissions at least in one pollutant and finally,
- as a low polluter, when it passes the short test and emits below the standard in all pollutants.

Therefore, references to vehicle groups do not concern particular pollutants, i.e. as indicated in each chart, but are made to pollutants as a whole, i.e. as indicated in all charts and according to the above definitions. Figure 2 illustrates in the form of a flow chart the way that vehicle grouping is performed.

The basic concept of the methodology evaluating the effectiveness of alternative short tests is the calculation of the overall emission reduction achieved in each pollutant when the vehicles that fail the short test (groups 2, 4 and 6) emit the same levels of pollutants as the low polluters (group 1). The major contribution to this reduction comes from the vehicles needing repair (group 6), while no emission reduction can be achieved by the errors of commission (group 2). The vehicles laying in group 4 at least in one pollutant, having though no pollutants in groups 2 and 6, are referred to as vehicles "with low benefit" since their average emissions are low compared to the emissions of the vehicles needing repair. The validity of this assumption depends on the value of *alpha* and the emission characteristics of the fleet. Considering the malfunction of these vehicles to be minor and perhaps difficult to detect, the methodology does not take into account the environmental benefits from these vehicles (worst case assumption). On the other hand, the methodology assumes that all vehicles needing repair emit after maintenance the same levels of pollutants as if they were brand new, i.e. it is assumed that they receive the best repair. This assumption is rather optimistic and therefore the emission reduction achieved is referred to as "potential". The effect of maintenance is believed to be a parameter independent of the short tests and thus it should be investigated separately.

2.2 Subscripts and indexes

Denoting by subscript i the pollutants and the fuel consumption and by subscript j the vehicle groups of the basic charts, three basic indexes are defined as follows:

- Nj : number of vehicles in group j
- Pj : percentage of vehicles tested laying in group j
- Eij : cumulative emissions of pollutant i by the vehicles in group j over the type approval cycle

If one of the subscripts i or j of the above indexes is omitted, this means that the index becomes more general including all pollutants or all groups respectively.

Based on the above basic indexes, some additional “derivative” indexes are defined as follows:

- Emission Factor (average emission) of pollutant i by the vehicles in group j:

$$EFij = \frac{Eij}{Nj} \tag{1}$$

- Emission Reduction Potential of pollutant i:

$$ERPi = (EFi6 - EFi1) \cdot N6 \tag{2}$$

- Emission Reduction Rate Potential of pollutant i:

$$ERRPi = \frac{ERPi}{Ei} \cdot 100\% \tag{3}$$

ERRP is the equivalent of the parameter *IDR* (Identification Rate) introduced by the U.S. EPA in similar evaluations (EPA 1995).

2.3 Parameters

The parameters that characterize a short test are the following:

- *ERRPi*: represents the potential environmental benefit achieved with respect to pollutant i, when the particular short test is applied in the framework of an I/M program
- *P6*: accounts for the part of the vehicle fleet sent to maintenance which contributes to the emission reduction achieved
- *P2*: represents the percentage of vehicles wrongly detected by the short test

Since fundamental objective of an I/M program is the achievement of high environmental benefit with low cost and minor inconvenience to citizens, *ERRPi* should be as high as possible, at minimum *P6* and *P2* values. *P6* and *P2* should range within the limits of political and social acceptance concerning the cost of maintenance of the program and the legal protection of citizens respectively. This approach does not take into account the errors of omission (*P5*), which indirectly indicate the “loss” of environmental benefit. Since the environmental gain is directly accounted for by *ERRP, P5* is believed to provide no additional information.

The methodology described above can be applied to all pollutants for which emission standards exist; e.g. CO, HC and NOx for gasoline vehicles. If the potential of reducing CO_2 emissions and fuel consumption (FC) through an I/M program is also investigated, direct application of the methodology is not possible due to the absence of respective standards. However, the potential reductions of CO_2 and FC may be evaluated from equations (1) - (3) as “come-along” benefit, based on the needing repair vehicles detected by their high emission levels only in the pollutants having emission standards. The same case applies to the reductions achieved in pollutants which are not measured during the short test either because of the short test definition (e.g. no NOx measurement at idle) or of lack of corresponding equipment (e.g. NOx cannot be measured with garage analyzers).

The estimated emission reductions are based on the emissions over the type approval cycle. Since it is generally recognized that this cycle is not representative of the actual driving conditions, the reductions so calculated are very likely to be over- or under-estimated. In order to approximate the "actual" reduction potential, while the vehicles are separated into the groups of Figure 1 according to their emissions over the type approval cycle, their emissions, i.e. *Eij* and *ERRPi*, are calculated according to their emissions over an "actual" real world representative cycle.

According to Figure 1 the application of the methodology requires the determination of two basic types of variables: cut-points and percentage *alpha*. The cut-points are as many as the number of pollutants measured by the short test, while *alpha* is suggested to attain one value for all pollutants measured.

2.4 Cut-points

The effectiveness of each short test is bound to depend substantially on the selected cut-points. As Figure 1 demonstrates, lenient cut-points lead to low identification rate and as a result to low cost and inconvenience but to low emission reduction as well, and vise-versa. For the purpose of the exercise, it was suggested that the errors of commission should not to exceed 5% of the vehicles tested with the particular short test without there being a dramatic decrease in the emission reduction potential. This supposition is based on the technical consideration and requirement that most of the vehicles that comply with the emission standards over the legislated test should also pass the short test. The exemptions to the above rule should be looked at separately and eventually dealt with separate specific cut-points. Moreover, an I/M program apart from being politically and socially accepted, it should also not be too costly. This means that the cut-points should be selected so that approximately not more than 20-25% of the vehicles tested fail the test and are sent to maintenance, as experience from the US indicates.

2.5 Percentage alpha

Unlike cut-points, percentage *alpha* does not appear in practice. It is a parameter introduced at the design stage of an I/M program and it serves only for approximating the effectiveness of the program. The percentage *alpha* separates the so called needing repair vehicles and those with low benefit, which are treated differently by the methodology. As stated above the estimated emission reduction is exclusively based on the needing repair vehicles, while those with low benefit have no contribution to the estimated reduction with respect to the maintenance effectiveness. Therefore, *alpha* could be a variable accounting for the effectiveness of the maintenance body. This effectiveness is not only related to the performance of local garages which may vary from one country to another, but also to the fact that some minor failures cannot be detected and thus the corresponding repairs cannot be implemented. For instance, by setting a=0%, then $P4$=0% as well, and so all vehicles above standard are supposed to receive effective maintenance even though their malfunction may not be detectable. In view of the need to approximate the actual emission reduction taking into consideration to a certain extent the effect of maintenance, it is suggested that percentage *alpha* should not take values below 50%.

3. Special Cases

3.1 Different emission standards

It has been stressed that both horizontal lines in the basic chart depend on the vehicles' emission standards. These standards, even for a particular vehicle category, vary with the vehicle production year in order to reflect both legislative and technological steps. Therefore, the methodology as described above is restricted to vehicles complying with the same emission standards. An alternative approach in order to overcome the non homogenous nature of the emission standards could be the normalization of each vehicle's emissions with the corresponding emission standard.

3.2 Sum of emission standards

According to the Euro 1 European exhaust emission regulations, the certification of gasoline vehicles involves emission standards for CO and the sum of HC and NOx. This creates a difficulty in applying the methodology since it has been stated that a basic chart is drawn for each pollutant measured by the short test. This difficulty could be overcome by adequately splitting this standard. Euro 2 and subsequent standards have separate values for NOX and HC limits.

3.3 Double cut-points

The same methodology could also be applied to short tests having double cut-points, i.e. when an interval is defined. For instance, the implementation of the short test determined by the European regulations on "Roadworthiness of in use cars" (Directive 92/55/EEC) apart from the measurement of CO at idle and high idle, also involves the calculation of lambda which has an upper and a lower limit ($0.97 \leq \lambda \leq 1.03$). Therefore, the basic chart becomes somewhat different since there are two areas defined as groups 2, 4 and 6. The modified chart is presented in Figure 3.

In order to evaluate the effectiveness of the short test in question, five charts should be drawn:

1. CO at idle - NEDC CO
2. CO at high idle - NEDC CO
3. Lambda at high idle - NEDC CO
4. Lambda at high idle - NEDC HC
5. Lambda at high idle - NEDC NOx

A vehicle needs repair when it belongs to group 6 in any of the above charts, while it is an error of commission when it belongs to group 2 in any of the charts but in none of them to group 6.

4. Results

The methodology has been applied to a sufficiently large sample of three way catalyst equipped vehicles, representative of the European fleet. All necessary data are taken from a European Commission funded program concerning the inspection and maintenance of in-use vehicles. Even though no thorough statistical techniques to gather the sample were used, the selection of vehicles was based on the relative share of sales of all car manufacturers in Europe and therefore the sample can be considered as being representative. The effectiveness of ten short tests has been evaluated, including steady state tests, both unloaded and loaded, and transient tests. The transient short tests include TUV and Modem short cycles, which were developed especially for this program. All short tests along with their abbreviations are presented in Table 1. The sample consists of approximately 130 vehicles but as the first two columns of Table 2 show, not all of them followed exactly the same test protocol due to technical restrictions.

All vehicles included in the database have been certified according to the corresponding European regulation. The emission standards are 3.16 g/km for CO and 1.13 g/km for the sum of HC and NOx. It has been found that HC constitute 53% of the sum of HC and NOx judging from the low polluters. As suggested above the percentage *alpha* has been selected 50% and the evaluation is based on the Modem cycle, which has been developed in the framework of the program in question and is supposed to be representative of the actual driving conditions.

Table 2 shows the selected cut-points for each short test and the corresponding number of available measurements. In view of an acceptable emission reduction the cut-points in the transient short tests measuring mass emissions are very close to the corresponding certification standards in contrast to the cut-points suggested by the U.S. EPA for IM240 which were 2 to 3 times higher (EPA 1995). This is proof of the already known fact that on average European cars are cleaner than their American counterparts. According to these studies, in Europe 20% of the vehicles emit 45% of CO and HC of the whole fleet (and about 35% of NOx), while the corresponding numbers in the United States suggest that 10% of the vehicles are responsible for as high as half of the pollutants emitted from the total fleet.

As an example, Figure 4 presents the way the cut-points have been selected for a transient short test measuring mass emissions. Keeping the HC and NOx cut-points constant and modifying the CO cut-point, it is clear that the latter should not exceed the value of 2 g/km. Smaller values lead to a very high identification rate (*P6*) and as a result to high environmental benefits (*ERRPs*), but also to errors of commission (*P2*) which by far exceed 5% of the tested vehicles. On the contrary, higher values lead to low *ERRPs* without though a significant (if any) decrease in *P2*. After a thorough sensitivity analysis these curves were found to be typical for all pollutants' cut-points and all short tests and therefore they were used for the selection of the cut-points presented in Table 2.

In Figure 5 the parameters characterizing the effectiveness of the above short tests are depicted, while the corresponding parameters of the short test determined by 92/55/EEC are shown in Figure 6. Figure 5 suggests that the transient short tests seem to have the greatest potential in terms of environmental benefit. The emission reduction potential varies between 15 and 25 % for all pollutants, while the steady state tests cannot achieve reductions more than 5% with the exemption of NOx at steady state loaded test using laboratory analyzers. Actually this test has been introduced especially for NOx high emitter detection since there are no significant NOx emissions under no-load tests. In this respect the equivalent test using garage analyzers is not expected to give any particular gain compared to idle tests. The incorporation of this test in the protocol aimed only to compare garage and laboratory analyzer performance under loaded steady state tests. Figure 4 suggests that there is not much difference as far as the measurement of CO and HC are concerned. The inability of steady state tests to achieve remarkable emission reductions is also suggested by Figure 6, which shows the effectiveness of the short test determined by 92/55/EEC. The total reductions achieved by each "partial" short test determined by the legislation on top of the other are of the same order with the unloaded tests of Figure 5.

The significant difference in emission reduction potential between the transient and the steady state tests can be justified by the difference in parameter *P6*, which stands for the percentage of very high emitters sent to maintenance. Obviously the steady state tests do not have the same ability identifying high polluters as the transient tests. A more illustrative parameter that reflects this ability would be the Identification Rate (*IDR*) of each short test to detect very high polluters. *IDR* is not an independent parameter since it can be derived from already defined parameters:

$$IDR = \frac{P6}{P5 + P6} \cdot 100\% \qquad \text{for very high polluters (a=50\%)}$$

$$IDR = \frac{P4 + P6}{P3 + P4 + P5 + P6} \cdot 100\% \qquad \text{for high polluters (a=0\%)}$$

IDR values for high and very high polluters are depicted in Figure 7. Most transient short tests can identify at least 2 out of 3 very high polluters, while steady state tests at the most 1 out of five with the exemption of the steady state loaded test using laboratory analyzers (la50-7), which is a little more effective. The current short test determined by 92/55/EEC identifies approximately 13% of gross polluters. The ability of almost all short tests is decreasing as *alpha* decreases since the dispersion is expected to be higher around the groups 3 and 4. Controversially if the objective is only the ultra high emitters (e.g. a=200%), the identification ability of all tests is increasing. The current sample does not contain many such high emitting vehicles for a thorough analysis to be carried out, but it was found that most transient tests seem to have *IDR* as high as 80% and la50-7 test reaches a value of 40% for a=200%. All other steady state tests do not appear to be reliable of detecting even such high emitting vehicles.

5. Discussion

The methodology described above provides an algorithm for the evaluation of alternative short tests, which could be applied in I/M programs. This approach takes for granted some conditions, which if not met could lead to misleading results. It has been already stated from past experience especially in the United States that actual emission reductions are much lower than the corresponding predicted ones. The first issue is the administrative and institutional setting which influences the organization of the whole I/M program. Non effective enforcement of vehicle compliance due to a weak registration process and exemptions such as repair cost waivers, affects negatively the reliability and effectiveness of the program. The second issue concerns the technical operation of the program. As far as the inspection procedure is concerned, experience from such programs in the United States has shown that improper checks, pre-maintenance and post-maladjustment before and after the check are prevalent. Therefore, the inability of previous I/M programs to achieve the predicted reductions is mainly attributed to the inspection procedure itself. The effect of maintenance on the other hand, has the major effect in attaining the desirable environmental benefit. The percentage *alpha* introduced in the methodology is a variable, which could account for the performance of the maintenance body, in order to predict the overall effectiveness of the I/M program with some accuracy. All above elements should be kept in mind when applying the methodology in order to estimate the emission reductions as accurately as possible. Failure to consider them could lead to overoptimistic environmental benefits.

Tables

Table 1: Short tests and abbreviations

Short Test	**Abbreviation**
Mass emissions in TUV	meTUV
Raw average concentration with lab analysers in TUV	ralaTUV
Raw average concentration with garage analysers in TUV	ragaTUV
Mass emissions in modem short	meMS
Raw average concentration with lab analysers in modem short	ralaMS
Raw average concentration with garage analysers in modem short	ragaMS
Idle	Idle
High Idle	H-Idle
Steady state loaded with garage analysers (50 km/h - 7 kW)	ga50-7
Steady state loaded with lab analysers (50 km/h - 7 kW)	la50-7

Table 2: Selected cut-points and corresponding number of measurements

Short test	**Number of Measurements**	**Cut-points**		
		CO	**HC**	**NOx**
meTUV	129	2	0.3	0.5
ralaTUV	74	0.3	1100	400
ragaTUV	63	0.2	500	-
meMS	130	3	0.4	0.6
ralaMS	78	0.3	1000	500
ragaMS	63	0.2	600	-
Idle	130	0.2	900	-
H-Idle	130	0.2	600	-
ga50-7	130	0.2	400	-
la50-7	114	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				

Figures

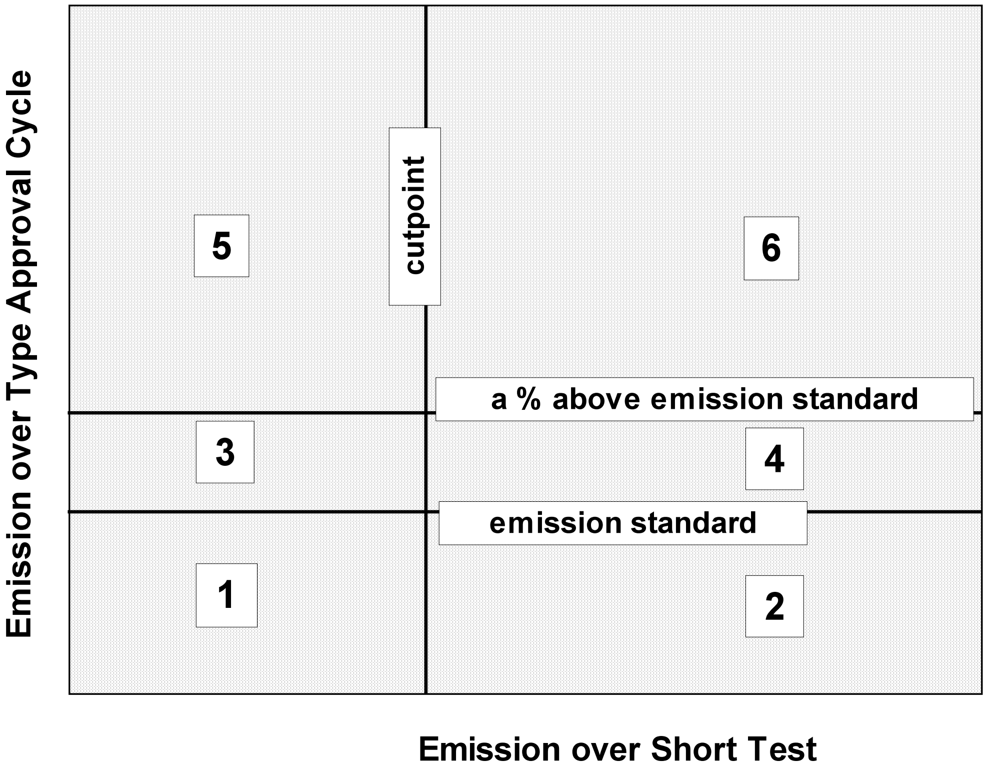
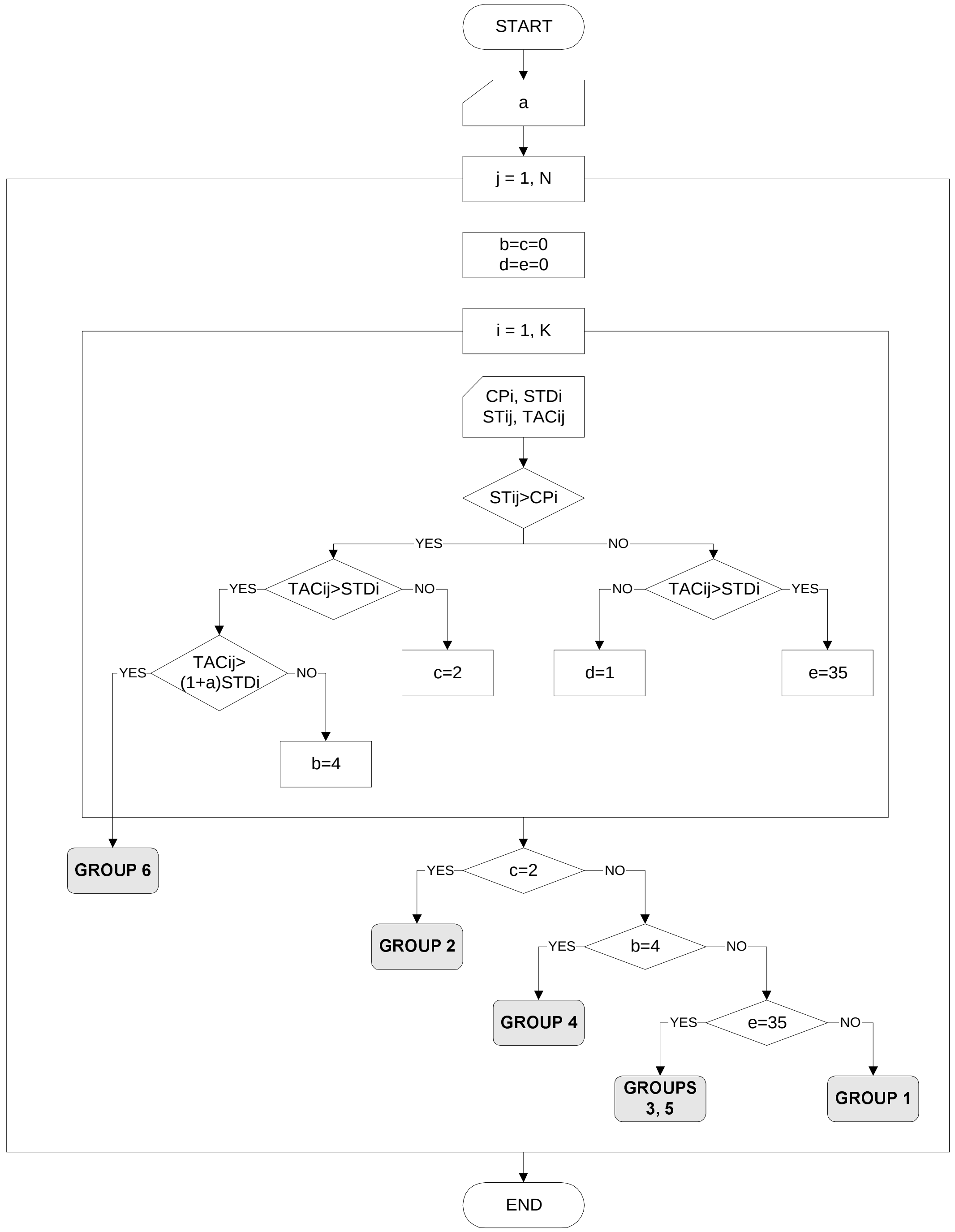


Figure 1: Basic chart



CP: cut-point

STD: emission standard

ST: emissions over short test

TAC: emissions over type approval cycle

a: percentage *alpha*

N: number of tested vehicles

K: number of pollutants

Figure 2: Flowchart for separating the vehicles into groups

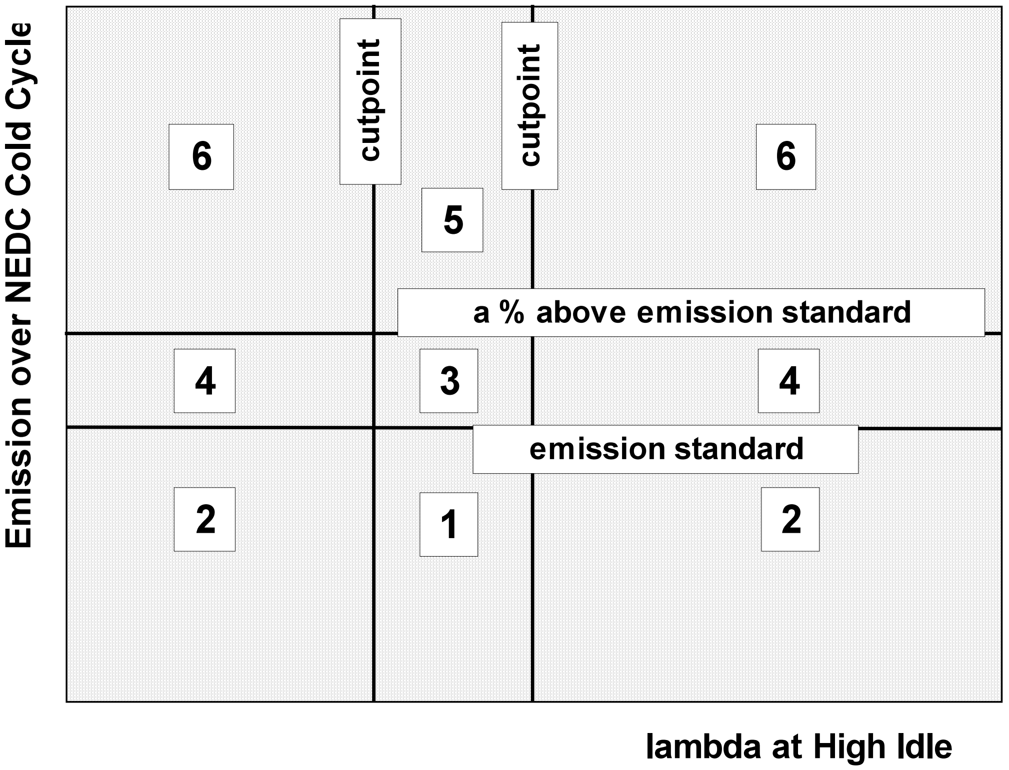


Figure 3: Modified chart for lambda

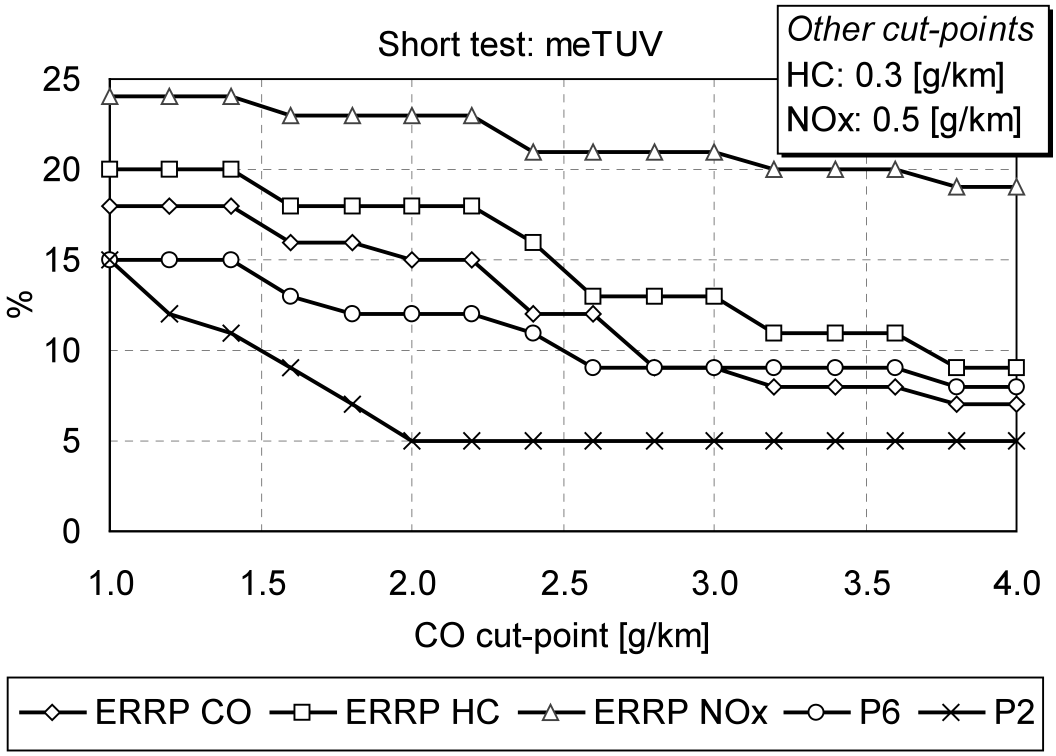


Figure 4: Cut-point selection

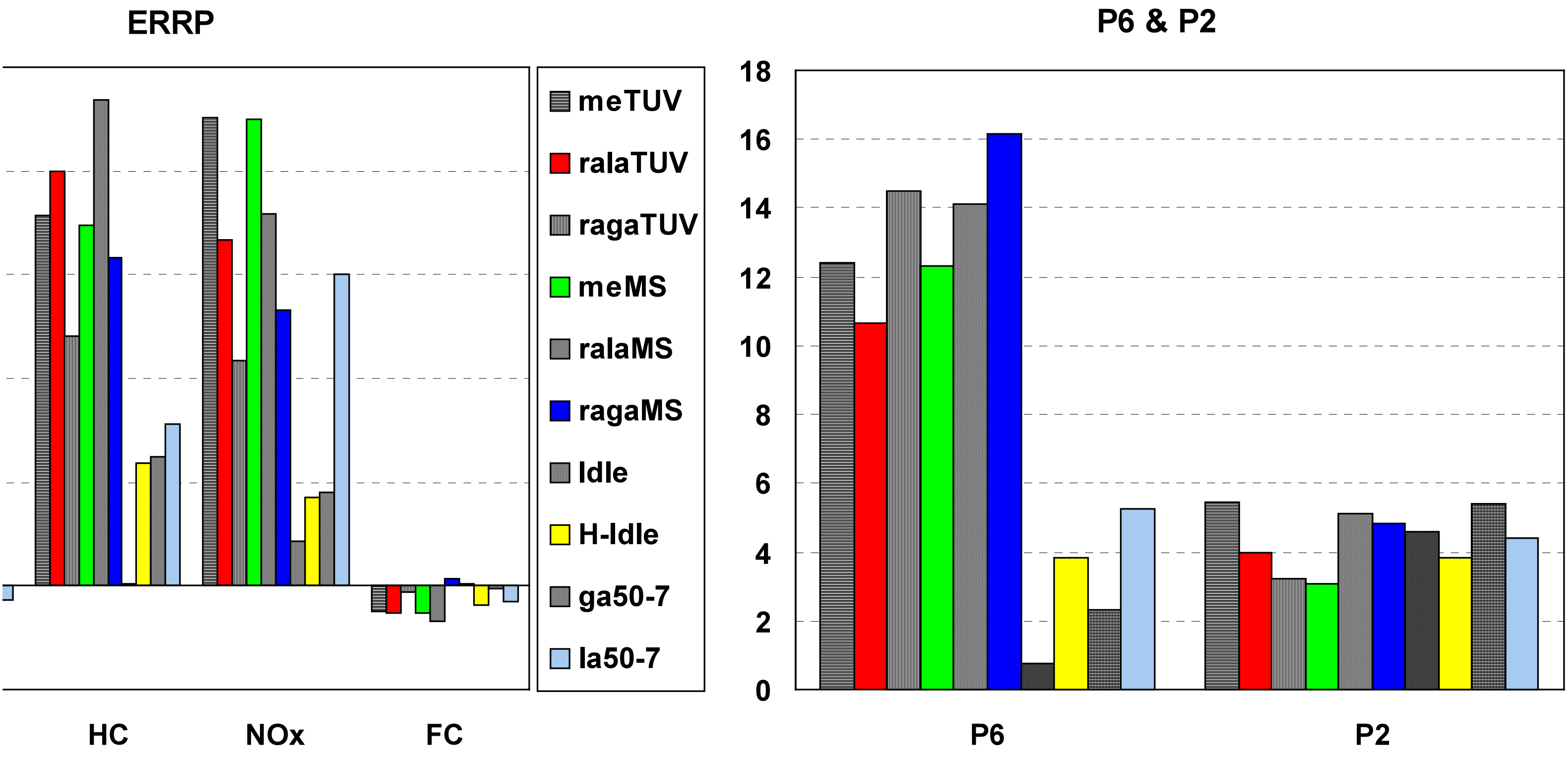


Figure 5: Short tests parameters

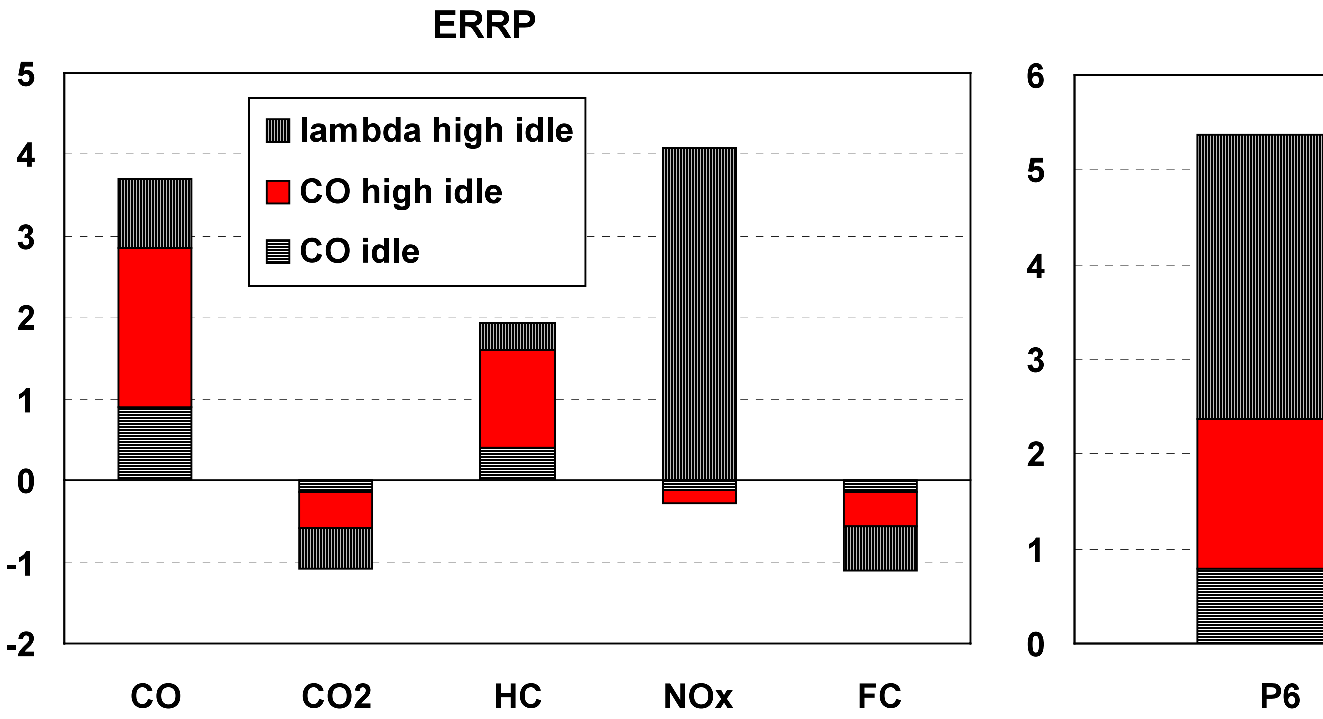


Figure 6: Parameters of short test determined by 92/55/EEC

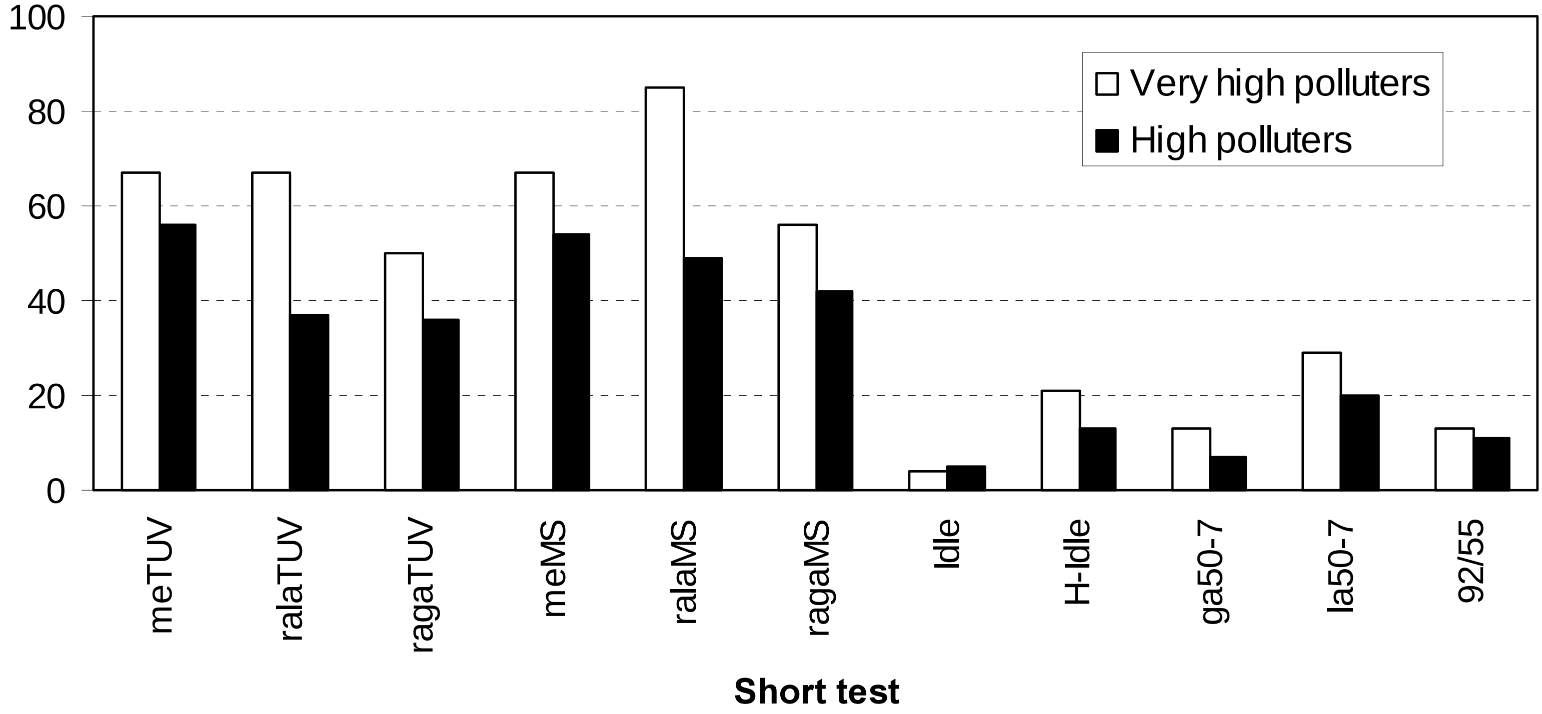


Figure 7: *IDR* for high (a=0%) and very high (a=50%) polluters

Assessment of Remote Sensing as an Inspection and Maintenance Tool

Remote sensing tests have been carried out at five locations in four countries - Greece, France, The Netherlands and England. The remote sensing allows the vehicle's exhaust emissions to be measured instantaneously as the vehicle drives past. A number of the vehicles were stopped and standard idle emission tests were carried out at the roadside. A further sub-sample was selected to undergo laboratory emission tests at a later date.

Comparison of the remote sensing results with idle test results showed poor agreement. However, comparison of the remote sensing results with dynamometer results showed a much better agreement. Based on the sample subjected to dynamometer tests, analysis of the data shows that remote sensing can have a very high emission reduction rate potential for carbon monoxide and hydrocarbon emissions.

Although the sample is biased in that it contains a large number of gross emitters, analysis of the entire remote sensing data shows that targeting gross emitters could significantly reduce total emissions. It is therefore concluded that remote sensing would be a useful tool in identifying gross polluting vehicles.

1. Introduction

Laboratory based emission testing over many years has shown that a large number of vehicles on the road have excessive emissions. It has also been reported that a small proportion of the vehicles on the road accounts for a very high proportion of the total emissions.

Identifying and correcting these high polluting vehicles could lead to a worthwhile reduction in total vehicle emissions. One way of identifying these vehicles is through an inspection and maintenance

(I/M) programme. This encourages the owners to keep the vehicles in a good state of repair and the service industry to do the maintenance properly.

However, inspection and maintenance programmes rely on periodic inspections, which can be one or two years apart. Between the inspections, the exhaust emissions could deteriorate dramatically. One way of supplementing an inspection and maintenance programme is the use of random roadside inspections. However, this is very labour intensive and, because it is random, will have varying success at identifying high emitting vehicles.

An alternative is to use a remote sensing system that can measure the exhaust emissions of the vehicles as they drive normally. This could either be used as a pre-screening tool to target vehicles for roadside checks or to identify possible high emitting vehicles and subsequently request the vehicle owner to submit the vehicle for testing at a local inspection and maintenance test station. Remote sensing could also be used as a means of judging the effectiveness of the local inspection and maintenance programme.

As part of a European project investigating alternative inspection and maintenance tests, TRL’s role was to carry out several series of remote sensing tests in order to judge the effectiveness of remote sensing in identifying high emitting vehicles.

2. The FEAT Remote Sensing System

The FEAT (Fuel Efficiency Automobile Test) system is based upon a conventional non-dispersive infra-red gas analyser. The impetus for the original development was with regard to fuel economy issues, and therefore originally concentrated on the detection of carbon dioxide and carbon monoxide. However, significant changes have been incorporated since its original conception - the system, currently used by TRL, now also includes the measurement of hydrocarbons and opacity of the exhaust plume as an indicator of smoke emissions. The current system also incorporates an ultra-violet source to measure nitric oxide.

The system consists of four components:

- a combined infra-red and ultra violet source

- detector
- computer
- video system

Under the standard operating procedures, the IR & UV source is positioned on one side of a single lane of traffic and the detector on the opposite side. The IR and UV beam generated by the source is directed horizontally towards the detector. The distance between the source and detector typically ranges from 6 to 15 metres, with the beam normally 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 FEAT system operates by continuously measuring the intensity of the beam. As a vehicle passes through the beam path, the voltages from the detectors drop to zero. This beam block is used to indicate the presence of a vehicle, which triggers the video system to record an image of the passing vehicle and also triggers the measurement system. 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 the vehicle’s exhaust, is recorded. Instantaneous measurements of CO, CO_2, HC and NO are recorded at a frequency of approximately 125Hz over a period of 0.5 seconds.

The precise position of the exhaust plume relative to the beam may vary widely, depending on the type and indeed model of the vehicle and the beam height and orientation. The true concentration of exhaust gas at different points in the plume may vary widely and reduces due to normal dispersion occurring. Therefore the FEAT system calculates average molar ratios (CO/CO_2 and HC/CO_2) from the instantaneous measurements which, theoretically, remain constant within the exhaust plume, irrespective of its dispersion and subsequent dilution. These molar ratios are subsequently converted to absolute concentrations through a software algorithm based on the chemistry of hydrocarbon fuel combustion in motor vehicles.

The FEAT system further operates a number of data rejection criteria. As a large number of data points are recorded, the software is able to quantify the data scatter. If the data scatter is excessive then the data is rejected, and is recorded by the FEAT system as invalid data.

The derived FEAT data is recorded in a number of formats. The video image is instantaneously transmitted to a monitor and additionally recorded as a still image onto a video tape. Superimposed onto this video image (from which vehicle details including registration number can be derived) are the vehicle's associated emissions concentrations, as illustrated by Figure 1, together with the date and time. In addition, the concentrations, date and time are also recorded numerically onto the computer's hard disc together with additional information, which on TRL's current FEAT system includes an opacity reading and the speed and acceleration of the vehicle as it passes through the beam. These two data formats can be cross-referenced using the date and time information.

3. Tests

The remote sensing tests were carried out in the following five locations:

Greece	Thessaloniki	27 May 1996	to	1 June 1996
France	Lyon	10 June 1996	to	14 June 1996
Netherlands	Delft	19 August 1996	to	23 August 1996
UK	Emberton (near Milton Keynes)	13 January 1997	to	17 January 1997
UK	Leicester	27 January 1997	to	31 January 1997

The test work consisted of the following elements:

- remote sensing
- roadside tailpipe emissions tests on a sample of vehicles

followed at a later date by:

- dynamometer tests on a sub-sample of vehicles subjected to roadside tests

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 (as illustrated by Figure 1).

A selection of vehicles were reported to the roadside test site where police officers stopped each vehicle for further tests. 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. However, other vehicles with valid remote sensing readings were also selected at random.

4. Results

At each site, several thousand remote sensing results were obtained.
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 1 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 the measurement of CO and CO_2, the success rate (i.e. the number of valid readings) was high. This was attributed to the relatively high concentrations of CO and CO_2 in the exhaust plume. For HC and especially NO, which are present in much smaller concentrations, the number of valid readings is much lower.

The table also shows the total number of vehicles stopped for a roadside idle test and selected for further dynamometer based tests (the 'repeats' column indicate the number of vehicles sent for servicing and then repeat tested). Comparison of the relatively large number of remote sensing readings and the much smaller number of idle tests carried out shows one potential advantage of using a remote sensing detector.

5. Emission Distributions

From the large amount of remote sensing data, emissions distributions can be derived. Figure 2 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 shows that there were a high number of low emitting vehicles in Delft, while in Thessaloniki there were a lower number. 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. All the sites were selected where the vehicles tested were expected to be operating with some load on the engine - either due to a gradient or due to acceleration. However, the site at Thessaloniki had a slightly more severe gradient than the other sites, which may have accounted for the higher emissions.

6. 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).

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 3 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 occurring at the point where catalysts were introduced.

7. Comparison of Remote Sensing with Idle Tests

The vehicles stopped at the roadside were subjected to a tailpipe emissions test. This was carried out using conventional garage-type four-gas emission analysers. The tailpipe emissions were measured with the engine idling. In most cases, a fast idle test was also carried out - with the vehicle in neutral, the engine speed was raised to a steady speed between 2,000 and 3,000 rpm. Figure 4 shows the comparison of the idle CO emissions measured at the tailpipe 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 but rather the different operating conditions the vehicle was under for the different tests. For example, the engine would normally be under some load while passing through the remote sensing device as opposed to being under no load for the idle test.

In Figure 5, similar results have been plotted for catalyst equipped cars only undergoing the fast idle test. Additionally, only vehicles travelling at steady speeds have been included (i.e. vehicles undergoing high accelerations or decelerations have been rejected). For this data set, which consists of the results from 130 vehicles, the correlation is better although the residual scatter is still high.

Considering 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% (the default fast idle limit for the in-service emissions test as per Directive 96/96/EC) indicated by the horizontal line. There are, however, seven vehicles with remote sensing readings exceeding 5% and fast idle readings below 0.3%. A possible explanation of this is that 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, giving high readings. 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).

8. Comparison of Remote Sensing with Dynamometer Tests

A sub-sample of the vehicles stopped for the roadside idle test were submitted to dynamometer based tests. These tests included the type approval emissions test (NEDC cycle) as per Directive 91/441 as well as a number of custom test cycles. 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 at least one valid remote sensing CO reading. Some of the vehicles passed through the site on several occasions, resulting in a number of readings. These values have been averaged in the data set

Figure 6 shows an example of the dynamometer results plotted against the remote sensing values. Both catalyst and non-catalyst vehicles have been included. In this case, the CO emissions from the NEDC cycle are plotted against the corresponding remote sensing CO measured values (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 for a total of 71 vehicles.

The data plotted in Figure 6 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.

8.1.1 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 7 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 (1.5 has been used in this work to indicate vehicles with emissions well over the emissions 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 (shown as the vertical line on the graph), 12 vehicles would be identified using remote sensing as high emitters. Similarly, the dynamometer tests also identified the same 12 vehicles as high emitters although in one case the dynamometer result was only just over the limit.

However, using this cut-point, there are also a number of vehicles that are over the emission limit, as measured using the dynamometer (ranging from 1.5 to about 7 times the limit), that remote sensing would not detect as high emitters.

8.1.2 Hydrocarbons (HC)

For hydrocarbons, the result is not as convincing as for CO. Figure 8 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+NO_X limit. This is based on the ratios between HC and NO_X observed in previous emission tests). The figure shows that the correlation between the two types of reading is relatively poor. A large number of remote sensing measurements gave relatively high reading of %HC but low values of HC (i.e. below the limit) when measured on the dynamometer. Hence it seems unlikely that the remote sensing device can currently discriminate between vehicles that would pass and fail the HC limits during a standard dynamometer test.

However, plotting the same dynamometer HC emission ratios against the CO remote sensing, as shown in Figure 9, 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. If follows that by targeting high emitters of CO using remote sensing there will also be some control of high emitters of HC.

8.1.3 Oxides of Nitrogen (NO_X)

Figure 10 similarly shows the dynamometer NO_X 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 NO_X emissions. There is only one vehicle that has significantly high NO_X emissions - about 4 times the NO_X limit. This vehicle also has a high remote sensing reading.

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

9. Emission Reduction Rate Potential

The effectiveness of any inspection and maintenance programme is its ability to detect high emitting vehicles and subsequently require those vehicles to be rectified. To quantify the effectiveness of remote sensing, the following analysis considers the possible reduction in vehicle emissions that could be achieved. This is based on the Emission Reduction Rate Potential and follows the analysis method used in the evaluation of alternative 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 Figure 11, where:

Group 1	Vehicles correctly identified by remote sensing as low emitting vehicles
Group 2	Vehicles incorrectly identified as high emitting vehicles - when in fact they are 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 using remote sensing all the vehicles with high emissions (i.e. vehicles in Group 6) and send them for maintenance so that their emissions are reduced to a normal level (i.e. to become the same as vehicles in Group 1).

Based on a remote sensing cut-point of 5% CO, then from Figure 7, it can be seen that there are 11 catalyst equipped vehicles that fall into the group 6 category. The remote sensing readings and dynamometer test results for these 11 vehicles are listed in Table 2. As previously mentioned, the remote sensing readings have been averaged where more than one pass has been measured. 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 NO_X are shown as ratios with respect to their corresponding limits. Because the EC legislation specifies the limits in terms of the sum of HC & NO_X, the HC and NO_X limits has been approximated as being 51% and 49% of the total limit respectively.

The Emission Reduction Rate Potential (ERRP) of a test for the remote sensing tests has been determined as follows:

Emission Reduction Rate Potential of i pollutant

$$ERRP_i = 100.\frac{.(EF_{i6} - EF_{i1}).N_6}{\sum E_i}$$

i.e. the total reduction in emissions for vehicles detected as high emitters and subsequently rectified, divided by the original cumulative emissions of the entire sample. The subscript *i* indicates the pollutant under consideration and the subscripts *1* and *6* indicate the group category as defined in Figure 11.

- the Emission Factor EF_{i6} has been calculated as the average of the values listed in Table 2 (i.e. vehicles with high remote sensing and dynamometer CO) for each of the pollutants tested.
- the Emission Factor EF_{i1} has been calculated for all pollutants from the vehicles with low remote sensing and dynamometer CO.

The resulting Emission Reduction Rate Potential are shown graphically in Figure 12.

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 above ERRPs are based on just a CO cut-point (5% CO). The inclusion of a NO cut-point (at, say, 1%) would modify these values, possibly increasing the NO_X reduction and decreasing the CO and HC values. However, as previously mentioned, there was only one vehicle with significantly high NO_X emissions. Further information on vehicles with high NO_X 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 practise, this would require a large number of vehicle from the remote sensing survey selected at random and subjected to dynamometer tests - this would be very 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 year of registration, and the number of vehicles with high emissions have been counted per age group.

Table 3 and Table 4 show the results of this analysis for the UK and Greek results respectively. The tables show the total number of modern vehicles detected by registration index and the number with excessive remote sensing readings - based on cut-points of 5% CO and 1% NO. These modern vehicles 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.

It seems likely 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 7 and Table 2 show that the vehicles with high CO emissions range from 4 to almost 30 times the legislative emissions limit, with an average emission rate of 49.7 g/km. The remaining vehicles - i.e. those vehicles not detected as gross emitters - have average CO emissions of 5.75 g/km. Assuming that:

- the 3% of vehicles with high CO emissions have average emissions of 49.7 g/km,
- the remaining 97% of the fleet have average CO emissions of 5.75 g/km,
- all gross polluters are subsequently repaired to reduce their CO emissions to an average of 3 g/km,

then the ERRP for the whole fleet (rather than the sample that was used above) can be estimated as:

$$\begin{aligned} \text{ERRP} &= [49.7-3] * 3\%/[97\%*5.75+3\%*49.7] \\ &= 20\% \end{aligned}$$

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

$$\begin{aligned} \text{ERRP} &= [49.7-3] * 0.5\%/[99.5\%*5.75+0.5\%*49.7] \\ &= 4\% \end{aligned}$$

Therefore, for a fleet with 3% gross emitting catalyst cars, remote sensing might be able to reduce the total CO emissions by 20%. However, if only 0.5% of the fleet are gross emitters, then the reduction in CO emissions is only 4%.

10. Conclusions

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 fleet’s 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 while 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 and is particularly good at identifying gross emitters in the catalyst petrol group.

Based on just a remote sensing CO cut-point of 5%, the sample subjected to dynamometer test produces very high Emission Reduction Rate Potentials for carbon monoxide and hydrocarbons respectively. It should be noted, however, that the sample was biased in that it contains a large number of high emission 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 since most of the vehicles with high HC emissions will also have high CO emissions. A few vehicles with high NO_X emissions will also be detected using a CO cut-point.

An analysis of our unbiased data set collected in the UK and Greece showed that high emitting 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. It is likely that the number of gross emitters would increase as the catalyst fleet gets older. 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.

Using these statistics, an Emission Reduction Rate Potential of up to 20% for the whole fleet was obtained. This shows that targeting the gross emitters could significantly reduce total emissions.

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

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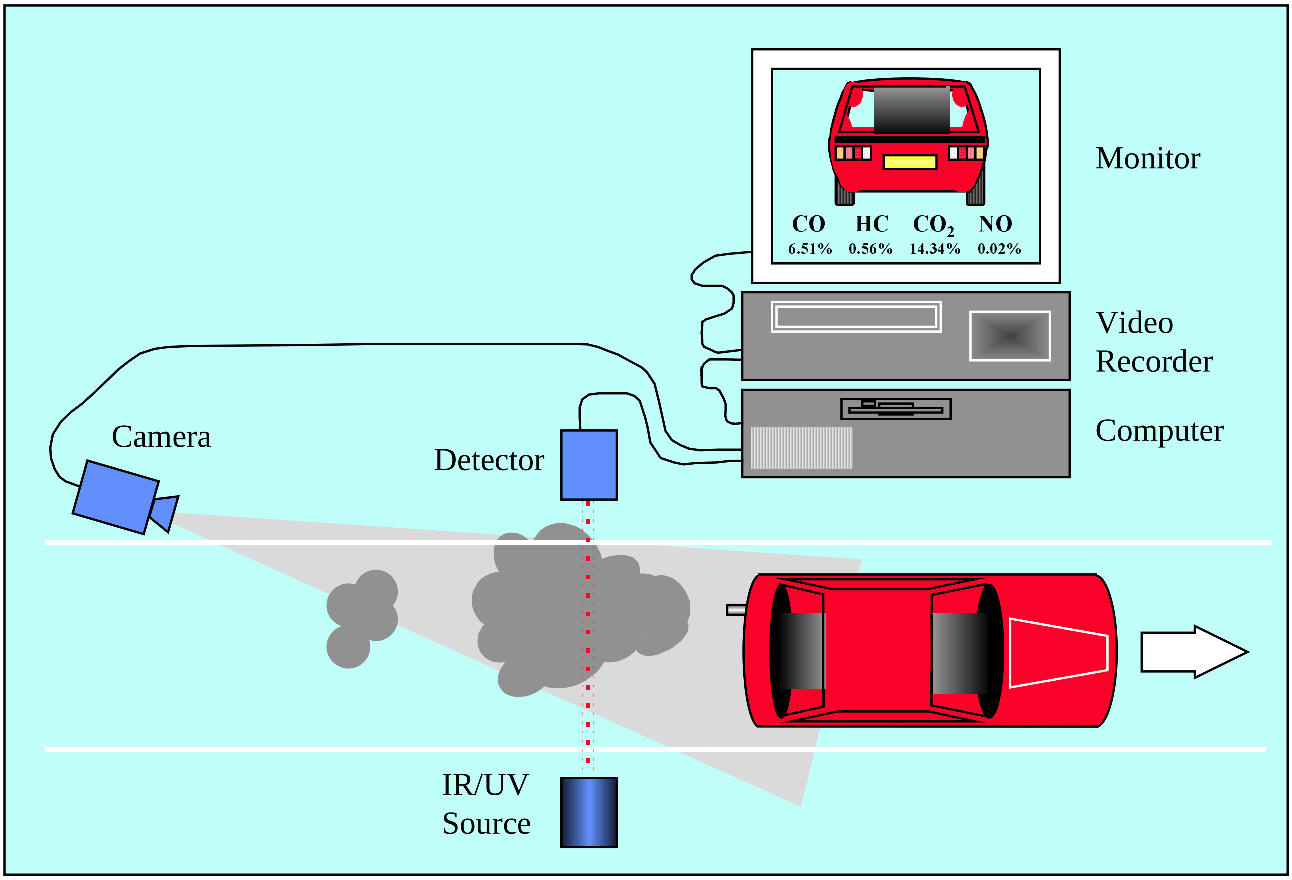

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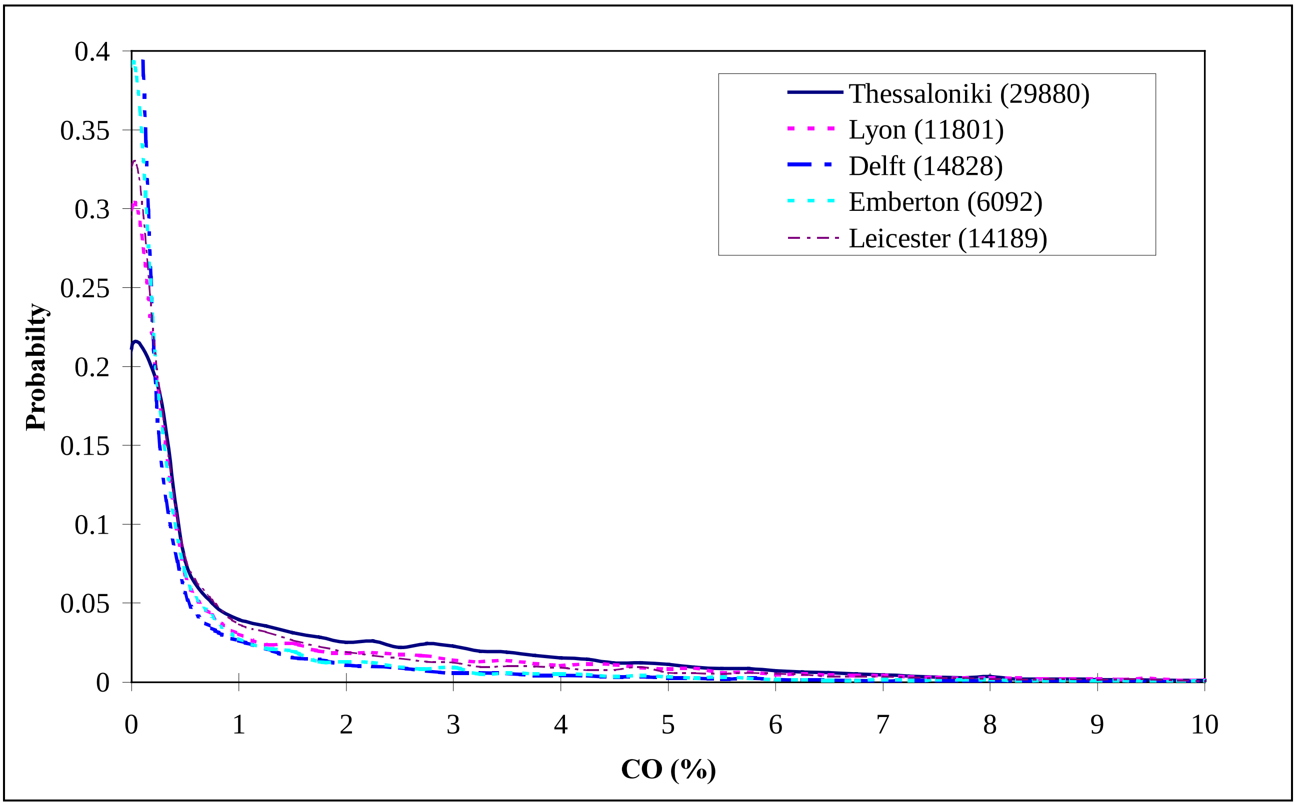

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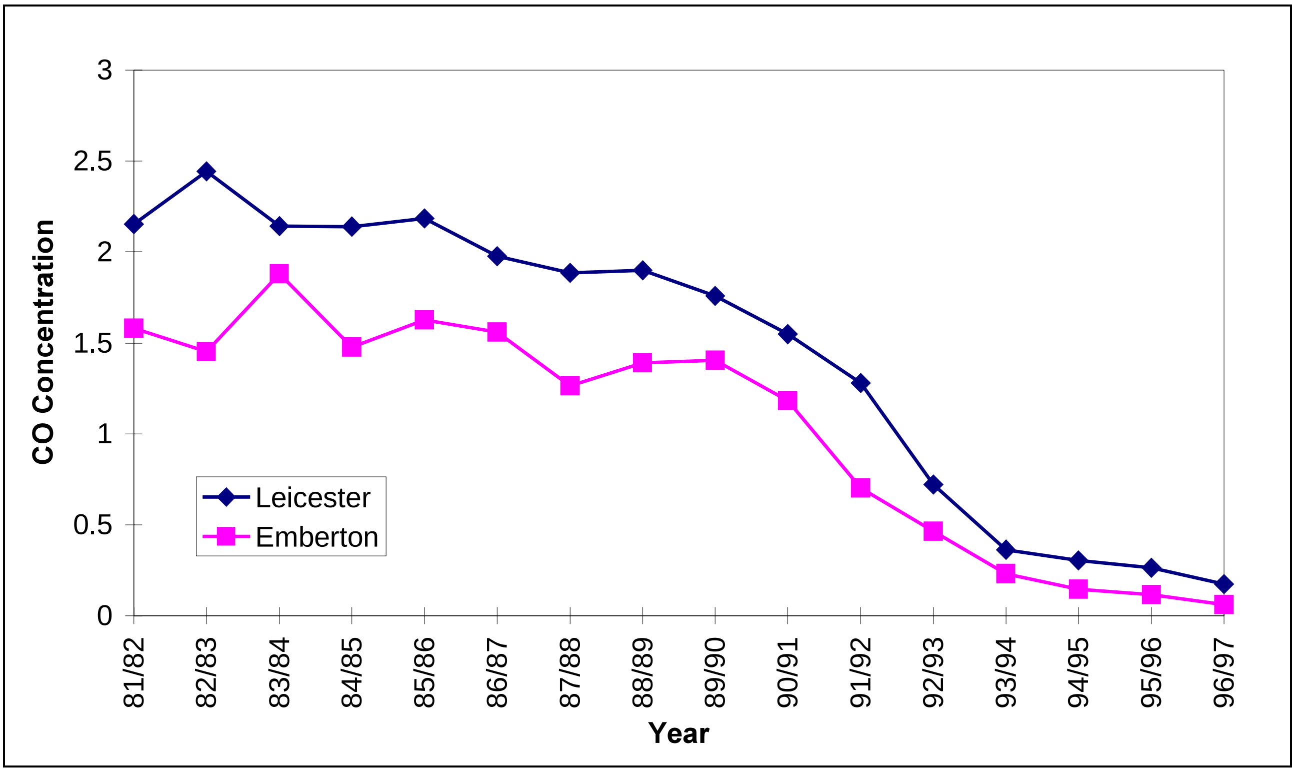

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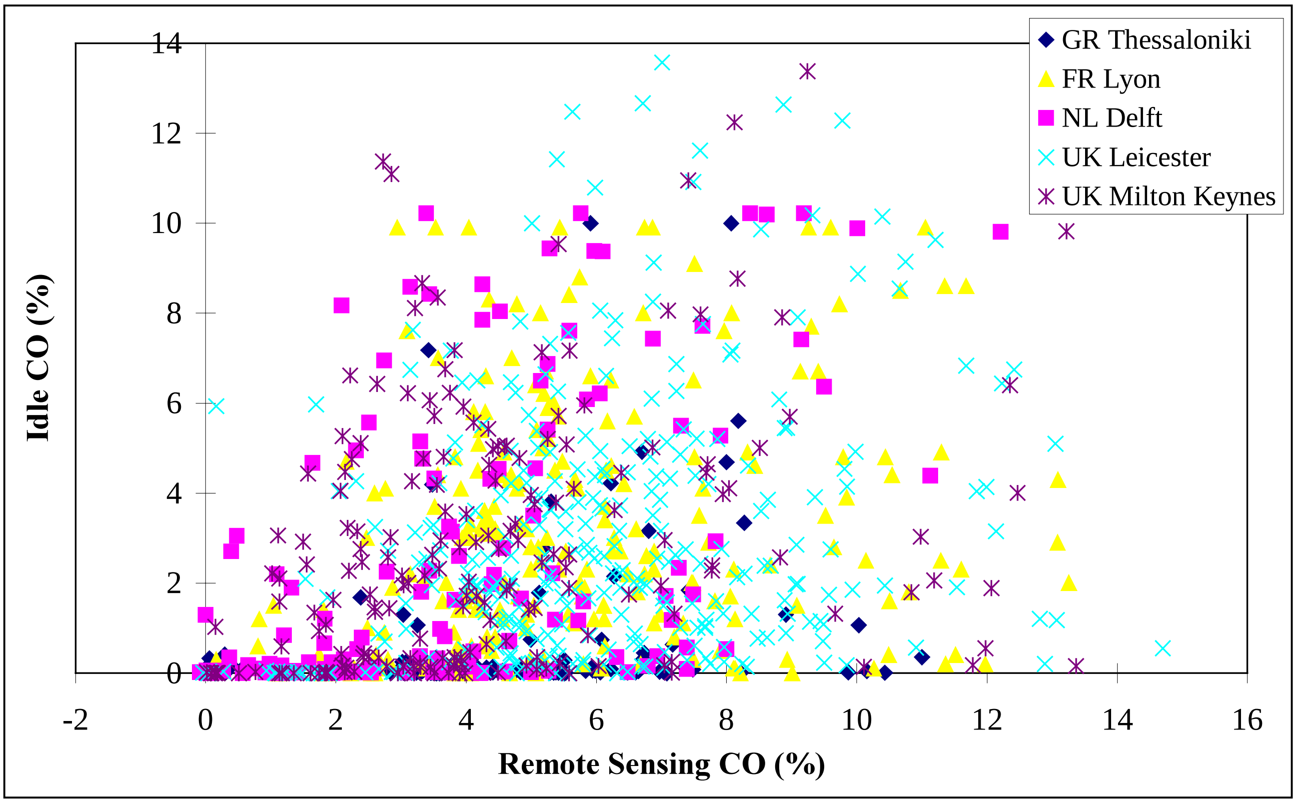

Idle CO (%)
14
12
10
8
6
4
2
0
-2
0
2
4
6
8
10
12
14
16
Remote Sensing CO (%)
◆ GR Thessaloniki
▲ FR Lyon
■ NL Delft
× UK Leicester
✳ UK Milton Keynes

Figure 5. Comparison of Fast Idle Test Results with Remote Sensing:
Catalyst Cars with low Accelerations & Decelerations

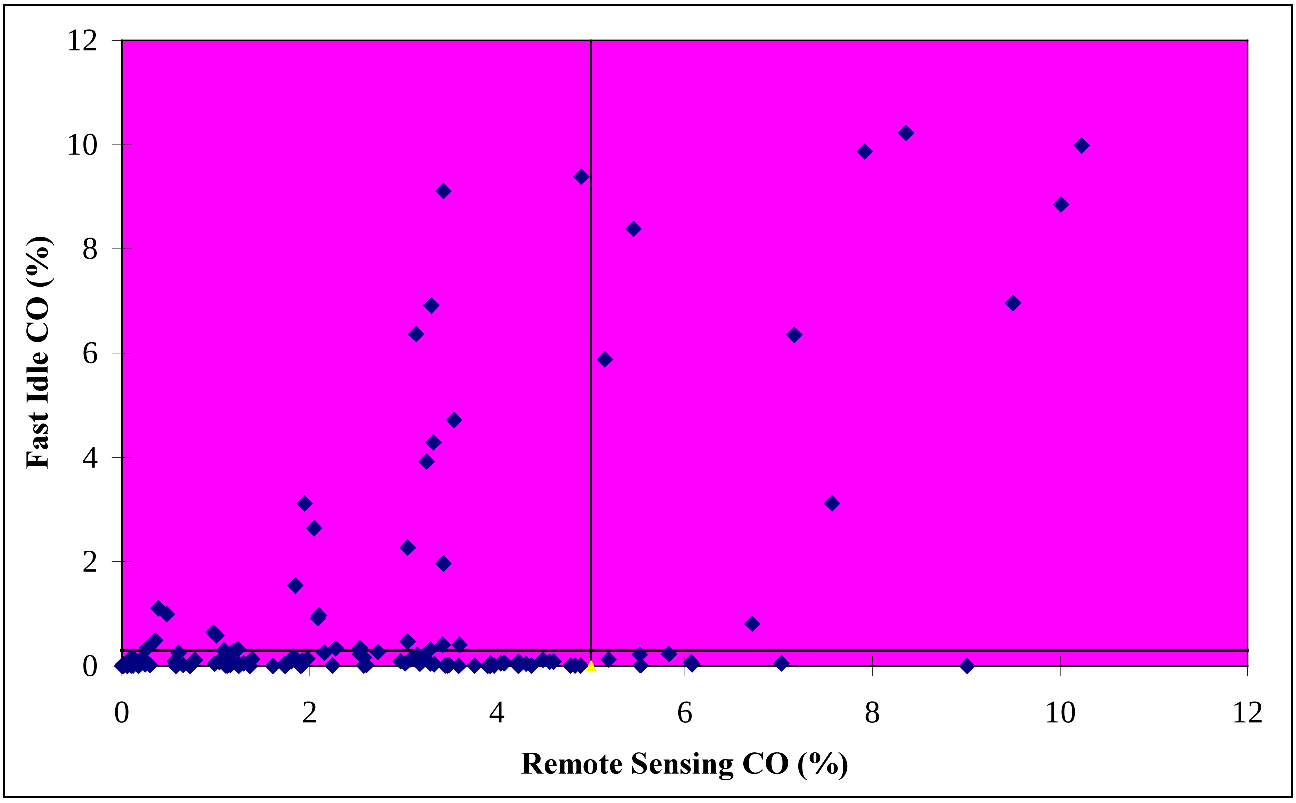
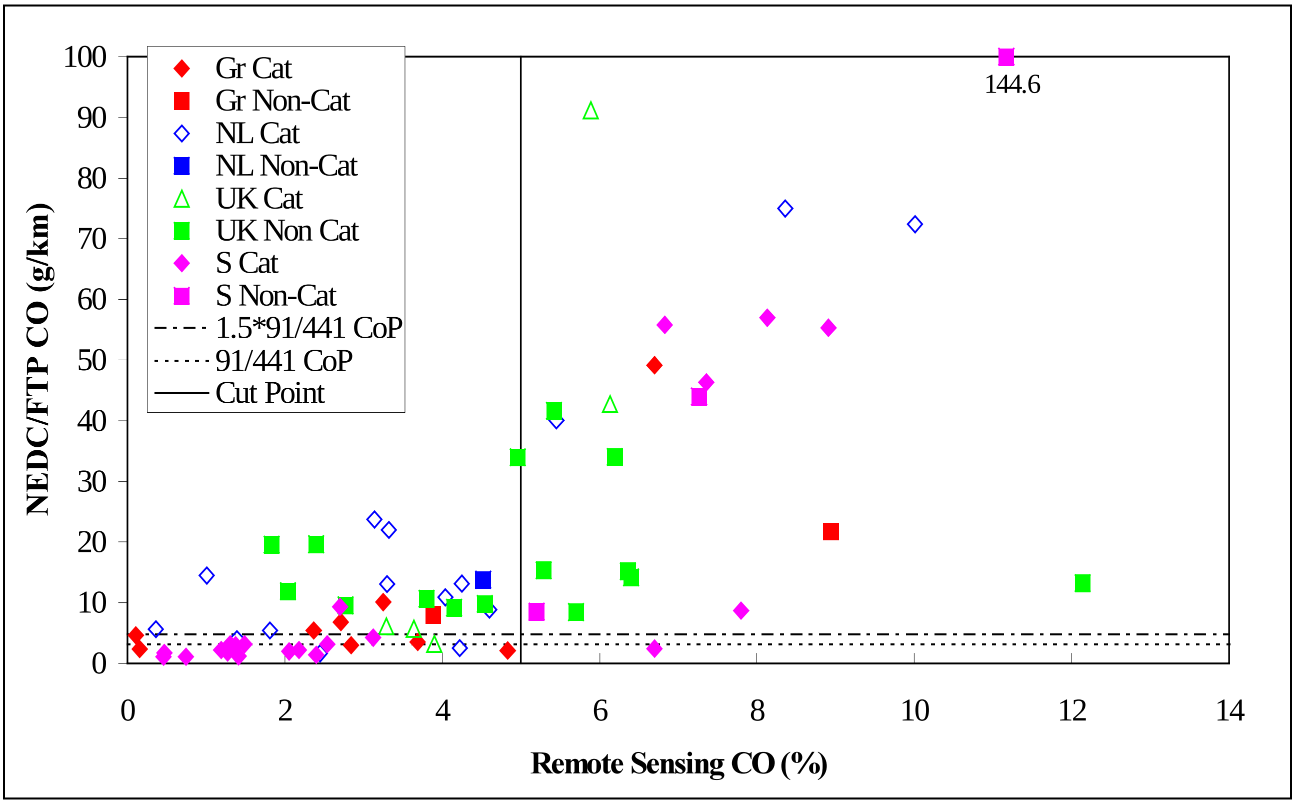


Figure 6. Dynamometer CO plotted against Remote Sensing CO for all vehicles



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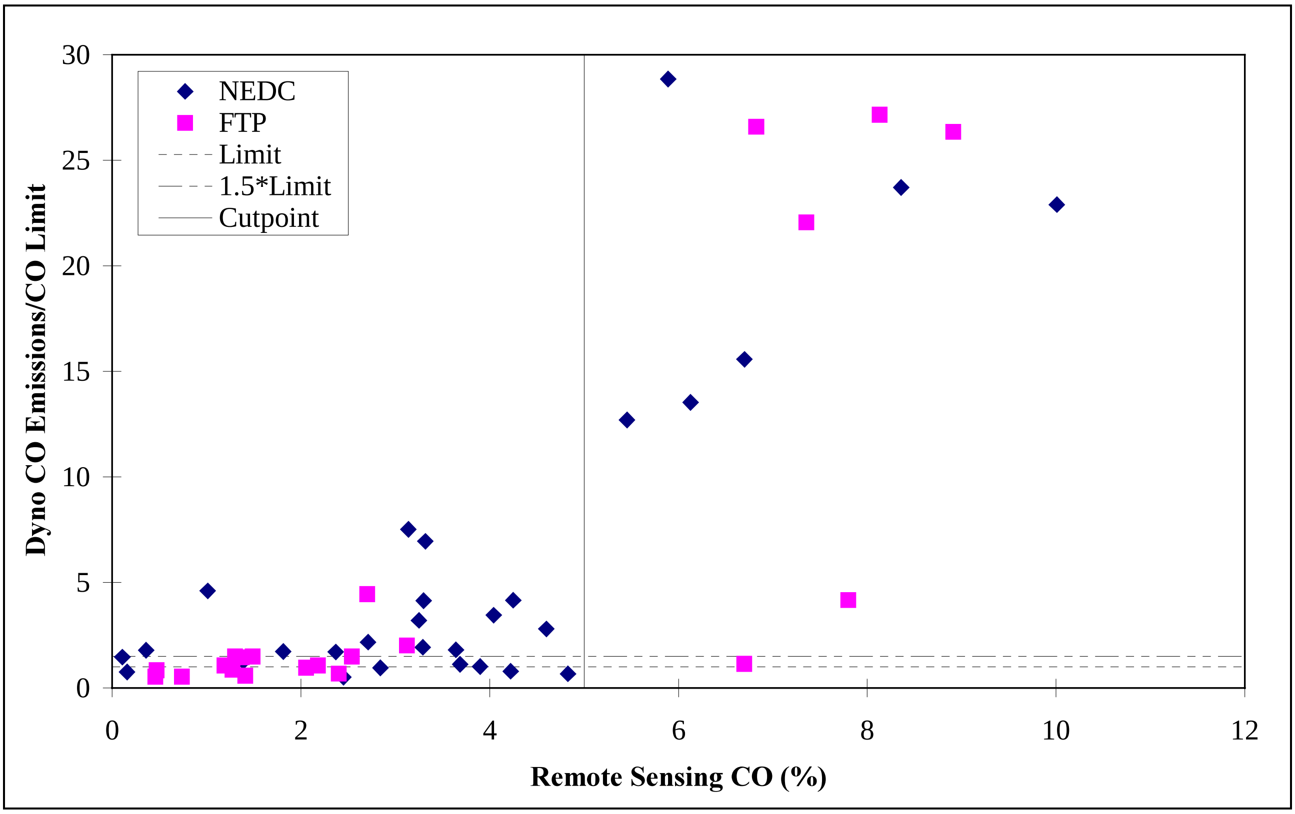

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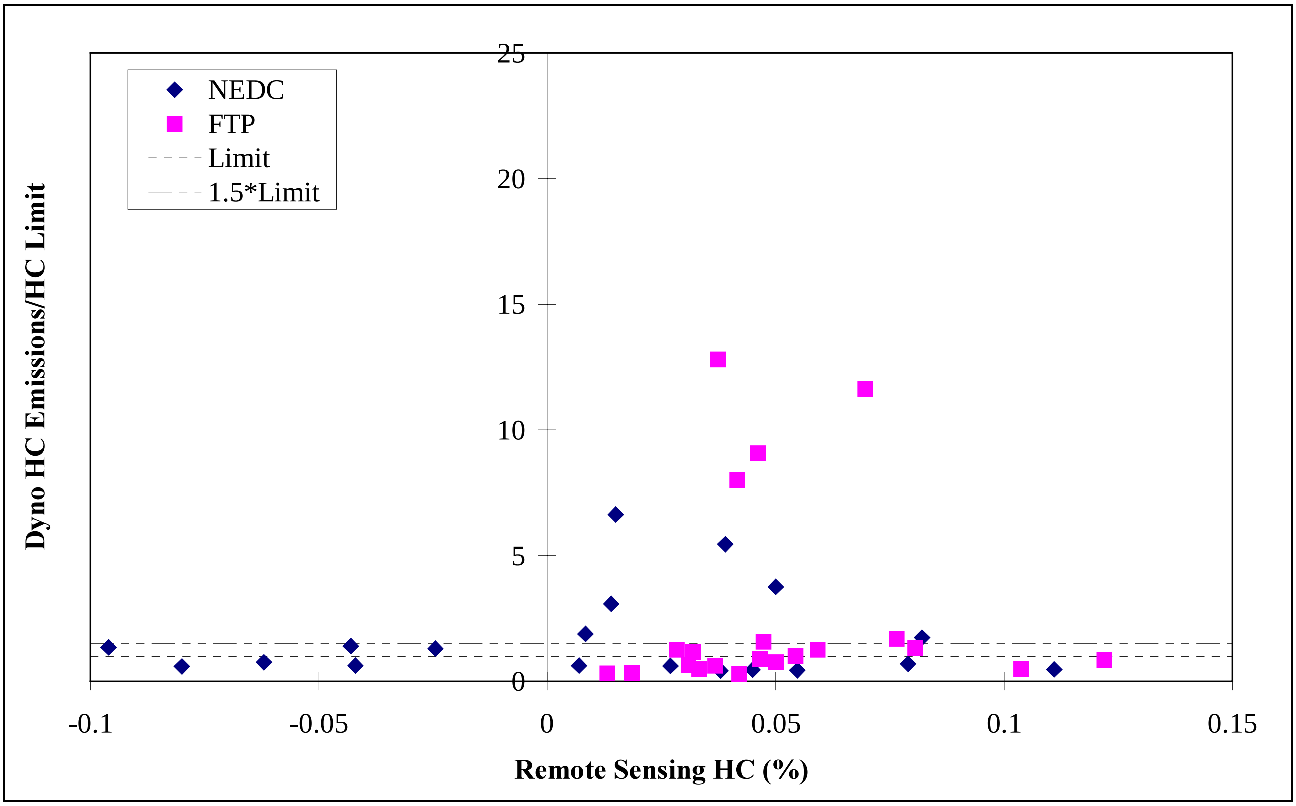

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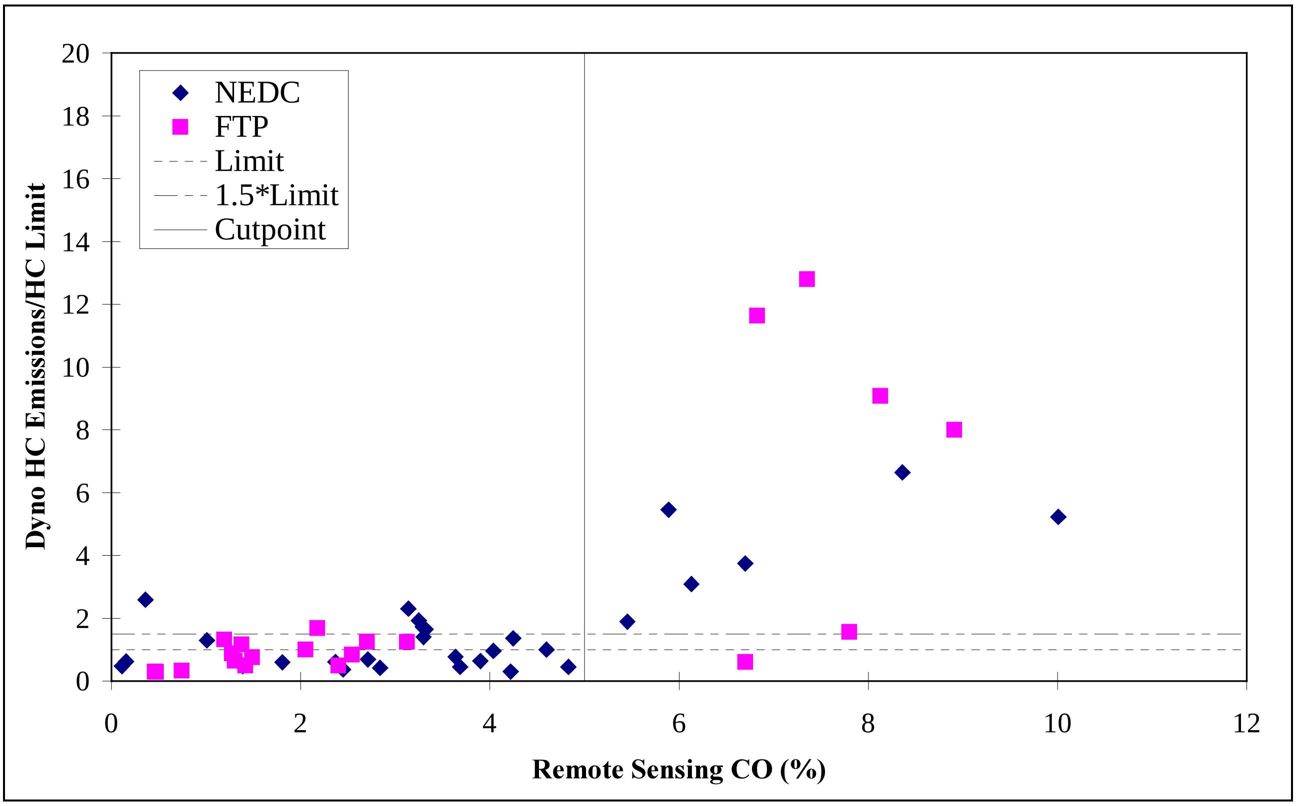

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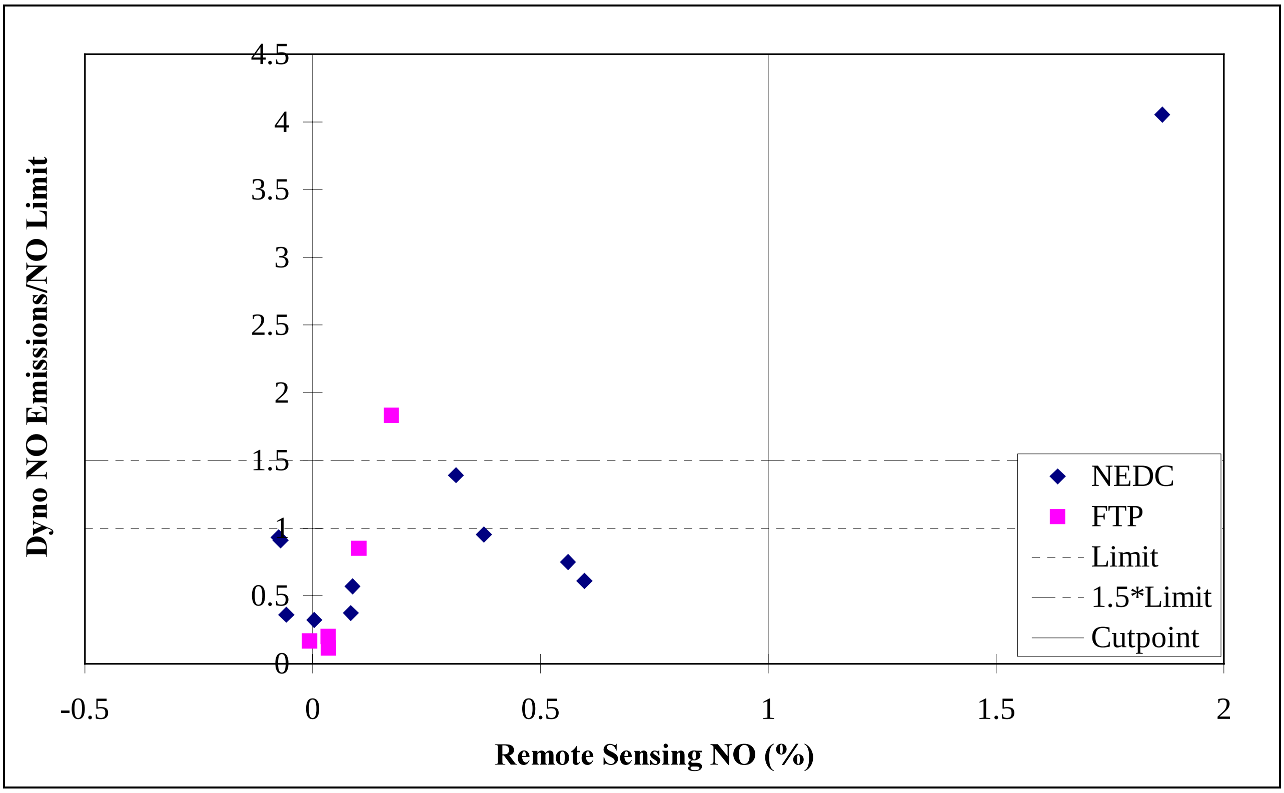


Figure 11. Group Categories

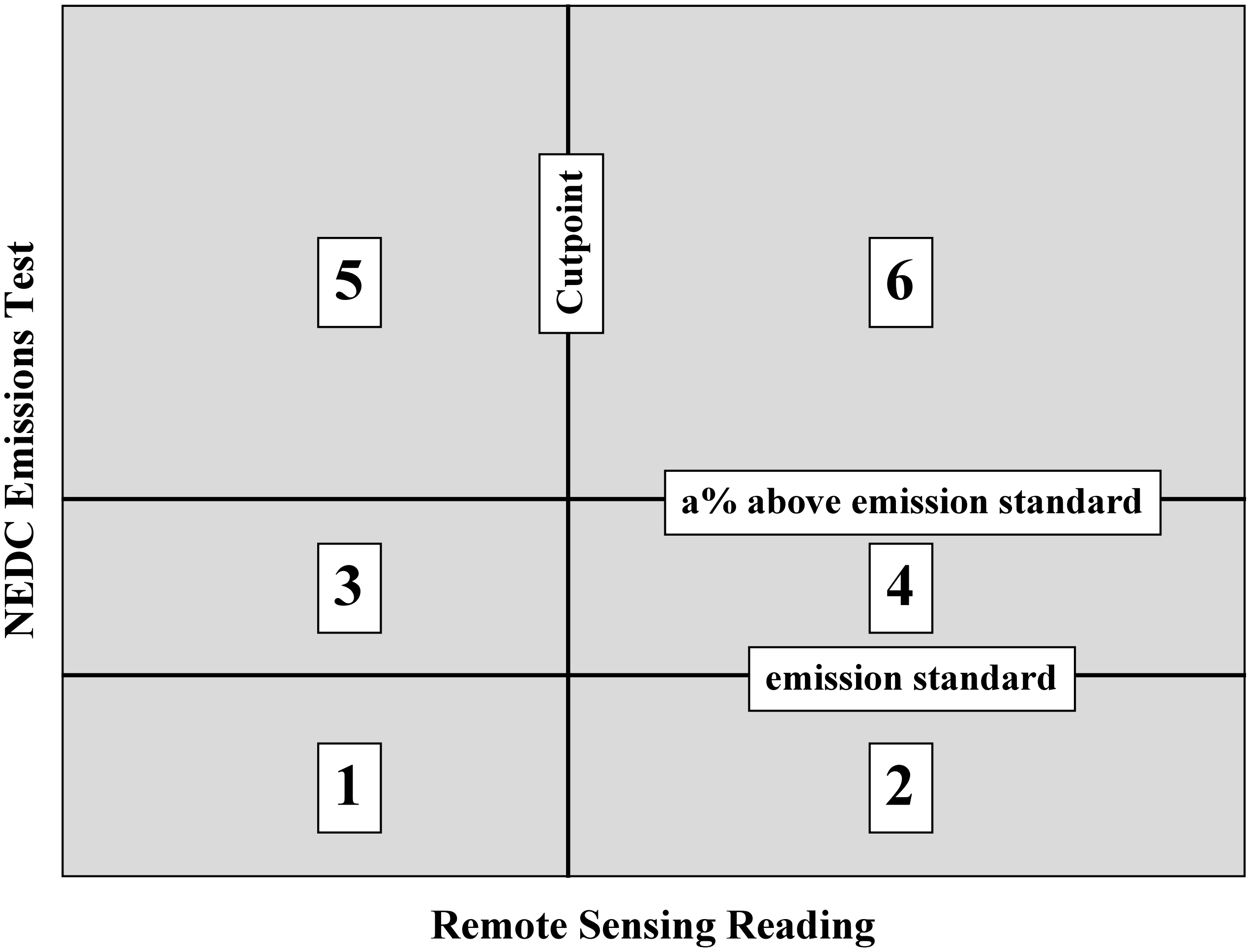
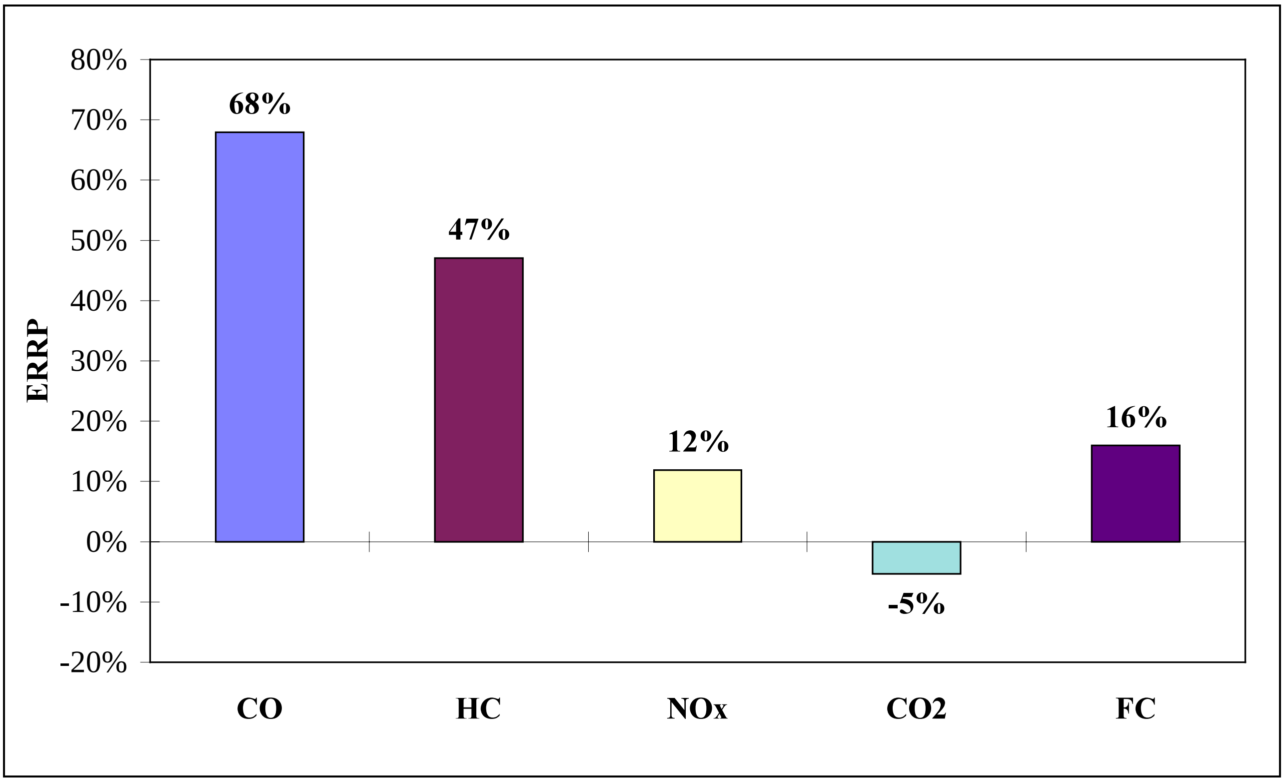


Figure 12. Emission Reduction Rate Potential (ERRP) of Remote Sensing based on a CO cut point of 5%



Paper (final) submitted for "Transportation Research Part D: Transport and the Environment" - PA3499/99

Cost-Effectiveness of I&M

Abstract

This contribution is one item in the series about “The inspection of in-use cars in order to attain minimum emissions of pollutants and optimum energy efficiency”. It deals with the cost-effectiveness of the various I/M systems considered in the project. Section 1 elaborates a methodology for the evaluation of cost-effectiveness. Section 2 gives a calculation example on the basis of the Dutch situation. Section 3 evaluates the outcome of the calculation, gives the results in a graphical representation and compares the outcome for the Netherlands (a typical north European country, with a large share of catalyst equipped cars already) with the calculation results for Greece (a typical south European country, with a continuing high share of non catalyst cars).

1 Methodology

1.1 General outline

This contribution describes the methodology used to calculate the cost-effectiveness of the various inspection methods described in the other contributions. The methodology is elaborated in Rijkeboer (1998) and outlined in the flowchart of Figure 1. 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 dependant on the cost of labour in the country considered (top box column three). The variable input consists of the type of inspection programme chosen and the number of cars subject to the programme (column five). This last item depends on the choice of the first year that vehicles are subjected to the programme (e.g. after three years from new) and the frequency of the inspection (annually or biannually).

The selectivity of the inspection programme 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 contribution. For the present contribution they are treated as fixed input. The selectivity of the inspection programme 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 o.k. The number of faulty vehicles in the fleet will partly depend on the general state of maintenance of the fleet considered, but when such detailed information is lacking the boxes ‘selectivity of the inspection programme’ and ‘number of faulty vehicles in the fleet’ may 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. In that case 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 kton 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 section 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 programme 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 programme column four/five). This is the second interim result.

When the total cost of the I/M programme 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).

1.2 Types of inspection programme considered

In this contribution the following types of inspection programme 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 programme (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. In the project two different driving cycles were evaluated: the TÜV-A cycle and the MODEM short cycle. Since the results of these two cycles were rather similar, they have been averaged for this evaluation. 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’)

1.3 Selectivity of the programme and average emission reduction potential

The selectivity of the inspection programmes mentioned under 1.2 and the emission reduction rate potential (ERRP) have been determined by the Aristoteles University of Thessaloniki (Samaras, et al, 1998). 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 9 in paragraph 2.3) .

The ERRP has been determined relative to the certification cycle and relative to the MODEM cycle. The ERRPs relative to these two cycles do not differ greatly, but since the MODEM cycle was included in the programme because it did give a better representation of reality, the ERRP relative to this cycle has been used in this evaluation. The selectivities of the inspection programmes are given in Table 1.

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 programme, combined with the experience with the Dutch in-use compliance programme (see Table 2). A sensitivity analysis of the influence of this assumption showed that the variation of the sharing over minor and major repair influences the calculated results for the year 1995 to 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 sensitivity for 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 for 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.

The ERRPs have been identified on the basis of the evaluation by the Aristoteles University of Thessaloniki as shown in Table 3. 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 in this contribution. The effect on fuel consumption of 3-way catalyst equipped vehicles is small, in the order of about 2 % maximum. This does seem too 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.

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. The amortisation period has been chosen as 7 years. The interest has been assumed as 10% over the average loan. By way of example the Dutch case is given in Table 4.

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.

The cost of maintenance was supplied by the partners in the project 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 5. 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 programme indicates 27 % of the catalyst equipped vehicles (tax incentive) as faulty (‘dynamic me’, Table 1), the cost of maintenance is (see also Table 2):
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 vehicles

2 Calculation example

2.1 The emission benefits

By way of example the calculation will be performed for the Dutch case. In 1995 the composition of the fleet and the emission factors were as follows:

The inspection set-up for the Netherlands is 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 (see also Table 6):

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 given in Table 3. 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 cat tax incentive
0.528 x 22500 x 1.3 x 0.031 = 0.48 kton/yr LPG (cat 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 7.

2.2 The costs

The cost of the inspection schemes is given in Table 4. 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 1.5). 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	

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. On the other hand simply sharing the cost over the cumulative amount of ktonnes avoided, irrespective of the pollutant, would relate the cost-effectiveness mainly to the amount of CO avoided, since this is numerically the largest amount, although not necessarily the most important effect. 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 8.

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. Some partners of the consortium had defect cars repaired at local garages, without special instructions. It may be assumed that the maintenance provided in those cases is typical for the standards in those countries. The relative real effectiveness of these repairs is given in Table 9:

The following comments can be made. In the first place it may be noted that these percentages may differ for different countries. Some countries may have a higher standard of quality for garage maintenance than others. In the sample of Table 9 the south-European countries are dominant. In the second place a second I/M test after the repair might have identified some of the vehicles insufficiently maintained as such. So in a real-life scheme the situation would presumably be somewhat better. This means that the real-life situation would tend to lie somewhere between the figures of Table 9 and 100%.

It can then be concluded that the actual emission reduction of CO and HC will most probably lie very close to the potential one. On the other hand the actual emission reduction for NOx may be as low as half the potential; only in the case of a short test that actually does measure NOx may the garage have an indication of the repair needed and would a possible check after the repair detect any shortcomings in the maintenance.

In the case of real effects below 100% the actual reductions would be the potential reductions multiplied by these figures and the cost-effectiveness would be the potential cost-effectiveness divided by these figures. In real-life cases Member States would have to determine the quality of the standards in their garages and, if necessary, improve these by separate actions.

3 Evaluation

3.1 The Dutch example

The amount of pollutants avoided per type of inspection system for the Netherlands in 1995 is shown in Figure 2 below. The number of vehicles identified as faulty, as a percentage of the total number of vehicles inspected, is shown in Figure 3. The costs of inspection and maintenance per kton of pollutant avoided are shown in Figure 4. The trends in the amount of pollutants avoided is shown in Figure 5.

From Figure 2 it can be seen that there are generally no big differences between the effectiveness of the various inspection systems. In particular it is noteworthy that the procedure according to 92/55/EEC gives good results. Two things should be noted here, however. In the first place the results of this procedure for 1995 are very much influenced by the results from the non-catalyst vehicles. But the ERRPs from the non-catalyst vehicles are based on a relatively small sample, since the emphasis in the selection of cars lay on the catalyst equipped ones. So the ERRPs of the non-catalyst cars have a larger margin than those of the catalyst cars. In the second place, for the same reason the picture changes significantly when the share of catalyst cars rises in 2000 and 2005, as can be seen from Figure 5. Similarly Figure 3 seems to indicate that there is not much difference between the inspection systems in the percentage of otto vehicles identified as faulty, but again this picture changes significantly in future years (see Figure 5), especially for NOx.

The Figures 2 and 5 indicate a much higher amount of NOx avoided in the case of the ‘dynamic me’ test. This is a direct result from the fact that in that case NOx is actually measured in the short test, whereas in the other test it is simply a come-along effect.

Figure 3 shows a clear difference in the number of diesel engined cars indicated as faulty between the free acceleration test according to 92/55/EEC and the ‘dynamic ra’ test. This is a direct result of the large number of errors of commission (vehicles incorrectly identified as faulty). Figure 2 shows that indeed the amount of PM avoided does not actually increase with this high number of vehicles repaired. But Fig. 4 shows that the additional unnecessary cost of repair does actually make this an expensive option, even though the actual testing is cheap.

In Figure 6 the trends in cost-effectiveness are given. As can be seen the dynamic tests show a much better cost-effectiveness in future years, when the share of catalyst equipped vehicles is higher than today. The cost-effectiveness of the dynamic tests also tends more towards a constant amount, notwithstanding the fact that vehicles become cleaner. The present procedure tends to deteriorate the cost-effectiveness in coming years.

3.2 The Greek example

By way of comparison the cost-effectiveness is shown for a South-European country, in this case Greece. The cost-effectiveness over the years 1995, 2000 and 2005 is shown in Figure 7. As can be seen the procedure according to 92/55/EEC remains cost-effective for a much longer period, due to the continuing high number of non-catalyst vehicles in the Greek fleet.

4 Conclusions

From the study the following conclusions may be derived:

- ◊ 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 much 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 much 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.

Table 1: 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	

Table 2: 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%		

Table 3: The emission reduction rate potential of the various inspection methods

CO

FUEL	petrol/LPG				diesel	
technology	convent	cat tax inc.	Euro I/II	Euro III	< Euro III	Euro III
92/55/EEC	16%	5%	5%	7%	0%	0%
static	15%	3%	3%	5%	0%	0%
dynamic ra	13%	16%	16%	20%	0%	0%
dynamic me	17%	16%	16%	20%	0%	0%

HC

FUEL	petrol/LPG				diesel	
technology	w/o cat	cat tax inc.	Euro I/II	Euro III	< Euro III	Euro III
92/55/EEC	8%	5%	5%	12%	0%	0%
static	5%	6%	6%	14%	0%	0%
dynamic ra	5%	14%	14%	26%	0%	0%
dynamic me	5%	15%	15%	29%	0%	0%

NOx

FUEL	petrol/LPG				diesel	
technology	w/o cat	cat tax inc.	Euro I/II	Euro III	< Euro III	Euro III
92/55/EEC	8%	5%	5%	10%	0%	0%
static	3%	10%	10%	14%	0%	0%
dynamic ra	3%	10%	10%	14%	0%	0%
dynamic me	5%	20%	20%	33%	0%	0%

PM

FUEL	petrol/LPG				diesel	
technology	convent	cat tax inc.	Euro I/II	Euro III	< Euro III	Euro III
92/55/EEC	0%	0%	0%	0%	25%	33%
static	0%	0%	0%	0%		
dynamic ra	0%	0%	0%	0%	25%	31%
dynamic me	0%	0%	0%	0%		

Table 4: Calculation of the cost in ECU/vehicle of an inspection in a centralised system

the NETHERLANDS	92/55/EEC	Static	Dynamic ra	Dynamic me
Investment ECU		30000	45000	50000
Amortisation/yr ECU		4286	6429	7143
Interest/yr ECU		1500	2250	2500
Housing/yr ECU		3000	3000	3000
Subtotal ECU		8786	11679	12643
vehicles/yr		10000	10000	8000
Fixed cost/vehicle		0.88	1.17	1.58
Labour/hr		50	50	50
Vehicle/hr		5	5	4
Labour/vehicle		10	10	12.5
Administrative/vehicle		3	3	3
Total/vehicle ECU	10.00	13.88	14.17	17.08

Table 5: Cost of maintenance

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

Table 6: Composition of the Dutch car fleet and emission factors in 1995

1995	number millions	km/yr	CO g/km	HC g/km	NOx g/km	PM g/km
Otto conv	1.710	9700	11.30	1.80	2.76	
cat tax inc	0.420	13600	2.80	0.30	0.58	
Euro I	2.680	13600	1.60	0.16	0.44	
diesel	0.420	25000	0.60	0.17	0.71	0.19
LPG	0.660	22500	1.30	0.39	0.95	
total	5.890					

Table 7: 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	

Table 8: 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 9: 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

List of figures

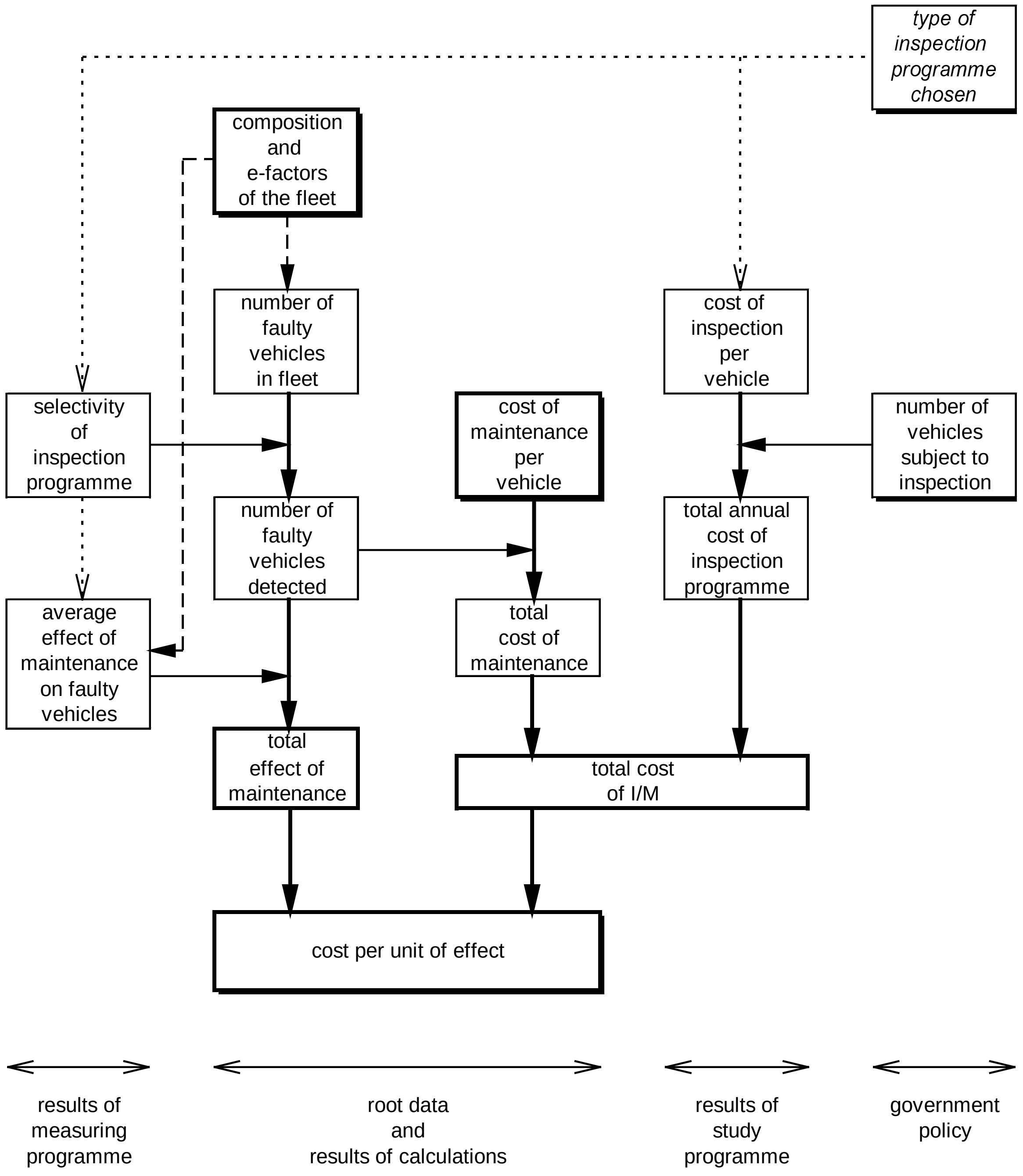

type of inspection programme chosen
composition and e-factors of the fleet
number of faulty vehicles in fleet
cost of inspection per vehicle
selectivity of inspection programme
cost of maintenance per vehicle
number of vehicles subject to inspection
number of faulty vehicles detected
total annual cost of inspection programme
average effect of maintenance on faulty vehicles
total cost of maintenance
total effect of maintenance
total cost of I/M
cost per unit of effect
results of measuring programme
root data and results of calculations
results of study programme
government policy

Figure 1

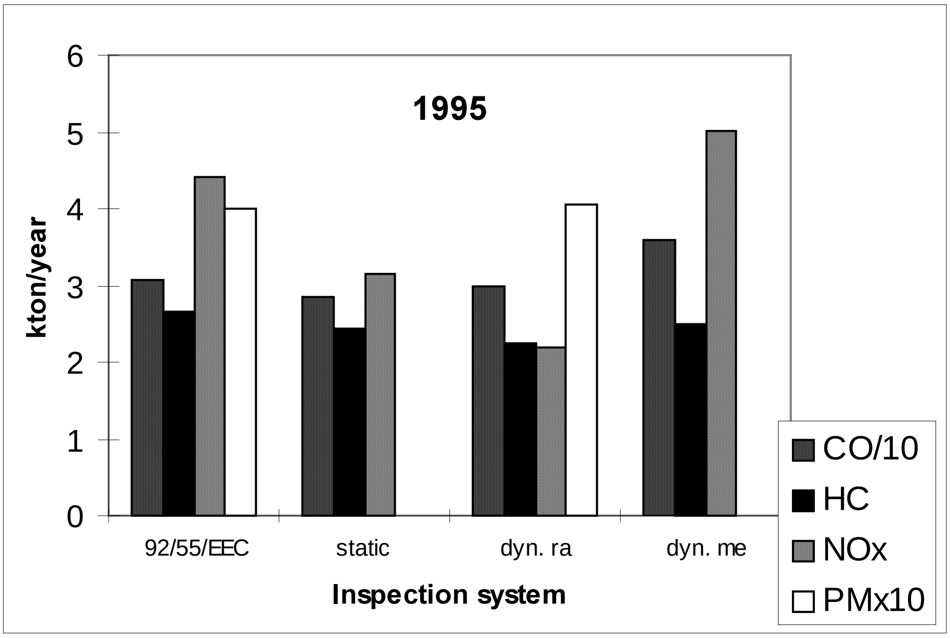


Figure 2

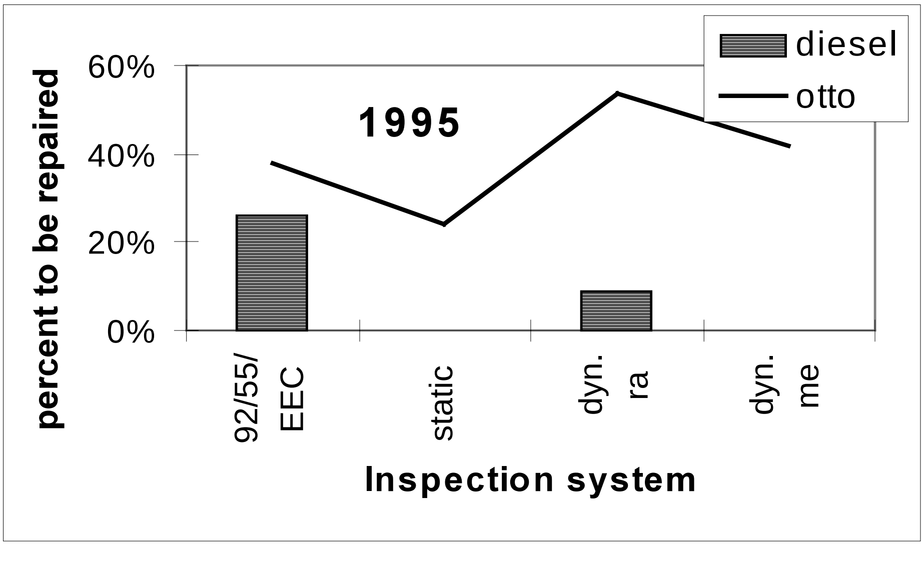


Figure 3

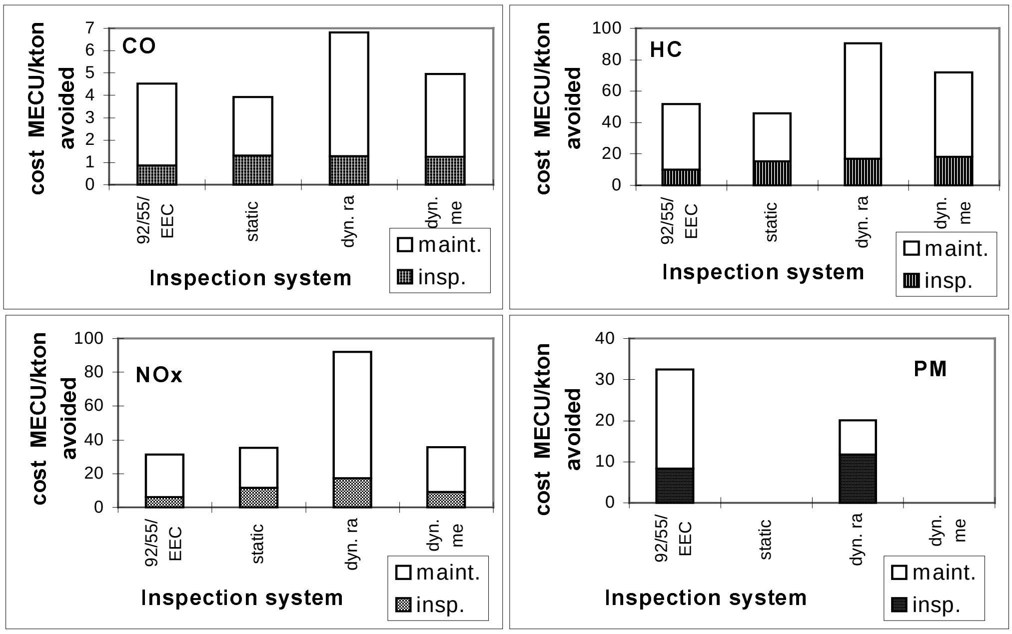


Figure 4

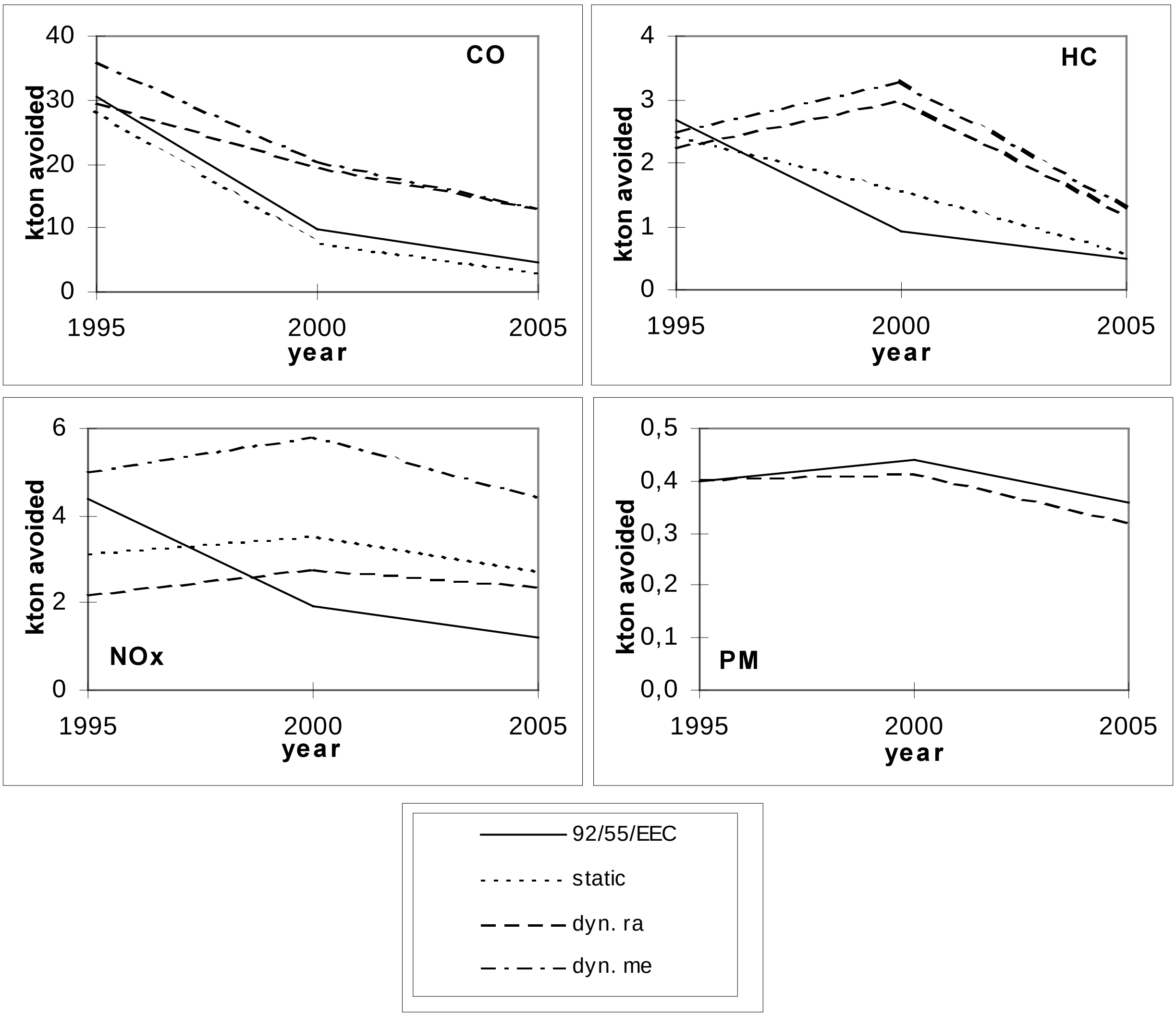


Figure 5

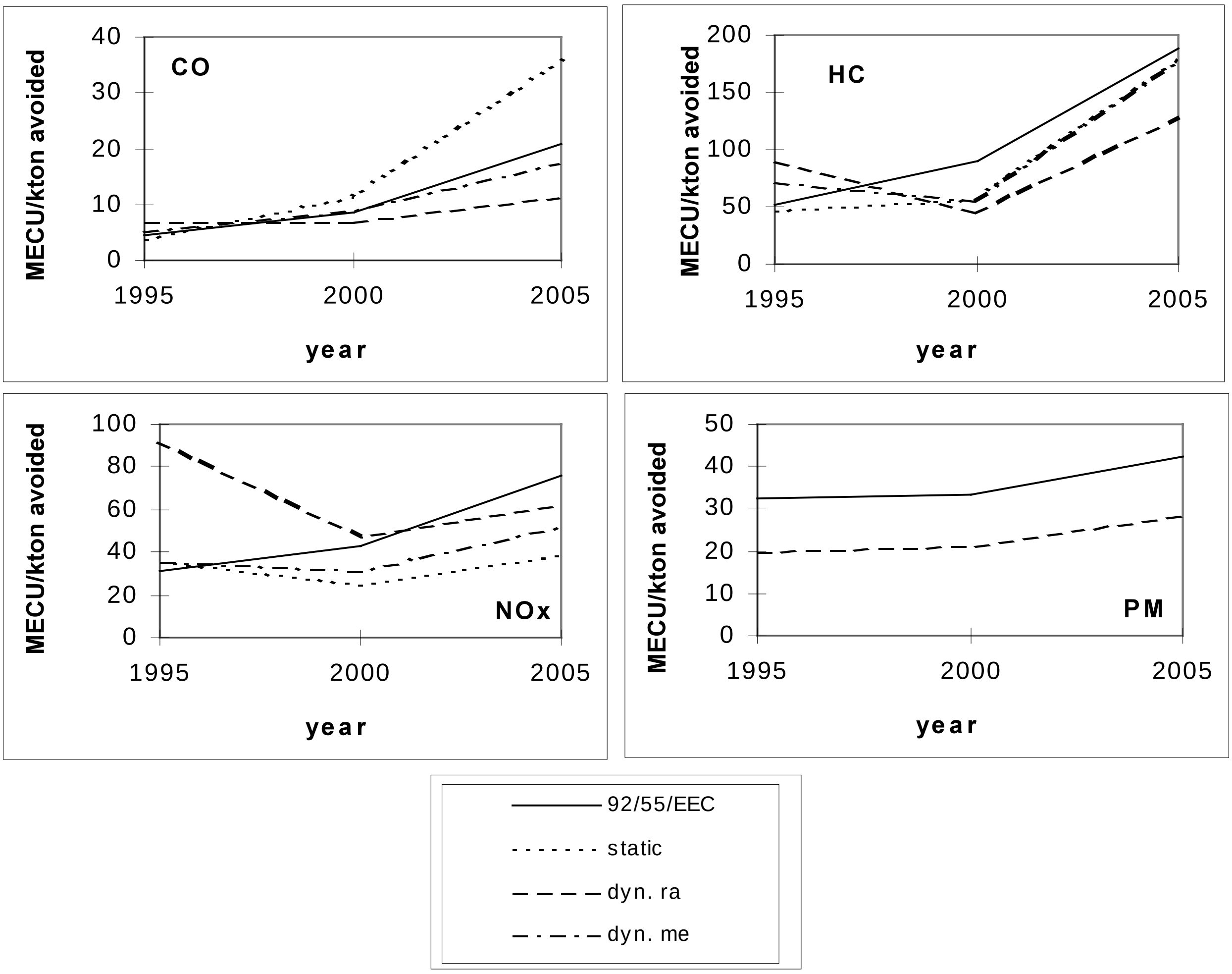


Figure 6 **The Dutch Example**

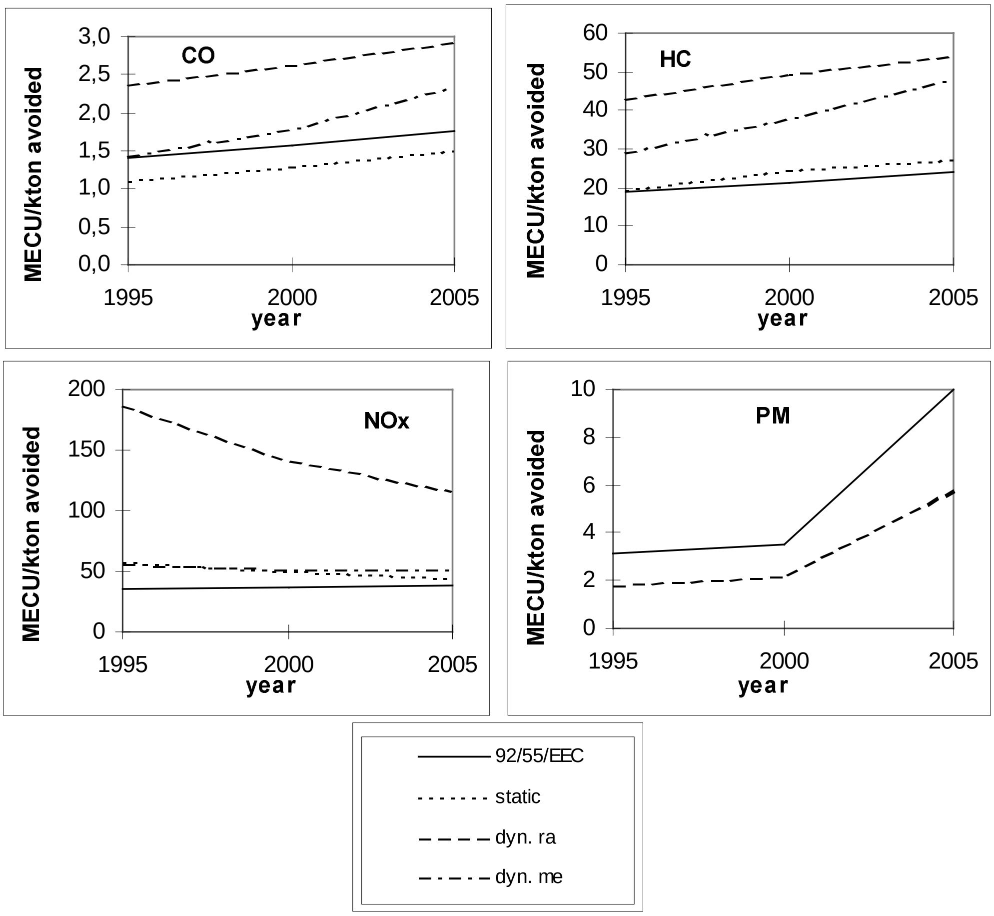


Figure 7 **The Greek Example**