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Feasibility study of a large scale data gathering exercise of the emissions produced by vehicles in-use

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Summary

The aim of the study is to investigate whether current and proposed data collection projects will provide a statistically significant set of data, which will enable the proper evaluation of emission testing policy options. Therefore a number of activities involving emission testing are investigated and eventually the Joint Commission Services study on I&M and the German AU study are depicted as the most representative. The two studies are then compared in order to assess their methodologies and the data they used. The analysis performed demonstrates the insufficiency of the current data collection programmes and thus a large-scale exercise to collect data from vehicles in-use is proposed. The vehicle sample proposed includes 4 000 gasoline vehicles and 4 000 diesel vehicles, which will be evaluated separately. The testing programme involves the certification cycle and one transient short test, maintenance of the vehicles exceeding the emission limits and re-testing of the latter. In order to assess the emission deterioration effect a repeat of the testing programme is proposed. The total cost of the exercise is estimated at around 16 M€ and an evaluation of the cost-effectiveness of the proposed approach is performed based on the potential emission reductions achieved.

Keywords

Inspection, maintenance, emission testing policy, transient loaded test, ageing effect

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Executive summary

There is currently not much data about the emission performance of vehicles in-use, particularly those with the latest technology. Following a proposal by the Working Group 4 of the Auto-Oil II Programme the current study was undertaken as part of the CITA second programme of studies on emission testing at periodic and other inspections. The final proposal was for a feasibility study into the need and benefits of a large-scale data gathering exercise of the emissions produced by vehicles in-use. The data from such an exercise would enable the proper evaluation of emission testing policy options and it would also provide information that would help refine the emission factors used in air quality modelling programmes.

Three types of activities involving emission testing are identified in the EU: (a) Emission factor development and modelling programmes, such as MEET, Artemis and a large number of national programmes; (b) European and national I&M evaluation programmes, such as the Joint Commission Services (JCS) study on I&M, the German AU study, the UK Vehicle Inspectorate study etc; and (c) National I&M programmes, resulting in % failure rates and concentrations at low and high idle.

The information collected within the inspection centres seem to have the potential of regular and constant emission behaviour monitoring. The question is though what could be done in the framework of the current activities of the inspection centres in order to utilise the data resulting from the periodic inspection and thus making better use of the inspection centres themselves. That means the information on emissions collected from the inspection centres is valuable as regards the current condition of the in-use fleet but cannot been further utilised for the proper evaluation of other emission testing policy options. If the resulted percent failure rates and concentrations of pollutants at low and high idle could be correlated to emissions in grams per kilometre then the data coming from the inspection centres would be more useful. However, it was inherently known that such a correlation couldn't be achieved. On the other hand, loaded short tests proved to exhibit acceptable correlations to the type approval test.

The conclusion of the three I&M evaluation studies as regards the Roadworthiness Directive 92/55/EC significantly differentiate from each other. According to the UK study the current Directive is very effective in identifying high emitters resulting in considerable high emission reductions. The German study claims similar emission reductions though some reservations regarding the possible effectiveness of an enhanced I&M scheme are quoted. On the contrary, the JCS study concludes that the current Roadworthiness Directive is completely ineffective for the three way catalyst fleet.

Apart from the considerable variations in the findings among the above studies, the major drawback of their approaches is the lack of statistical representativity. More specifically:

The UK study is only based on statistical analysis and calculations without any hard experimental facts. The evaluation of the national I&M scheme is only based on already available data from the inspection test lanes while no other emission testing policy option is investigated. The major issue of the German study is the identification rate of the high emitters. The low polluters are totally excluded from any evaluation process and furthermore the actual high emitters and the errors of commission are not discriminated. On the other side, the JCS study is based on a rather small sample. Thus, even though the evaluation of several policy options can be realised, the statistical representativity of the results is questionable.

In view of the above and adding the fact that the degradation effect has not been evaluated by any of the proposed approaches, it is concluded that the existing data gathering projects cannot provide statistically reliable data that could be used to evaluate the benefits of various policy options. Therefore, a proposal for undertaking a large-scale data collection exercise of the emissions from vehicles coming for periodic inspection is made.

Inspection centres and laboratories related to I&M will participate in the large-scale exercise proposed. Based on the need for a statistically representative sample, 4 000 gasoline- and 4 000 diesel vehicles will comprise the vehicle sample, mainly selected in a random manner from vehicles coming for periodic inspection.

As the basic aim of undertaking such an exercise will be to evaluate more precisely the benefits of introducing a short test using a chassis dynamometer, a transient loaded short test with good correlation to the type approval will be chosen. All vehicles will then undergo the same testing programme according to a common test protocol including the certification cycle and the short test. All vehicles exceeding the emission limits will be sent to maintenance and be re-tested. As the assessment of the emission degradation of in-use vehicles is essential for the proper evaluation of any emission testing policy, a repeat of the testing programme seems to be necessary.

The total cost of the exercise, including the cost of the emission tests conducted, the cost of the necessary maintenance and the cost of the data evaluation performed, is estimated at around 16 M€. In order to evaluate the cost-effectiveness of the proposed approach, the emission reductions achieved following the above testing programme will be calculated.

1 Introduction

This is the final report of the study 5 of CITA Second Programme of Studies on Emission Testing at Periodic and Other Inspections [1] and is entitled 'Feasibility study of a large scale data gathering exercise of the emissions produced by vehicles in-use'.

The current study was undertaken following the proposed research on Inspection and Maintenance (I&M) by the Working Group 4 of the Auto-Oil II Programme [2]. According to this "*a feasibility study would 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 COPERT [3], MEET [4] and their successors. It would also provide information on whether there would be any benefits from changing the frequency of periodic statutory emission tests*."

The final proposal of CITA Working Group 1 was eventually amended in order to enable the evaluation of other policy options as well. According to the contract, the major objectives of the study are summarised below:

- To research the data that is needed to enable the proper evaluation of emission testing policy options;
- To evaluate current and proposed data collection projects (both national and European) to see whether they will provide a statistically significant set of data;
- To specify, if necessary, a programme to collect statistically significant data and to estimate the costs involved;
- To evaluate the cost-effectiveness of the proposed approach.

In view of the objectives set above, the report is divided into five sections.

In section one a short introduction is presented including the background of the study and its major objectives.

Section two includes a review of the major emission data collection programmes finalised or currently running in the EU. The aim of this review is to identify the policy options that have been adopted based on emission testing and to investigate whether they can provide a statistically significant set of data for the evaluation of other policy options. In order to enable the proper evaluation of such policy options, two main directions are identified on which the evaluations should be based.

The two most comprehensive and relevant from the above approaches are identified in section three. The methodologies used and the accompanied results are examined in detail so as to see in what extent they can be considered as comparable. In order to further investigate and evaluate the data used by each approach, the calculations are re-performed using different sets of data.

Based on the above calculations the final evaluation of the two approaches in question and the available set of data is performed in section four. In view of the main directions described in section two, it is concluded that the data provided by both approaches is not sufficient in order to properly evaluate the policy options introduced.

As the conclusion of insufficient data is drawn above, a proposal for a large-scale data gathering exercise is specified in section five. The technical details of such a programme as well as the costs involved are determined. Finally, the cost-effectiveness of the proposed approach is evaluated.

2 Data collection programmes in EU

There are three main reasons for conducting emission testing of in-use vehicles:

- To investigate the performance of the type-approval standards;
- To investigate the performance of the in-use emission policy; and
- To enable emission forecasts, which are utilised for air quality modelling and for assessing the need for newer stricter emission standards for both type-approval and in-use compliance.

In the following the main activities involving emission testing are presented.

2.1 Emission factors development and modelling programmes

In this category of activities a number of European projects (e.g. MEET, Artemis) and a large number of national programmes can be identified.

The MEET project, which was part of the COST Action 319 [5] and was funded by the European Commission under the transport research and technological development programme of the 4th framework programme, provided a basic, Europe-wide procedure for evaluating the impact of transport on air pollutant emissions and energy consumption.

The Artemis project (acronym for Assessment and Reliability of Transport Emission Models and Inventory Systems) is funded by the European Commission under the 5th framework programme and its main aim is to produce a harmonised emission model for road, rail, air and ship transport. It does not wish to add an additional model on the basis of the presently existing data, but it proposes a new model taking into account new emission measurements and results which are proposed in other related projects (e.g. PARTICULATES). The expected product of the project is to provide consistent emission estimates at the national, international and regional level.

A report on the in-use compliance project in the Netherlands and its related subprogrammes [6] covering the first ten project years (1987 to 1997) is a representative example of national on-going programmes. Vehicles from all legislative categories were chosen either for initial testing or for durability test. The initial target was to measure five vehicles of each vehicle category which was then reduced to three vehicles. In the case of vehicles selected for initial testing their mileage was less than 25 000 km. In the case of vehicles selected for durability test the effect of emission deterioration was investigated and thus, especially in the case of three way catalyst (TWC) vehicles, it was attempted to cover a wide range of mileage per type. The main test for each vehicle type was the one in which it was certified while an additional number of extra tests were also performed, including the New European Driving Cycle (NEDC), the Federal Test Procedure (FTP) and the Modem cycle.

2.2 I&M evaluation programmes

These kinds of activities involve both national and European studies dealing with the evaluation of current test procedures and the efficiency of the national I&M schemes. The most representative studies are presented in the following.

2.2.1 The German Abgasuntersuchung (AU) Study

The project [7] was funded by the Federal Road Research Institute (BASt) and its main objective was to perform an efficiency analysis of the current German AU procedure for the TWC gasoline vehicles. A vehicle sample coming from the test lanes of RWTÜV and TÜV Rheinland and failing the AU procedure was examined for this purpose. The vehicles were tested on a chassis dynamometer before and after maintenance following the same testing programme.

The annual emission reductions achieved by repair of the AU-failed vehicles were then calculated by the same projection model that was used by BASt and the Federal Environmental Agency (UBA) for calculating the emissions from road traffic in Germany.

The proposed approach and the main findings are presented and evaluated below.

Annual AU-related emission reduction

The calculation of emission reductions achieved by repair of the vehicles failing the AU procedure was performed according to the following procedure:

- Determination of the annual mileage of the vehicles subjected to AU;
- Determination of the failure rate, i.e. the percentage of vehicles failing the AU test;
- Calculation of emission factors before and after maintenance;
- Expansion of the emission reductions for a defined reference period of time.

Mileage

The total annual mileage of the vehicles subjected to AU was calculated according to the ‘Transport Emission Estimation Model’ (TREMOD) [8]. The total annual mileage was then distributed into vehicle- and road classes.

The distribution into vehicle classes was done according to the vehicles’ model year and engine capacity, while the distribution into road classes was done according to road traffic modes (e.g. urban, rural, highway).

Failure rates

The representativity of the failure rate, which has to be determined in conjunction to the model year and engine capacity, is essential for the informative value of the calculated results. Representative failure rates, which are valid for the whole fleet subjected to AU, were determined for the reference year 1997.

Data from a sample of 280 824 TWC vehicles tested at the inspection lanes of RWTÜV and TÜV Rheinland in 1997 were used to determine the failure rate of the AU procedure. The failure rate was then distributed into the corresponding vehicle classes.

Emission factors before/after repair

In order to determine emission factors before and after maintenance, a sample of 122 Euro I vehicles failing the AU procedure taken from the test lanes of RWTÜV and TÜV Rheinland was investigated. The vehicles of the sample were measured before and after repair following a specific testing programme, which included the cold NEDC as certification cycle, the US-FTP and the Autobahn cycle, which is part of the testing programme to determine emission factors.

Emission factors were then determined for all vehicle- and road classes. These emission factors were established from the hot driving cycles of the measurement programme and thus cannot be applied for cold start conditions.

Emission reduction

For a defined vehicle- and road- class the annual emission reduction achieved by repair of the AU-failed vehicles was calculated by multiplying the failure rate of the respective class by its mileage and the difference in emission factors before and after maintenance.

The total annual emission reduction by repair of the AU-failed vehicles in 1997 was then determined by summing the emission reductions of all vehicle- and road- classes.

As already mentioned, the emission factors and the associated annual emission reductions are only valid in case the total mileage of a vehicle class is determined with hot engine conditions which are not realistic due to the unavoidable cold start effect.

Therefore, following the methodology applied in the computer forecast model of UBA an assessment of the emission reduction was made including the cold start. According to this model, the cold start extra emissions are allocated to urban conditions only. For CO and HC the higher emission reductions can be observed in the urban areas, while the higher reductions of NO_x are allocated to rural areas. In urban areas taking the cold start extra emissions into account leads to a further increase of the emission reduction for CO and HC while there is a slight decrease for NO_x.

Efficiency of the AU procedure

The AU-related emission reductions calculated for one reference year were expanded to the total emissions of the TWC fleet subject to AU, as the efficiency of the AU procedure has a direct impact on the environment.

The highest efficiency of the AU procedure (18 to 20 %) can be observed for the CO and HC emissions in the urban and rural mode. If the cold start conditions are taken into consideration, the above efficiency for urban driving is reduced to 9 % for HC and 14 % for CO respectively. The efficiency of the AU procedure for the highway mode is about half the efficiency of the rural mode. As regards the NO_x emissions, the efficiency of the AU-procedure lies between 4 and 9 % according to the road category. Referring to all road classes, the AU-efficiency is 12 % (18 %) for HC, 13 % (14 %) for CO and 6 % (7 %) for NO_x emissions. The values in brackets refer to the case of all the mileage being driven with a hot engine. The efficiency of the AU-procedure for CO_2 emissions and fuel consumption is insignificant (maximum 0,2 %). When the cold start effect is taken into account, the efficiency becomes considerably lower as the AU-related repairs have a negligible effect to the cold start emissions.

2.2.2 The 1994-1998 Joint Commission Services (JCS) Study on I&M

The objective of the study [9,10] 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 TWC and diesel vehicles, it was considered necessary to investigate test procedures that in theory have a larger potential in detecting wrong engine and/or catalyst settings and possibly defective components. In this respect it was examined if emission measurements under load may be better at identifying faults than measurements at idle speed. Evaluation of the test results was conducted with a methodology aimed at the maximisation of high emitter identification, with minimum burden to the citizens.

The focus of the study was on catalyst-equipped cars of current technology, as these will constitute the major part of the vehicle stock in the following years, i.e. when it is envisaged to introduce enhanced I&M schemes at European level. Nevertheless, conventional spark-ignition and diesel cars were also covered (to a lesser extent) by the project.

The study was funded by the European Commission – Directorates General for Transport, Energy and Environment and several institutions from different countries participated in the experimental and evaluation phase of the project.

Test Protocol

As a first step a number of visual checks were performed before the emission test started, in order to ensure that specific components of the car existed and/or operated properly. At a second step, the certification cycle (NEDC) was run 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 are normally carried out under hot operation conditions. In addition to the legislated cycle, the 'Modem' cycle (a 'real-world' cycle developed on the basis of large scale driving behaviour measurements) was also driven, to be used for the further evaluation of the effectiveness of I&M schemes.

Following the long cycles, the TÜV and 'Modem short' cycles (two transient short tests developed in the framework of the study) were performed.

The short cycles were followed by a no-load test at idle and fast idle and finally by a steady state loaded test at 50 km/h and 7 kW power absorption.

As regards the emission measuring equipment, both continuous pollutant concentration measurements either in the raw or in the diluted exhaust gas and average bag values were used. In addition, two types of analysers were used: laboratory quality analysers and garage type ones. Finally, simplified laboratory equipment was used for the transient loaded short cycles, in order to investigate the possibilities of employing such equipment in real-world test lanes.

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 fleet per country and the future trends.

However, since the purpose of the exercise was also to identify gross emitters, a minimum share of high emitters was also necessary, which was initially specified to be of the order of 20 % of the total vehicle sample. 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. Eventually the percentage of non-randomly selected vehicles was about 30 % of the total as it was very difficult to find high emitters among the random sample and even among the likely high emitting groups.

The sample eventually comprised of 196 TWC Euro I cars (including 17 LPG), 34 non-catalyst and 7 oxidation catalyst equipped cars, which were treated together as one group, and 28 diesel cars.

Remote Sensing

In parallel to the laboratory tests, remote sensing was conducted in a number of European cities, where more than 80 000 cars were checked. In conjunction with the remote sensing measurements, 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.

General Approach

Figure 1 below presents schematically the basic concept upon which the evaluation of short tests was based and it is a correlation chart between each short test and the type approval cycle as regards a particular pollutant. Actually there are as many such charts as the number of pollutants measured over each short test. The first horizontal line represents the emission standard (conformity of production), while the above parallel line a percentage above it. This line has been drawn in order to distinguish the high (groups 3 and 4) and the very high polluters (groups 5 and 6). The vertical line, which is referred to as cut-point, is a limit for approving or not a vehicle according to each short test.

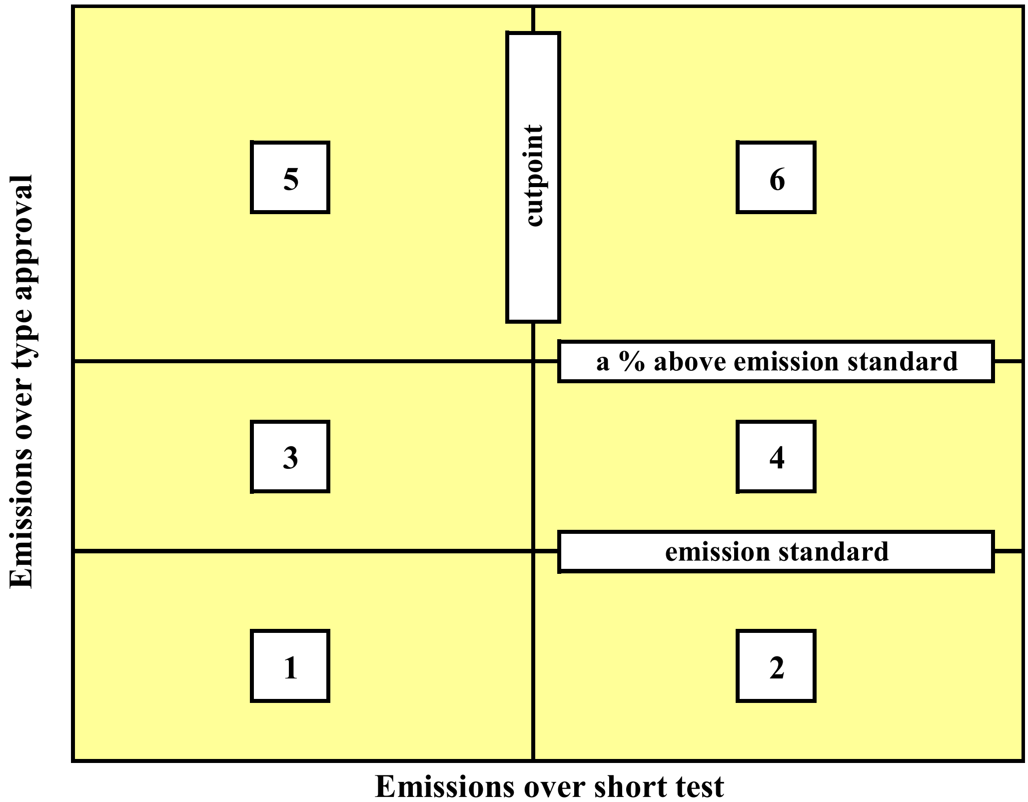


Figure 1: Correlation chart

The group 1 vehicles are referred to as low polluters, while the very high polluters of group 6 are referred to as vehicles to be sent to maintenance. The vehicles in group 2 are the errors of commission while those in group 5 are the errors of omission.

The basic concept of this methodology is to identify the vehicles in group 6, send them to maintenance and make them emit afterwards as the low polluters in group 1. Such approach assumes that all vehicles sent to maintenance receive the best repair, i.e. after maintenance the vehicles emit the same as if they were brand new. Actually, this does not always occur and this is the reason why the achieved emission reduction is referred to as 'potential'. The vehicles in group 2, which are also detected by the short test are not taken into account, since they are actually low polluters and they emit the same after maintenance as well. These vehicles may have an effect on the cost of the programme since the maintenance team is searching for faults, which do not actually exist. The environmental benefit after maintenance of the vehicles of group 4 is supposed to be quite small and it is not taken into account, since the malfunction of these vehicles seems to be minor and perhaps non repairable. This applies when the percentage above standard for considering a vehicle as a very high polluter is not too high (e.g. 50 %) and it is the worst case assumption. Therefore these vehicles are also referred to as vehicles with low environmental benefit.

The parameters that have been taken into consideration and characterise a short test are (a) percentage of errors of commission (P2), (b) percentage of vehicles to be sent to maintenance (P6) and (c) environmental benefit according to Modem 'actual' cycle (Emission Reduction Rate Potential: ERRP). P2 should be minimum (legal protection of citizens), P6 should be minimised as well (minimum number of vehicles maintained), while ERRPs should be maximised (environmental benefit). These parameters characterise adequately the short test without taking into account the errors of omission, because the main objective is an acceptable reduction of the emissions with the minimum cost.

Three Way Catalyst Cars

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 NO_x 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 NO_x) or both HC and NO_x (i.e. being low emitters in CO). This means that HC gross polluters emit high CO as well and thus may be captured via this pollutant.

The short test legislated in the EU by Directive 92/55/EC was found to be ineffective in environmental terms. It can identify only 15 % of the high polluters, while the environmental benefit from it (ERRP) does not exceed a 4 % emission reduction in any of the pollutants involved. Especially as regards the air/fuel ratio test, it was found to add in the direction of NO_x emitter identification, having the drawback of increasing the errors of commission. There is virtually no improvement if a HC measurement is added to the current CO measurement at idle and high idle. However, the efficiency of this test clearly increases with increasing share of gross polluters in the fleet. This is demonstrated in the case of the whole sample, where the 92/55/EC test was found to be 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 NO_x on the basis of the random vehicle sample.

Most gross polluters (and consequently the major part of emission reduction potential) 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 NO_x measurement is almost confined to NO_x emissions only: via NO_x measurement 40 % of the total NO_x emission reduction potential is achieved. It adds about 5 % to the CO and HC emission reduction potential. However, NO_x 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 (in the order of ± 2 %).

The two short transient cycles used in the programme were found to be equivalent in identification of high emitters. The transient test can be performed either with a constant volume sampling (CVS) and bag system in order to measure mass emissions, i.e. like the certification test, or with continuous measurement of the raw exhaust gas concentrations. A simplified dynamometer set-up 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 emissions measurement is performed under hot conditions, the effect of ambient temperature on the test results is negligible.

2.2.3 UK National Audit Office report

The study [11] is about the effectiveness of the regime for the in-service testing of vehicle emissions in England, Scotland and Wales (Britain), which is the responsibility of the Vehicle Inspectorate, an agency of the Department of the Environment, Transport and the Regions.

It focuses on the in-service testing, both annual and roadside, of vehicle emissions in Britain, on the roles of the Vehicle Inspectorate and the Department of the Environment, Transport and the Regions, and examines:

- The design of the current emissions testing regime and its fitness for purpose;
- How emission tests are carried out in practice; and
- The impact of vehicle emissions testing.

Design and fitness for purpose of the emission testing regime

Subject of examination:

- The consistency of emissions testing with the policy framework for air quality, especially whether emissions tests cover those pollutants which pose the greatest risk;
- Whether the extent and frequency of emission testing is matched to the vehicles most at risk of polluting;
- Whether current technology is sufficiently accurate and reliable as a basis for testing.

Practical application of the testing regime

Most vehicles must undergo an annual emissions test, as part of annual roadworthiness tests. Passenger cars and light duty vehicles over three years old are tested by private garages around Britain, as part of the annual Ministry of Transport (MOT) test. Inspectorate staff tests all heavy duty vehicles and public service vehicles at one of the Inspectorate's testing stations or at one of the privately owned 'designated' premises, as part of the annual statutory tests.

Data on actual emission levels are not routinely collected as part of the annual test. The computerisation of the MOT scheme will enable actual emissions to be recorded automatically. Therefore, the emission levels recorded at annual tests carried out in August 1998 were analysed, in a sample of garages and Inspectorate testing stations around Britain covering a total of 2 500 tests. The analysis conducted showed that:

- Testers' pass or fail decisions were consistent with the emissions level recorded, and with the legal limits;
- The distribution of test results was consistent with what might be expected. The average level of emissions was below the test limit and the proportion of test results above the legal limit was broadly consistent with the annual failure rates reported by the Inspectorate.

Non-catalyst petrol tests and diesel tests did not reveal any anomalies. However, over a quarter of catalyst petrol tests in the sample recorded zero emissions. A quarter of garages recorded zero results in at least 40 % of cases. Whilst a zero is technically possible, since vehicles with very low emissions may record this result due to the imprecision of test equipment, the high proportion of zero results and their concentration in some garages suggests that test equipment was not working or was not being used properly.

All vehicles may also be tested in-year at roadside emission tests, though public service vehicles tend to be checked at vehicle operators' premises or other suitable locations. The Inspectorate carries out most of these checks. In 1997-98 it carried out 117 000 roadside tests on all categories of vehicles, around 0,5 % of all testable vehicles.

Vehicles found to have excessive emission levels at roadside tests are issued a prohibition notice. The prohibition notice should be cleared at a police station on presentation of a new valid test certificate for passenger cars and light duty vehicles within 10 days. Prohibitions of heavy duty vehicles are cleared by correcting the fault and re-presenting the vehicle for testing by the Inspectorate within 10 days. Total prohibition rates for emissions have fallen from 6 % in 1995, when roadside testing was introduced, to 3,5 % in 1998.

Current roadside testing by the Inspectorate is neither random nor fully targeted. A random selection of vehicles would provide useful information about emission compliance in general. Better targeting might be achieved by use of remote sensing equipment to identify possible gross polluters for roadside testing although this would entail the significant additional cost of the equipment.

The Inspectorate requires its vehicle examiners at roadside tests to allow 10 % tolerance above the emission standards used in the annual test. This tolerance is meant to reflect the imprecision inherent in the testing equipment, an allowance for in-year deterioration in emission performance, and the less than ideal conditions in which roadside tests are conducted (for example, test results can be affected by weather conditions). Examiners are expected to apply prescribed standards, although the Inspectorate allows its examiners to use 'engineering discretion' to pass vehicles which are more than 10 % above the annual test limits, where they believe the vehicle could pass the emissions test under other conditions.

An examination on a sample of Inspectorate roadside checks carried out in one region in 1997-98 showed that examiners made considerable use of engineering discretion. Whilst 19 % of vehicles were above the annual test limits and 15 % of vehicles were more than 10 % above the annual test limits, only 7,6 % of vehicles were actually prohibited. This may partly explain the regional differences in prohibition rates at roadside checks. Prohibition rates in 1997-98 ranged from 1,9 to 9 %. It seems unlikely that these variations can be wholly explained by regional differences in the vehicle fleet, although they may be due in part to different regional approaches to targeting vehicles for roadside tests.

Since January 1998, seven local authorities have been involved in a trial scheme giving them the authority to carry out roadside tests. Local authorities have imposed a fixed penalty on 7,7 % of vehicles tested whereas the prohibition rate at Inspectorate checks is just 4 %, although the same tolerance is recommended in both cases. This is almost certainly because local authorities make less use of engineering discretion to pass vehicles over the 10 % tolerance limit.

The impact of emissions testing

There are no explicit objectives or targets for the effectiveness of emissions testing and current measures of performance are of limited use. Nonetheless the regime must ensure compliance with European and UK law.

Recent Department figures show that around 3 % of all vehicles evaded vehicle excise duty and therefore the annual roadworthiness and emissions test. The evasion rate for heavy-duty vehicles is thought to be lower than this at around 1 %.

Of those vehicles that take an annual test, the great majority comply with legal emissions limits. The average recorded failure rate at annual tests for vehicles of all types fell from around 11 % in 1992-93 to 6,4 % in 1997-98. In each year, the failure rate for heavy-duty vehicles and public service vehicles was around 2 %, but failure rates for passenger cars and light duty vehicles (other than those equipped with catalysts) were much higher (between 6 and 11 %).

However, the annual test failure rates reported by the Department and the Inspectorate are not a measure of the proportion of vehicles which fail to comply with legal emissions levels at an annual test. One reason is that the reported failure rates exclude the 3 % of vehicles which evade the test. Moreover, where a vehicle fails several tests before passing, testers are expected to record and report each separate fail result and the reported statistics show the proportion of tests failed, not the proportion of vehicles that never achieve a pass result. In practice, many cars require more than one test before they are passed. For example in 1997-98 there were 27 million tests on 22 million eligible vehicles, which means that the reported failure rates overstate the proportion of eligible vehicles failing to comply annually with the legal limits. From a survey of garages, it was found that 3 % of vehicles (around 700 000) fail the test and leave the garage with emissions in excess of the legal limits. However, it was not possible to discover how many of these vehicles were subsequently rectified or retested and achieved a pass at another garage. It is likely that many were retested and passed elsewhere, and that only a minority of the 3 % continued to be driven without a valid test certificate. The vast majority of vehicles which are submitted for test eventually achieve a pass result.

Annual compliance leads to the rectification of many vehicles. According to the above survey 25 % of vehicles tested were rectified before or during the annual test mainly because of the need to pass the annual emissions test. Whilst the deterrent effect of roadside tests on vehicle owners in general cannot be estimated, the tests do at least require rectification of those vehicles which fail. In 1997-98 some 4 700 vehicles of all classes were required to be rectified after failing roadside tests.

There are no data currently available on the proportion of vehicles which are removed from the roads because they fail the emissions test. However, this proportion is likely to be low because the necessary repairs and retuning to rectify an emissions problem are usually relatively inexpensive. Whilst around 1,4 million vehicles are scrapped each year in Britain, it is unlikely that emissions performance will be a major factor in the decision to scrap a vehicle.

According to the same survey of garages it was found that the proportion of high emitters lies somewhere between the less than 3 % which leave testing stations having failed the test (some of which may be repaired and retested at a later date) and the 28 % which would fail (a year later) if they were not serviced prior to the test. A small percentage (less than 3 %) must be added to these figures to reflect the number of vehicles which are never tested because they evade the test and may be high emitters.

Annual and roadside test results suggest a pattern of vehicle emissions performance deteriorating from less than 3 % failure at the annual test to 28 % a year later, with in-year failure rates in between.

The significant in-year deterioration in emissions performance of the vehicle fleet supports the UK practice of annual testing rather than biennial testing allowed by the

European Commission. This in-year emissions performance also suggests that there is scope for roadside testing to have greater impact.

The study concluded that the current testing regime was the most cost-effective option, with little to be gained from an investment in more sophisticated and costly testing technology, "*except for the possible introduction of dynamic loaded tests for catalyst cars*". It also concluded that dynamic loaded tests would only become cost-effective when catalyst cars constitute a larger proportion of the vehicle fleet and if they were tested at centralised inspection stations rather than at local garages.

2.3 I&M programmes

Most of the I&M programmes currently in force in the EU use idle tests according to Directive 92/55/EC and result in % failure rates of the vehicles subject to periodic inspection and in % concentrations of pollutants at low and high idle.

The Swedish annual mandatory inspection is a typical I&M scheme common to most EU countries, e.g. Finland [12]. It involves CO concentration measurements at low and high idle, HC concentration measurements at low idle and lambda test at high idle.

As an example, data deriving from 743 937 gasoline passenger cars coming for periodic inspection between February and September 1999 were evaluated [13]. The sample was divided into 9 categories consisting of vehicles of the same model year (MY). The percentages of vehicles failing the emission test and the average values for each of the failure criteria for each category are presented. The failure rate of the total sample (MY 1989 to 1997) was found to be as low as 2,4 %.

2.4 Evaluation of an emission testing policy

There are two primary directions on which to base the evaluation of an emission testing policy. Firstly to increase the confidence to its results by correctly identifying the high polluters and avoiding errors of omission and commission and secondly to simulate ageing effects and hence to derive emission level improvements (e.g. by vehicle servicing or fleet renewal frequency increase).

2.4.1 Correlation to the type approval

The most important issue of any emission testing policy is to correctly identify all high polluters, send them to maintenance and make them emit afterwards as the low polluters. The basic concept of this approach has been already discussed in section 2.2.2 (see also Figure 1). The resulting correlation enables the identification of the low and the high polluters as well as the errors of commission, which are wrongly detected by the in-use emission policy, and the errors of omission, which are wrongly not detected. The errors of commission and omission should be as low as possible with regard to legal protection of citizens and environmental benefit respectively.

If short cycle tests are to be included in an enhanced I&M scheme, the correlation of the short tests to the type approval test has to be determined [14]. Figure 2 shows an example of the evaluation of short cycle tests.

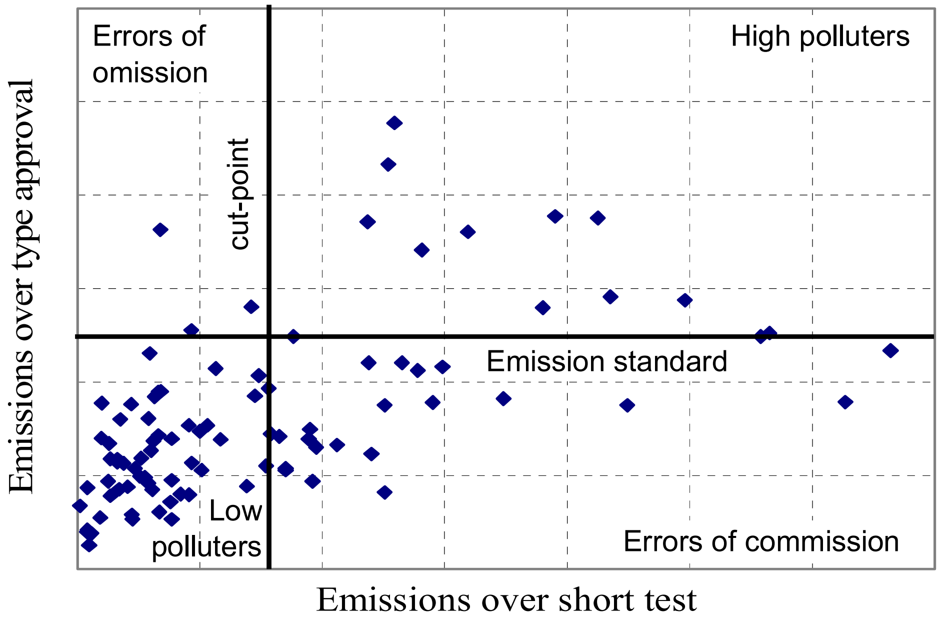


Figure 2: Evaluation of short tests

2.4.2 Simulation of ageing effects

It has been shown that emissions from vehicles (except of CO_2) are dependent on the mileage they have been driven [15]. The quantification of mileage effect on emissions is necessary in order to provide information for the evolution of emissions for different policy options, e.g. fleet renewal scenarios by promotion of fiscal incentives for the replacement of older vehicles.

For simulating these deterioration effects degradation functions are utilised as shown in Figure 3. The degradation functions are derived on the basis of in-use vehicles emission testing and are approximated with increasing linear functions of mileage, while emissions tend to stabilise at the higher mileage region [16]. Such emissions functions of fleet mileage should be seen as the product of the combined effect of normal degradation of the emission control system and of the increased probability of high-emitters, as fleet mileage increases.

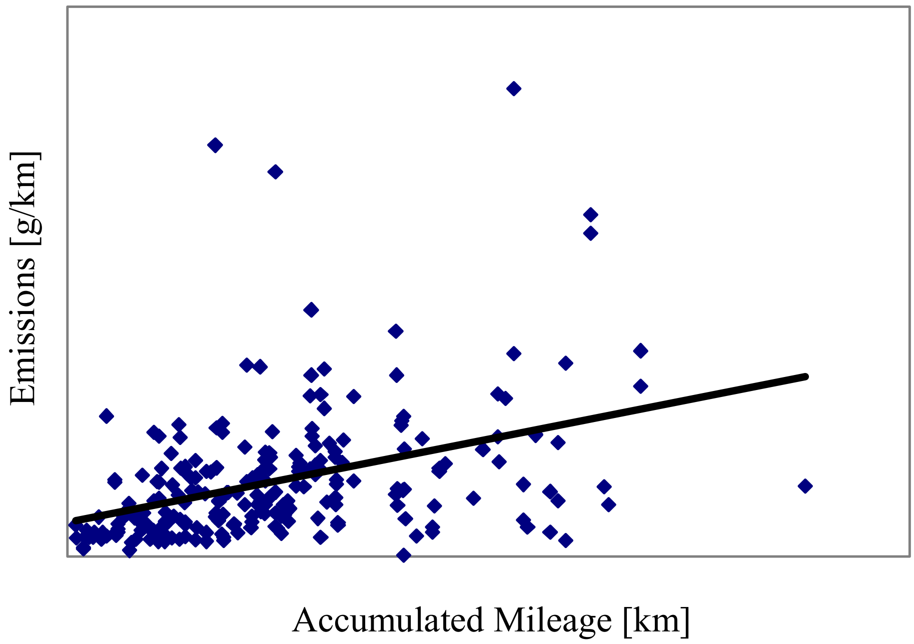


Figure 3: Degradation line

As well as the immediate impact on the emission testing, it is also important to take account of the deterioration rate in emissions performance in the interval between emission tests. This will affect the average level of emissions over the interval as a whole, and will also be relevant in determining the most appropriate frequency of testing. In the case of periodic inspection the value and impact of passing the I&M test would be severely diminished if vehicles emissions quickly deteriorated after leaving the test station.

Figure 4 shows the effect of mileage on CO emissions of a large sample measured over the EUDC. Three different mileage regions are identified. The first includes vehicles driven for less than 10 000 km. Those vehicles are supposed to be in their ‘run-in’ phase. The second region constitutes of vehicles in the range of 10 000 to 100 000 km. This region includes the majority of passenger cars in circulation in the European countries. The third region constitutes of relative older vehicles with more than 100 000 km odometer reading. The inclination of the degradation line of the first and the second region has been defined by regression analysis on the basis of the available sample.

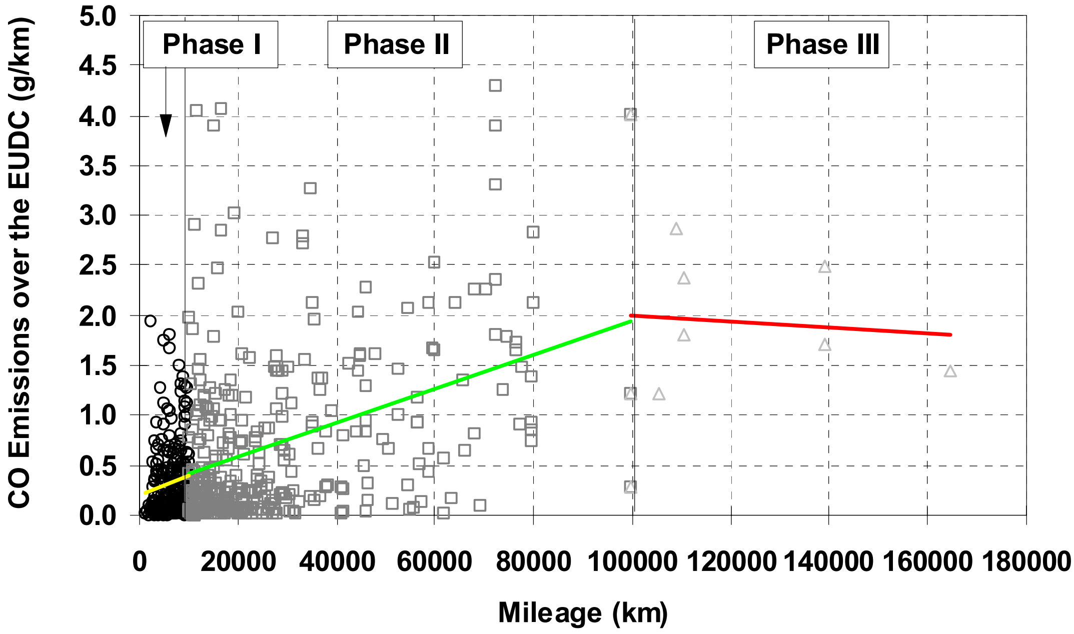


Figure 4: Effect of mileage on the CO emissions

The degradation lines are normalised according to the average mileage of the sample. This means that they should not modify the value of the emission function when applied for an equal mileage to the average mileage of the sample. To eliminate the danger of overestimating the influence of mileage on emissions, mileage limits have been set for the application of the degradation lines. The above figure shows that the uncertainty is higher at the end-tail of the line. The exact end of continuity is difficult to define because of the insufficient sample at high mileage. After this point it is assumed that emissions remain constant mainly because of emission regulating systems or engine repair.

2.5 Linkage between the emission testing-related activities

The three types of activities described in section 2 have been rather independent so far. However, there have also been some attempts to link the above activities. The MEET methods have made use of data collected from many national and international studies (e.g. the JCS study), mainly in Europe. Moreover, the German study has used techniques and models already developed in the framework of national emission factor development programmes (e.g. TREMOD).

From the description of the emission testing-related activities it is easily recognised that the information collected within the inspection centres has the potential of regular and constant emission behaviour monitoring. The question is though what could be done in the framework of the current activities of the inspection centres in order to utilise the data resulting from the periodic inspection and thus making better use of the inspection centres themselves. That means the information on emissions collected from the inspection centres is valuable as regards the current condition of the in-use fleet but cannot be further utilised for the proper evaluation of other emission testing policy options. If the resulted percent failure rates and concentrations of pollutants at low and high idle could be correlated to emissions in grams per kilometre then the data coming from the inspection centres would be more useful. However, it was inherently known that such a correlation couldn't be achieved.

Based on the results of the JCS study Figure 5 shows the attempted correlation between CO concentrations at idle speed (in %) and CO emissions over the Modem cycle (in g/km) [17]. The correlation line is mainly determined from the few high polluters, while there is a very large concentration of emission data in the lower part of the figure.

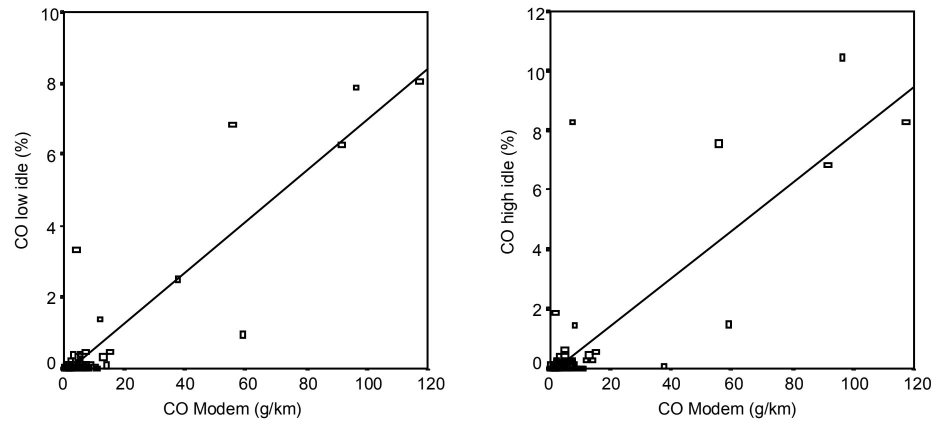


Figure 5: Correlation between CO concentrations at idle/high idle and CO emissions over the Modem weighted

While the above figure shows that there is hardly any correlation between the percent concentrations of the idle tests and the emissions derived over a long cycle, loaded short tests proved to exhibit acceptable correlations to the type approval (hot but also cold-start) as shown in Figure 6. The latter shows a wider scatter of the CO emissions, which enables the correlation line to be defined more precisely.

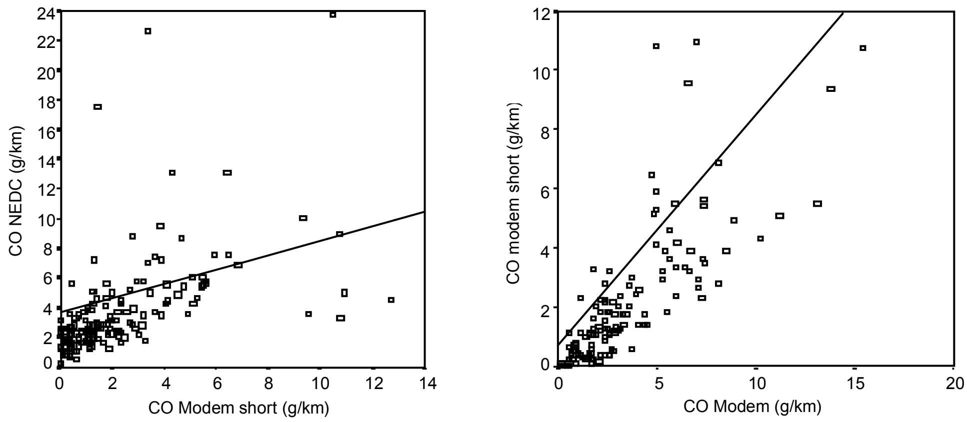


Figure 6: Correlation between CO emissions over two short cycles and over the Modem weighted

The conclusion of the three I&M evaluation studies as regards the Roadworthiness Directive 92/55/EC significantly differentiate from each other. According to the UK study the current Directive is very effective in identifying high emitters resulting in considerable high emission reductions. The German study claims similar emission reductions though some reservations regarding the possible effectiveness of an enhanced I&M scheme are quoted. On the contrary, the JCS study concludes that the current Roadworthiness Directive is completely ineffective for the TWC fleet.

From the three I&M evaluation programmes described in section 2.2 the UK study is only based on calculation analysis with lots of assumptions while the JCS- and the German studies are based on comprehensive and complementary emission testing.

In the following the JCS study and the German study are closer examined and compared in order to determine their similarities and differences and thus to evaluate their methodologies.

3 Comparison of the German- and the JCS study

3.1 Main differences

The main differences of the two studies can be identified in the vehicle sample selection, the test programme conducted and the calculation method used.

3.1.1 Vehicle sample selection

In the JCS study the test sample consisted of randomly selected vehicles and a percentage of deliberately chosen high emitters. An assessment of the vehicles' representativity of the fleet cannot be accomplished due to the random manner of the selection.

Only vehicles failing the AU procedure were accepted in the sample of the German study. Though most of these vehicles were expected to be high polluters, the actual share of the high polluters and the errors of commission is unknown. The vehicles were selected according to the AU-criteria they failed (CO content at low and high idle, lambda control at high idle and loop control) and the contribution of the latter in the failure rate of the total fleet and thus the representativity of the sample is assessed.

3.1.2 Testing programme

Both full cycle tests and short tests were performed in the as-received sample of the JCS study. All types of short tests, including idle-, loaded static- and transient tests were performed and evaluated as part of the testing programme. A small number of vehicles was sent to maintenance and was then retested.

In the framework of the German study only a limited number of full cycle- and short tests were performed. From the available short tests only idle tests were performed as part of the evaluation of the current AU procedure, while long cycles were used in order to derive emission factors. Moreover, the vehicle sample was tested twice, before and after maintenance.

3.1.3 Calculation method

The emission reduction calculation proposed by the JCS study is internally consistent, as it only needs data from the vehicle sample selected. The failure rate of the sample, though it can be calculated, is not necessary for the calculations involved. Moreover, it is assumed that all vehicles sent to maintenance receive the best repair, i.e. after maintenance the vehicles emit the same as if they were brand new and thus the achieved emission reduction is referred to as 'potential'.

In order to perform the calculations as suggested by the German study, data regarding the whole fleet are necessary as well. More specifically, data on the mileage, the failure rate and the total emissions of the fleet subjected to AU are needed for the calculations. The vehicle sample is only used for the production of emission factors before/after maintenance and the actual emission reduction is thus calculated.

3.1.4 Comparison of the results

According to the JCS Study, the Directive 92/55/EC detected 8,7 % of the random sample as high polluters. The potential emission reduction calculated was 4,7 % for CO, 0,9 % for HC and 3,8 % for NO_x.

According to the German study, a mean failure rate of 5,1 % was found for TWC vehicles. Defective TWC vehicles emit 4,8 times higher for CO, 3,9 times higher for HC and 2,4 times higher for NO_x than repaired vehicles. The emission reduction achieved by repair was 13,3 % for CO, 11,7 % for HC and 5,9 % for NO_x (incl. cold start).

3.2 Comparability of the calculated emission reductions

From the results presented above it is obvious that there are some variations in the calculated emission reductions. While these variations are small in the case of the failure rate and the NO_x emissions, they are considerable for the CO- and especially for the HC emissions.

Before examining the possible effect of the selected vehicle samples on the results, the influence of the differences in the applied methodologies, as they are presented in Annex A, has to be investigated.

From the 8,7 % of the vehicles detected by Directive 92/55/EC within the JCS study, 5 % were the actual high emitters and thus sent to maintenance, while the rest are the errors of commission. From the 5,1 % of the vehicles that failed the AU test, the share of the actual high emitters and the errors of commission is unknown.

As already mentioned above, the vehicle sample of the JCS study is only tested as-received and the emission reductions thus calculated are based on the difference in emissions between the low and the high polluters. On the other hand, the vehicle sample of the German study is tested twice and the emission reductions thus calculated are based on the difference in emissions before and after the maintenance.

The potential emission reductions calculated according to the JCS study refer to the whole TWC fleet, while the emission reductions achieved according to the German study refer only to the TWC fleet subjected to AU in 1997 (MY 1988, 1990, 1992 and 1994).

From the above it is obvious that the emission reductions calculated by the two approaches are not directly comparable.

In order to evaluate the suggested methodologies and the results accompanied, two cases are studied. In the first case data from the German study are used to calculate the Emission Reduction Rate Potential according to the JCS study. In the second case data from the JCS study are used to calculate the efficiency of the AU procedure according to the German study.

3.2.1 Case 1

In order to calculate the emission reduction potential as suggested by the JCS study, the emission factors of the low and the high polluters as well as the number of high polluters in the sample need to be known.

As already mentioned the vehicle sample from the German study consists only of vehicles failing the AU procedure but the exact number of high emitters and errors of commission in the sample is unknown and thus the method can not be applied.

In order to assess the likely effect of a high share of high polluters in the sample, all AU-failed vehicles are considered high polluters for the respective calculations. Moreover, the emission factors before/after maintenance of the sample are considered as emission factors of the high and the low polluters respectively.

As expected, the ERRPs calculated are very high, in the order of 59 % for CO, 57 % for HC and 38 % for NO_x. As this case of a sample consisting of equal numbers of low and high polluters is not realistic it is no further examined.

3.2.2 Case 2

Three vehicle samples coming from the JCS study were used for the calculation of the AU efficiency according to the German study:

- Random sample (135 vehicles);
- Sample of retested vehicles (52 vehicles);
- Sample of vehicles failing the IM test and being retested (24 vehicles).

The calculations are performed using the indexes described in Annex A and giving the following values to the failure rate:

- 20,9 % (Failure rate of the total sample);
- 8,7 % (Failure rate of the random sample);
- 5,1 % (Failure rate of the German AU);
- 2,4 % (Failure rate of the Swedish IM programme).

Because of the relatively small samples, the distribution into road- and vehicle classes could not be established as required. The total mileage needed for the calculations was taken from TREMOD.

3.3 Results

An overview of the results and a short description on the calculations performed is presented in Table 1.

Table 1: Results of the calculations performed based on case 2

Random sample (135 vehicles)	HC	CO	NO_x	CO_2	
Emission factors of high polluters [g/km]	0,328	5,190	0,591	169,329	
Emission factors of low polluters [g/km]	0,235	1,694	0,269	203,259	
Effect of maintenance [%]	92%	94%	36%	100%	
Potential reduction in emissions [%]	8,01	23,26	4,27	-3,69	For α= 20,9%
	3,33	9,68	1,78	-1,54	For α= 8,7%
	1,95	5,68	1,04	-0,90	For α= 5,1%
	0,92	2,67	0,49	-0,42	For α= 2,4%

Total sample retested (52 vehicles)	HC	CO	NO_x	CO_2	
Emission factors before maintenance [g/km]	0,98	14,65	0,62	213,53	
Emission factors after maintenance [g/km]	0,43	3,12	0,45	224,43	
Actual reduction in emissions [%]	51,91	81,64	5,99	-1,19	For α= 20,9%
	21,61	33,98	2,50	-0,49	For α= 8,7%
	12,67	19,92	1,46	-0,29	For α= 5,1%
	5,96	9,37	0,69	-0,14	For α= 2,4%

Failing IM test (24 vehicles)	HC	CO	NO_x	CO_2	
Emission factors before maintenance [g/km]	1,28	23,74	0,58	186,41	
Emission factors after maintenance [g/km]	0,38	4,33	0,48	200,89	
Actual reduction in emissions [%]	85,10	137,43	3,99	-1,57	For α= 20,9%
	35,42	57,21	1,66	-0,66	For α= 8,7%
	20,76	33,54	0,97	-0,38	For α= 5,1%
	9,77	15,78	0,46	-0,18	For α= 2,4%

3.3.1 Random sample

From the 135 vehicles of the random sample 12 vehicles were detected by the idle tests, but only 7 were high polluters. From the remaining vehicles 74 were low polluters. Emission factors were determined for both the low and the high polluters and were used in the place of the emission factors before/after maintenance for the calculations.

In order to calculate the 'potential' emission reduction, the effect of maintenance was also taken into account for the calculations (94 % for CO, 92 % for HC and 36 % for NO_x).

Taking the failure rate of the random sample (8,7 %), the potential emission reduction is 9,7 % for CO, 3,3 % for HC and 1,8 % for NO_x. It has to be stressed though, that the low value for NO_x can be mainly attributed to the low effect of maintenance for NO_x (36 %).

3.3.2 Sample of retested vehicles

52 vehicles of the total sample were retested after being repaired, regardless of passing or failing the idle tests. 22 of them were from the random sample and 30 from the high emitters. Emission factors were determined before and after maintenance.

The emission reduction achieved by repair was 19,9 % for CO, 12,7 % for HC and 1,5 % for NO_x for a failure rate of 5,1 %. When a different failure rate is chosen, the emission reductions change proportionately.

3.3.3 Sample of vehicles failing the IM test and retested

From the vehicles failing the IM test, 24 vehicles were retested. 5 vehicles were from the random sample and 19 from the high emitters. Emission factors were derived before and after maintenance.

The emission reduction achieved by repair was 33,5 % for CO, 20,8 % for HC and 1 % for NO_x for a failure rate of 5,1 %. When a different failure rate is being chosen, the emission reductions change proportionately.

3.3.4 Remarks on the above results

From the above it is obvious that the emission reductions achieved are directly correlated to the failure rate of the sample selected. As Figure 7 shows, the potential emission reduction is a linear function of the failure rate of the sample.

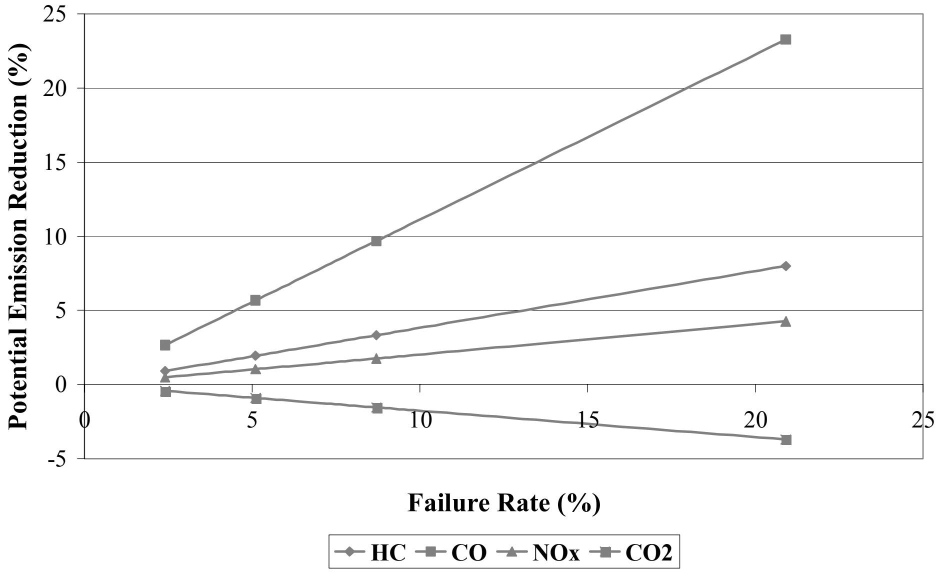


Figure 7: Correlation of ERRP and failure rate

From the results presented above the following emission reductions achieved can be considered as most comparable to those of the German study:

Table 2: Summary of the most representative results

	α	CO	HC	NOx
Random sample	8,7 %	9,7 %	3,3 %	1,8 %
Retested sample	5,1 %	19,9 %	12,7 %	1,5 %
IM-failed and retested	5,1 %	33,5 %	20,8 %	1,0 %
German study	5,1 %	13,3 %	11,7 %	5,9 %

As shown in Table 2, the largest deviations from the German study in the emission reductions calculated when different samples of the JCS study are applied to the German study's method can be observed for NO_x. The main reason for the above differences in reductions seems to be the selectivity of the vehicle sample.

4 Conclusion

4.1 Assessment of the used methodologies

As mentioned in section 2.4 the proper evaluation of an emission testing policy should be based on two main directions, i.e. the correlation to the type approval and the simulation of ageing effects.

The methodology proposed by the JCS study has the advantage of enabling the assessment of all four groups of the correlation chart of Figure 2 and thus emissions factors for both low and high polluters can be calculated. This provides a better assessment of the emission status of a vehicle fleet representing a certain vehicle technology.

On the other hand, the German study does not take into account the vehicles passing the AU test, though there might be some high polluters among them (errors of omission). The correlation chart thus consists only of high polluters and errors of commission.

Figure 8 shows that the correlation chart may vary as regards the share of the real high polluters and the errors of commission. However, this parameter is not taken into account in the evaluation of the AU procedure as the vehicles are sent to maintenance in any case. The efficiency of the procedure is then determined only from the emission factors before and after the maintenance.

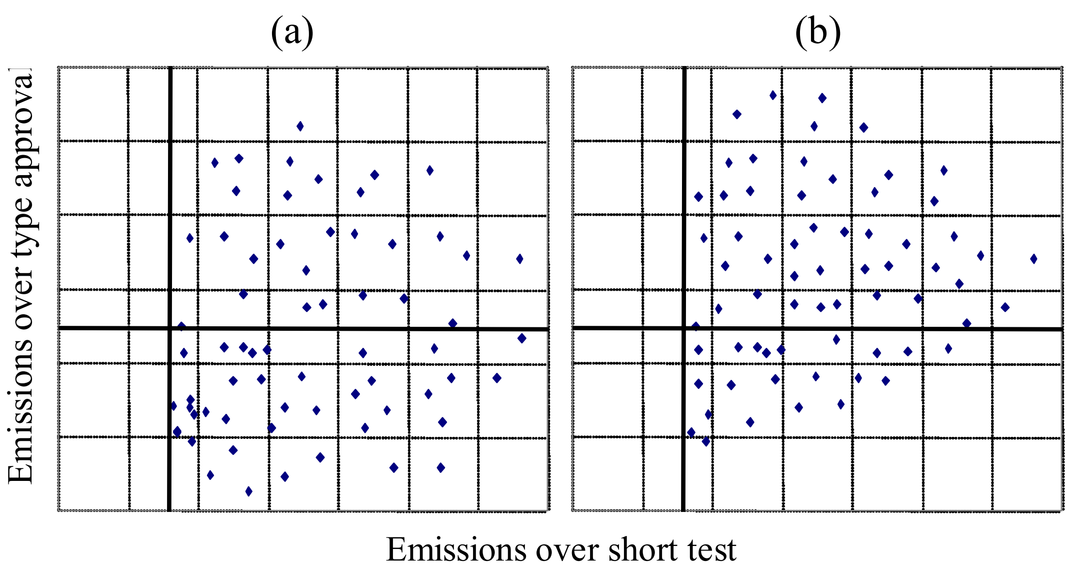


Figure 8: Correlation charts of samples failing a short test (a) high share of errors of commission and of high polluters (b) high share of high polluters – low share of errors of commission.

Although emission factors for both low and high polluters can be calculated, they will not be representative of the fleet as they will be derived only from vehicles failing the AU test.

As regards the simulation of ageing effects, the JCS approach enables the determination of the emission degradation with mileage as it provides emissions information on in-use vehicles, which are randomly chosen and are covering large mileage regions. An overview of the emission status of the fleet is thus given and the effectiveness of the implemented policy can be assessed.

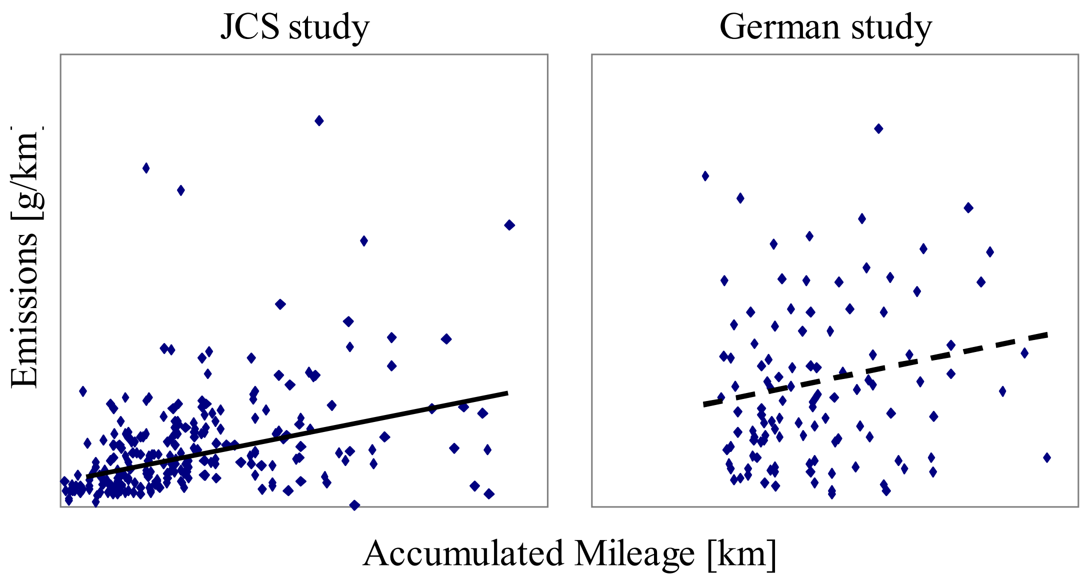


Figure 9: Degradation lines of two approaches. Left based on the JCS study – right based on the German study

The degradation line deriving from the German approach is less informative as Figure 9 shows. The inclusion of AU-failed-only vehicles provides information on the emissions performance of vehicles before and after maintenance but it does not provide any information on the whole fleet, including all those vehicles passing the AU test and thus not needing to be repaired. The lower mileage region is not covered, as new vehicles have to undergo an AU test three years after their registration.

4.2 Assessment of the necessary data

The emission collection programmes examined in section 2 provide some results gathered from small numbers of vehicles but there is still not much data about the in-use performance of vehicles with the latest technology (e.g. Euro III, IV).

As already mentioned the failure rate of Euro I and II vehicles is known to be higher when an enhanced I&M scheme is adopted as compared to the Roadworthiness Directive. The number of high emitters identified by the latter and the environmental benefit accompanied are expected to be even lower for Euro III and IV vehicles.

However, more experimental data from vehicles with the latest technology are necessary to support the above argument

Legislation calls for increased emission conformity up to 80 000 km (Euro III) and 100 000 km (Euro IV) and requires extended catalyst durability. It is reasonable therefore to expect that the degradation rate of Euro III and IV vehicles will decline compared to Euro I ones. Most probably, not only hot emissions but also cold start related emissions will be affected by the additional legislation requirements. However, in view of the lack of experimental data, one may assume that the degradation of Euro III & IV vehicles can be best approximated by the degradation of Euro I vehicles, when an enhanced I&M scheme is adopted. In other words, it is assumed that on board 'inspection' will have the same results with an enhanced I&M scheme.

In order to model the degradation of Euro III and IV vehicles, the reductions originating from the application of an enhanced I&M scheme are applied to the degradation of Euro I vehicles. Although one may claim that relative emission degradation of recent vehicle technologies may eventually stabilise at a lower level than that of older vehicles, experimental data are not sufficient to support this argument.

Figure 10 gives an example of the NO_x degradation of 604 in-use vehicles tested over the hot UDC [16].

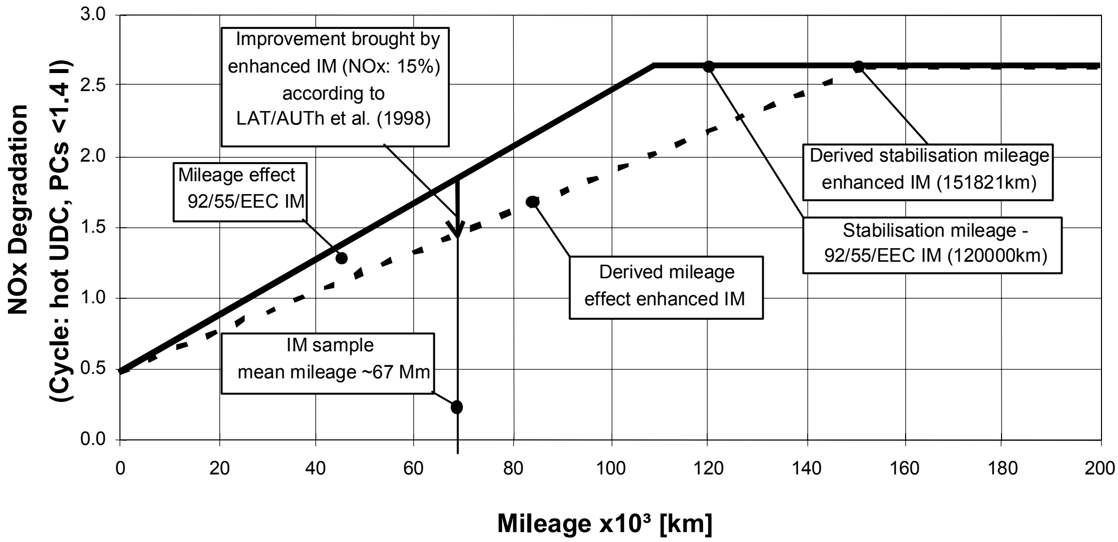


Figure 10: Mileage effect on mean fleet emissions. Bold line corresponds to measured data from MEET; it represents emission degradation of current vehicles. Broken line is produced using the expected emission reduction based on the JCS study at ~68 000 km and assuming the same starting point at 0 km; it represents expected degradation if an enhanced IM was introduced.

4.3 Final assessment of the I&M evaluation programmes

The main outcome of the comparisons presented in section 3 is that there are considerable variations in the findings among the I&M evaluation programmes. Apart from that, the major drawback of the presented approaches is the lack of statistical representativity. More specifically:

The UK study is only based on statistical analysis and calculations without any hard experimental facts. The evaluation of the national I&M scheme is only based on already available data from the inspection test lanes while no other emission testing policy option is investigated.

The major issue of the German study is the identification rate of the high emitters. The low polluters are totally excluded from any evaluation process and furthermore the actual high emitters and the errors of commission are not discriminated. On the other side, the JCS study is based on a rather small sample. Thus, even though the evaluation of several policy options can be realised, the statistical representativity of the results is questionable. It has to be mentioned though that in the cases of both the UK- and the German studies the aim was not to evaluate different policy options, as it was in the JCS study, but to investigate the efficiency of the current I&M test procedures.

In view of the above and adding the fact that the degradation effect has not been evaluated by any of the proposed approaches, it is concluded that the existing data gathering projects cannot provide statistically reliable data that could be used to evaluate the benefits of various policy options. Therefore, a proposal of undertaking a large-scale data collection exercise of the emissions from vehicles coming for periodic inspection is made in the following.

4.4 Emission testing policy options

As the data collection process will be supplemented by periodic inspection centres, the following elements defining an emission testing policy have to be taken into account:

4.4.1 Visual check

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

4.4.2 Types of short tests

The short tests which have been so far developed for exhaust emission testing can be classified in three major categories: (a) idle, (b) loaded static and (c) transient loaded short tests.

The term idle tests denotes all tests during which no external load is exerted and the car operates with the transmission in neutral position. The test involves carbon monoxide (CO), hydrocarbons (HC) and eventually carbon dioxide (CO_2) concentration measurements in the raw exhaust gas at idle speed and/or a higher engine speed (2 000 to 3 000 rpm). A garage-type non-dispersive infrared (NDIR) analyser capable of measuring CO, HC and CO_2 concentrations is sufficient. Idle and fast idle tests are still widely used tests in I&M programmes because they are the fastest and easiest to perform with the minimum possible testing equipment. Though they are very effective at identifying defective conventional cars, they are not very effective at identifying emissions-related defects in catalyst equipped cars. For catalyst equipped cars a lambda test may also be coupled with an idle/fast idle test in order to check the performance of the mixture preparation system.

The loaded static tests are necessary in order to measure NO_x emission levels, as they are negligible at no-load conditions. The simplest loaded tests are the steady-state loaded tests, which involve a dynamometer with steady-state power absorption. A simulation of the car's inertia is not required because there is no transient phase in the emission test. The car is driven at constant speed and load and pollutant concentrations (CO, HC, NO_x and CO_2) are measured during the load phase.

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

4.4.3 Centralised or de-centralised testing

Centralised emission testing is performed in state-run facilities while a de-centralised system relies on private service stations.

A centralised inspection station has the advantage of having more sophisticated equipment, while it also eliminates the potential for fraud. Its major disadvantage is the inconvenience of having to go to a central testing station first, then to a private garage for repairs and back to the central testing station for a retest. Further drawbacks are the long waiting lines, as many motorists have to line up at a small number of facilities for tests, and the elimination of competition and choice in the test and repair business.

Private service stations on the other hand have the major advantage of conducting both the emissions tests and repairs. Furthermore, the inconvenience of waiting lines can be eliminated as motorists can get both their safety and emission tests done at the same time at private service stations.

4.4.4 Frequency of testing

The real effects of any emission testing 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.

4.4.5 Remote sensing

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 might be a viable approach and should be validated.

4.4.6 Random roadside

Periodic inspection tests can be supplemented by roadside tests. A random selection of vehicles would provide useful information about emissions compliance in general. Better targeting might be achieved by use of remote sensing equipment to identify possible gross polluters for roadside testing, although this would entail the significant additional cost of the equipment.

4.4.7 On-Board Diagnostics (OBD)

An OBD-I&M check consists of a visual check of the dashboard display function and status (also known as the malfunction indicator light (MIL) and/or bulb check) and an electronic examination of the OBD computer itself. For the latter the vehicle's data link connector (DLC) is located and a scan tool is plugged into the connector. By means of the scan tool the following elements of the vehicle are determined:

- Readiness status[1];
- MIL status (whether commanded on or off); and
- Diagnostic Trouble Codes (DTC) for those vehicles with MILs commanded on.

[1] The OBD system monitors the status of emission control related subsystems by performing either continuous or periodic functional tests of specific components and vehicle conditions. When a vehicle is scanned, these monitors can appear as either 'ready' (meaning the monitor in question has been evaluated), 'not ready' (meaning the monitor has not yet been evaluated), or 'not applicable' (meaning the vehicle is not equipped with the component monitor in question).

An interesting I&M prospect is the integration of OBD-I&M test procedures into an overall I&M programme. Based on experience from the US [18], in order for an OBD-I&M test programme to be most effective, it should be designed in such a way as to allow for:

- Real-time data link connection to a centralised testing database;
- Quality-controlled input of vehicle and owner identification information; and
- Automated generation of test reports.

The study 2 of CITA Second Programme of Studies on Emission Testing at Periodic and Other Inspections examines in detail the possibilities of using OBD at periodic inspection. A separate report of this work is being produced.

5 Proposal for a large-scale data gathering exercise

5.1 Selection of partners

Inspection centres and laboratories related to I&M programmes will be selected to participate in the large-scale exercise proposed. The choice of inspection test centres is based on their access to the whole vehicle fleet subject to periodic inspection. All partners will conduct the testing programme proposed according to a common test protocol. One Institute will perform the analysis of the results.

5.2 Selection of vehicles to be tested

The selection of vehicles to be tested will be realised by each partner. The selection will differ per country, in order to account for the particular characteristics of the in-use fleet per country and the future trends and will cover all types of engines and all current and future configurations of emission controls.

The size of the vehicle sample will be decided on the basis of its representativity of the fleet. Assuming that the sample follows a binomial distribution, the size of the sample can be calculated according to the following formula [19]:

$$n \geq \left(\frac{z_{1-1/2\alpha}}{d} \right)^2 \cdot p \cdot (1-p)$$

In this expression p is the probability of the binomial distribution, d is the confidence interval, 1-α is the confidence level and $z_{1-1/2\alpha}$ is the unit normal variable for the corresponding confidence limits.

For a confidence level of 95 % ($\alpha = 0{,}05$) from the normal tables we have $z_{1-1/2\alpha} = 1{,}96$. Since the probability of the binomial distribution is unknown, we assume a value of $p = 0{,}5$ as it returns a maximum value for n. For a confidence interval of 3 % (d = 0,03) the minimum size of the sample calculated according to the above formula is equal to around 1 000 vehicles. Other typical values for the confidence level and the confidence interval are 99 % and 1 % (α = 0,01 and d = 0,01) respectively. If these values are used for the calculations, the size of the sample changes as shown in Table 3.

Table 3: Size of the sample for different parameters

d \ **α**	0,05	0,01
0,03	1 067	1 849
0,01	9 603	16 638

In principle, the selection of the test vehicles will be done in a random manner from vehicles coming for periodic inspection in a number of member states. Nevertheless, the final selection of the vehicles has also to focus on vehicles which have already been identified as defective and thus, based on information from test lanes, a number of vehicles (e.g. 5 to 10 % of the total sample) have to be selected because they present known defects. Finally the selection of the vehicles will also account for the expected periodicity of the inspection system. This means that it should focus on vehicles of ages higher than 1 year.

5.3 Selection of test procedures and equipment

It is proposed that the idle tests according to Directive 92/55/EC and one transient loaded short test will be conducted, covering all types of engines and related emission controls (i.e. conventional and catalyst equipped cars, diesel as well as LPG cars, both conventional and catalyst equipped) and all pollutants, i.e. CO, HC, NO_x, PM (and/or smoke) as well as CO_2 and fuel consumption (either calculated and/or measured).

As a transient short test either the TÜV or the 'Modem short' test of the JCS study can be used as they proved to be equivalent and to exhibit acceptable correlations to the type approval.

Standardised chassis dynamometers will be used for the type approval tests and the transient short tests. Because of the costs involved and the large vehicle sample, it might not be possible to use the type approval chassis dynamometer for the whole vehicle sample. Simplified cheaper dynamometers with lower power absorption capabilities could be used instead for short test purposes.

Both concentration measurements in the raw exhaust gas and emission measurements with the CVS method will be adopted. Concentration measurements in the raw exhaust can be compared to type specific limit values, while emission measurements with the CVS method give more information. Emission and consumption can be calculated in grams per kilometre, but the additional costs for the CVS have to be taken into account as well.

For Euro III and newer vehicles an additional OBD check will be performed. Therefore, a scan tool will be used for reading diagnostic trouble codes and monitor readiness status.

Moreover, the specific test conditions have also to be taken into account. As it is expected, the short tests will be performed under ambient conditions (in a wide range of ambient temperature and humidity). Therefore, the influence of these parameters has also to be investigated and finally reflected to the test conditions (e.g. exhaust temperature and/or preheating time of the engine) and possibly to correction factors. In addition, as short tests will be conducted most likely with hot engine, the test conditions (e.g. engine temperature) have to be well defined.

5.4 Testing programme

The basic measurements will be conducted by each partner on the vehicles that will finally be selected taking into account the criteria mentioned above.

The emission tests on in-use vehicles will include: (a) Emission and fuel consumption tests on the vehicles as received; (b) Maintenance of the vehicles (if necessary); (c) Emission and fuel consumption tests on the vehicles after maintenance.

5.4.1 Emission and fuel consumption tests on the vehicles as received

It is proposed that gasoline- and diesel vehicles will be evaluated separately as well as the various legislative categories (conventional, Euro I, Euro II, Euro III) accounting for eight, in total, categories. In order to have a representative sample (see section 5.2), 1 000 vehicles will be selected from each category. The vehicle sample thus will consist of 4 000 gasoline- and 4 000 diesel vehicles. The testing programme will include the following modules:

- Performance of preliminary checks on the vehicle's basic components and settings, related to emissions and fuel consumption. Such checks will include: Visual inspection and check of components (e.g. component numbers, existence, completeness, leaks, damage), engine set at idle, direct component testing (e.g. oxygen sensor, catalyst), check of tire size, lead test etc. For OBD-equipped vehicles a visual examination of the instrument panel is also foreseen, in order to determine if the MIL illuminates briefly when the ignition key is turned to the 'key on, engine off' position, confirming that the bulb is in proper, operating condition.
- Performance of emission tests on chassis dynamometer, in order to record the actual emissions of the car. For this purpose a long cycle test will be used as reference. As a long cycle either the type approval test or a real-world cycle (with hot start) more representative of the actual driving conditions (e.g. Artemis) should be considered. An OBD-check will be additionally performed in all OBD-equipped vehicles by means of a diagnostic scan tool.
- Performance of short tests. As the vehicle sample will be selected from the inspection lanes, idle tests will be conducted in any case as part of the periodic inspection. The selected short cycle test will be additionally conducted on the vehicles of the sample. Idle tests (low and high idle) involve concentration measurements of CO, HC, CO_2 and smoke emissions, while the transient loaded short test involve more pollutants (i.e. NO_x, CO_2 and Particulates). The test programme may be different for the various gasoline engine concepts. In order to get representative results each partner of the project will participate in the classification programme.

Ideally, all vehicles comprising the sample should follow the above test sequence. However, as the size of the vehicle sample proposed above is relatively high, the cost of performing the type approval test for the whole sample using a standardised dynamometer will be consequently high. Therefore, two testing scenarios are envisaged.

- According to the first scenario, only 10 to 20 % of the sample (around 1 000 vehicles) will follow the above sequence. From the results of the emission tests performed on these vehicles, a correlation of the loaded short test to the type approval will be produced for each engine type- and legislative category. Then a simplified chassis dynamometer will be used for conducting the short cycle test on the remaining vehicles (around 7 000 vehicles). By combining the emission results of the latter with the derived correlation functions, the reference emissions of the vehicles according to the type approval will be calculated.
- According to the alternative scenario, only the selected short cycle test will be conducted on the vehicles of the sample, as the JCS study showed a reasonable correlation between short cycle tests and the type approval. A simplified chassis dynamometer located in the inspection centres conducting the periodic inspection will be used for that purpose.

5.4.2 Maintenance of the vehicles

In general maintenance will be conducted on the vehicles that will be found not complying with the emission standards during the type approval test. For those vehicles that will not undergo the type approval test, the calculated emissions (as described in the first testing scenario in the previous section) will be used as their reference emissions. In case the alternative scenario is adopted, the emissions over the short test are the only reference values available.

The maintenance will in principle comply with detailed specifications. However, as it is known that the quality of maintenance can have a significant influence on the emissions behaviour of the cars, two levels of maintenance can already be envisaged, to account for the quality of the maintenance:

- Maintenance at a garage of average level, as the latter is defined in each country. It should be attempted to use more than one garage, in order to get an average result.
- For those vehicles which will be identified as high emitters, either due to previous bad maintenance or due to inherent problems, the maintenance will be done at an authorised dealer who can ensure high quality.

A close collaboration with the vehicle manufacturers (especially in the latter case) will be looked for through contacts in the EU, governments and trade associations, in order to differentiate between the durability and degradation of the engine components on one hand and the quality of the manufacturer's production on the other. This also means that there will be a limit on the repairs carried out on the vehicle, depending on the overall cost allocation on repairs by each partner.

Moreover, it is aimed to identify (and consequently deal with separately) eventual inherent problems of the engine and/or its emission controls.

5.4.3 Emission and fuel consumption tests on the vehicles after maintenance

The test programme will be identical with the as-received vehicles, i.e. the same measurements will be conducted on each car after maintenance. It is anticipated that, as the magnitude of the test vehicle sample will be around 8 000 vehicles from which 5 to 10 % will be selected as possible high emitters, between 1 000 and 1 500 vehicles with defects of incorrect settings will be available for re-testing, assuming a failure rate between 5 and 10 %.

5.5 Cost estimation

The cost of the 'large scale data gathering exercise' includes the cost of the emission tests, the cost of maintenance and the cost of data evaluation involved.

As mentioned above, the testing programme will include the idle tests specified in the roadworthiness directive, one transient short test and one long-cycle test depending on the testing scenario chosen.

The cost of one full long cycle test using a type approval chassis dynamometer will be submitted by each partner, however it is estimated at around 1 250 € and will be considered as constant for all partners. The cost of a transient short tests (TÜV or Modem short) depends on whether a simplified or a standardised chassis dynamometer will be used. A fixed cost of 1 500 € per vehicle and per test day is estimated for conducting the two loaded tests on the type approval dynamometer. In case a simplified dynamometer will be used for conducting one short cycle test (alternative scenario), the cost is estimated to be reduced to around 800 €.

Table 4 summarises the cost elements and the total cost of the emission tests involved for the two testing scenarios presented in section 5.4.1.

Table 4: Cost of the emission tests needing a chassis dynamometer

	Option 1	Option 2
Type approval chassis dynamometer (type approval + loaded short test)		
Number of vehicles (as-received)	1 000	-
Number of vehicles (re-tested)	-	-
Cost per vehicle and per test-day	1 500 €	-
Total cost	1,5 M€	-
‘Simplified’ chassis dynamometer (loaded short test)		
Number of vehicles (as-received)	7 000	8 000
Number of vehicles (re-tested)	1 000	1 000
Cost per vehicle and per test-day	800 €	800 €
Total cost	6,4 M€	7,2 M€
Total cost of loaded tests	**7,9 M€**	**7,2 M€**

As regards the idle tests, the cost of the inspection methods vary with the country, mainly on the basis of the hourly rates of the technicians involved. The cost of an inspection according to Directive 92/55/EC will be supplied by each of the partners of the exercise and is estimated at around 30 € per vehicle. The total cost of inspection for the whole sample of 9 000 vehicles (8 000 as-received and 1 000 re-tested) is thus 270 k€.

The cost of maintenance will likewise be supplied by the partners for minor and major maintenance. Where necessary this will be corrected for the additional cost of replacement parts. An estimation of the cost of maintenance is presented in Table 5.

Table 5: Cost of maintenance

	Minor repair	Major repair	Catalyst replace
Percentage of vehicles	80 %	18 %	2 %
Number of vehicles	800	180	20
Cost per vehicle	150 €	250 €	500 €
Total cost	**120 k€**	**45 k€**	**10 k€**

It is estimated that around 12 man-months will be needed for the evaluation of the data. With an average cost of 10 k€ per man-month the data evaluation costs are estimated at around 120 k€.

It is obvious that the cost of inspection (270 k€), the cost of maintenance (175 k€) and the cost of data evaluation (120 k€) are much lower compared to the cost of the emission tests needing a chassis dynamometer. Thus, the total cost of the exercise when the above testing programme is conducted once will be around 8,5 M€ for the first testing scenario (option 1) and around 8 M€ for the alternative scenario (option 2).

In order to enable the assessment of the emission degradation the vehicle sample should be monitored against its mileage. As the vehicle sample will be selected from vehicles coming for periodic inspection, the same vehicles will be attempted to be depicted at their next visit to the inspection lanes after two or three years. It is thus proposed to repeat the same testing programme after its initial completion and the final evaluation of the results. The total cost of the exercise will then amount to around 16 to 17 M€.

5.6 Assessment of the two testing scenarios

The main difference between the two testing scenarios proposed in section 5.4 is the inclusion of the type approval test or any other long cycle test in the emission testing procedure.

Although the JCS study has shown an acceptable correlation between the short cycles and the type approval test, this includes only Euro I vehicles. It is expected that a similarly good correlation will be shown for Euro II, Euro III and newer vehicles, however this needs to be proved.

The combined effect of the very low emissions of vehicles with the latest technology and the short duration of the short cycle tests can lead to uncertainties as regards the final emissions in grams per kilometre. These uncertainties are not significant in pass-fail exercises targeting high emitters but can be considerable in the case of emission factor determination.

In view of the above, if a small number of tests involving both long- and short cycle tests would be included in the emission testing procedure, the emission data resulting from the large scale exercise would be more robust. It has to be mentioned though, that a preliminary exercise for the selection of the appropriate long cycle (NEDC, Modem, Artemis, etc) and the appropriate short cycle is necessary.

5.7 Cost-effectiveness analysis

In order to assess the cost-effectiveness of the large scale exercise, the total cost of the proposed approach will be divided by the total emission reductions achieved and thus the cost per unit of effect (in M€ / kton of pollutant avoided) will be obtained.

After selecting the vehicle sample (see 5.2) and conducting the testing programme on the as-received vehicles (see 5.4), the composition of the sample and its emission factors will be determined. The actual low and high emitters as well as the errors of omission and the errors of commission will be determined likewise. After identifying the vehicles needing repair and conducting the same testing programme on them, the emission factors after maintenance and the accompanied effect of maintenance will be determined.

The emission reduction potential will be calculated as described in Annex A. As said in section 5.2 the vehicle samples of some participating partners will contain a number of vehicles already identified as defective in order to test the capability of the short test to detect faulty vehicles. The selectivity will therefore be determined for an adapted sample containing the randomly chosen vehicles only as this approach is more representative of the situation in the field.

The selectivity of the proposed testing programme together with the actual number of faulty vehicles in the fleet determines the number of vehicles identified as faulty. This number includes also the errors of commission. The number of vehicles detected as faulty, multiplied with the average effect of maintenance results in the total effect of maintenance in kilotons of pollutant avoided.

As an example of the emission benefits achieved, the Dutch case is shortly presented in the following. Table 6 presents the fleet composition and the emission factors in 1995.

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

	vehicles [millions]	[km/year]	CO [g/km]	HC [g/km]	NO_x [g/km]	PM [g/km]
Otto conventional	1,710	9 700	11,30	1,80	2,76	-
Cat tax incentive	0,420	13 600	2,80	0,30	0,58	-
Euro I	2,680	13 600	1,60	0,16	0,44	-
Diesel	0,420	25 000	0,60	0,17	0,71	0,19
LPG	0,660	22 500	1,30	0,39	0,95	-

Since the periodic inspection in the Netherlands is annual, all conventional (pre 1989) and catalyst tax incentive (1989-1991) vehicles are subject to the mandatory inspection. It is estimated that around 80 % of the LPG- and diesel vehicles and 50 % of the Euro I (1992-1995) vehicles are subject to inspection as well.

Assuming that the identification rate of the proposed testing programme will be 50 % for gasoline and LPG vehicles without catalyst, 27 % for the gasoline and LPG vehicles with catalyst and 9 % for diesel vehicles, and based on the calculation method presented in Annex A, Table 7 presents the calculated ERRPs of the proposed testing programme.

Table 7: Emission reduction rate potential for various pollutants and vehicle categories

	CO	HC	NO_x	PM
Otto conventional	17 %	5 %	5 %	-
Cat tax incentive	16 %	15 %	20 %	-
Euro I	16 %	15 %	20 %	-
Diesel	0 %	0 %	0 %	25 %
LPG	16 %	15 %	20 %	-

Applying the figures of Tables 6 and 7, the expected effect of maintenance in kilotons of pollutant avoided can be calculated as shown in Table 8.

Table 8: Potential emissions avoided in kilotons of pollutant per year

	CO	HC	NO_x	PM
ktons/year	40,6	2,9	6,6	0,4

The above is a typical example of a calculation of the emission benefits achieved when an enhanced I&M programme is implemented. This, in turn, will enable the assessment of the cost-effectiveness of the proposed approach.

5.8 Final Results

In the closing stage of the exercise the final evaluation of the results will be conducted. The aims will be the following:

- Definition of an alternative emission testing policy;
- Evaluation of the emission testing policy in terms of effectiveness, costs and public acceptance;
- Evaluation of the overall environmental benefit for the proposed sequence.

Annex A

Emission reduction calculations

A. Emission reduction calculation according to the German study

The annual emission reduction for the vehicle class h and road class VS is calculated according to the following formula:

$$\Delta EW_{h,VS} = F_{h,VS} \cdot \alpha_h \cdot (SE_{h,VS,VR} - SE_{h,VS,NR})$$

$F_{h,VS}$: Mileage of the vehicle class h and road class VS;

α_h : Failure rate of the vehicle class h;

$SE_{h,VS,VR}$: Emission factor of the vehicle class h and road class VS before repair;

$SE_{h,VS,NR}$: Emission factor of the vehicle class h and road class VS after repair.

The total annual emission reduction by repair of the AU-failed TWC vehicles for a reference year is calculated according to the following formula:

$$\Delta EW_{ges} = \sum_{h} \sum_{VS} \Delta EW_{h,VS}$$

The total annual emissions of the TWC fleet subjected to AU for the same reference year are calculated based on TREMOD and they are calculated for all corresponded vehicle- and road classes. The efficiency of the procedure for each pollutant is then determined by dividing the annual emission reductions calculated for each pollutant by the total emissions of the fleet subjected to AU.

B. Emission reduction calculation according to the JCS study

The following indexes are used for the calculations:

Emission Factor of pollutant i by the vehicles in group j:

$$EF_{ij} = \frac{E_{ij}}{N_j} \quad [g/km]$$

Emission Reduction Potential of pollutant i:

$$ERP_i = \left(EF_{i6} - EF_{i1}\right) \cdot N_6 \quad [g/km]$$

Emission Reduction Rate Potential of pollutant i:

$$ERRP_i = 100 \cdot \frac{ERP_i}{E_i} \quad [\%]$$

N_j : Number of vehicles in group j;

P_j : Percentage of vehicles tested with the particular short test that lay in group j;

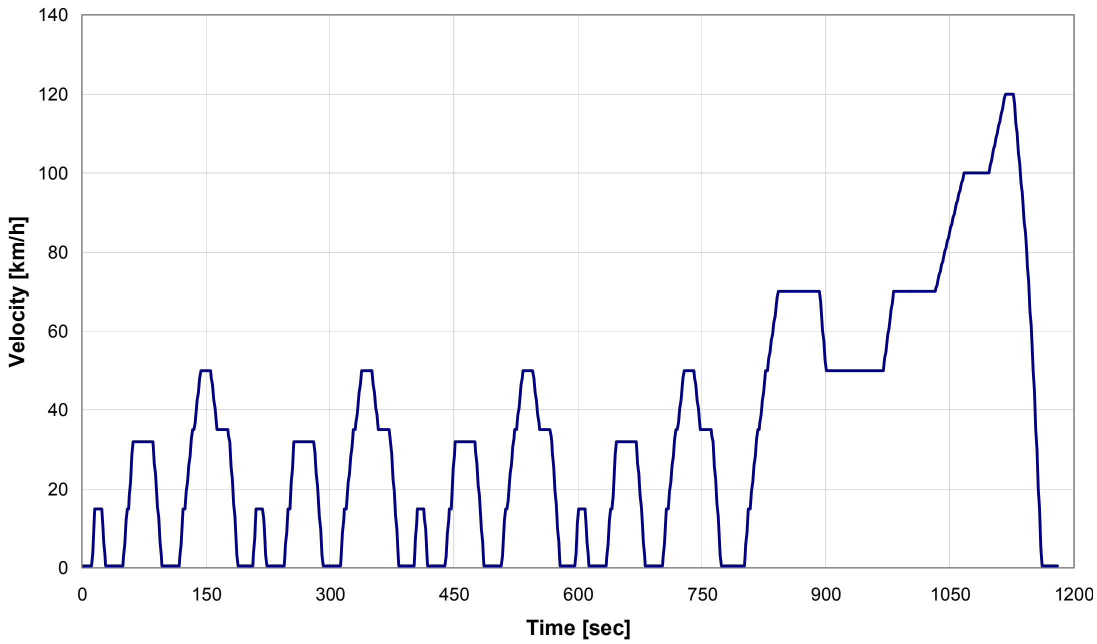
E_{ij} : Cumulative emissions of pollutant i by the vehicles in group j;

PE_{ij} : Percentage of total emissions of pollutant i by the vehicles in group j.

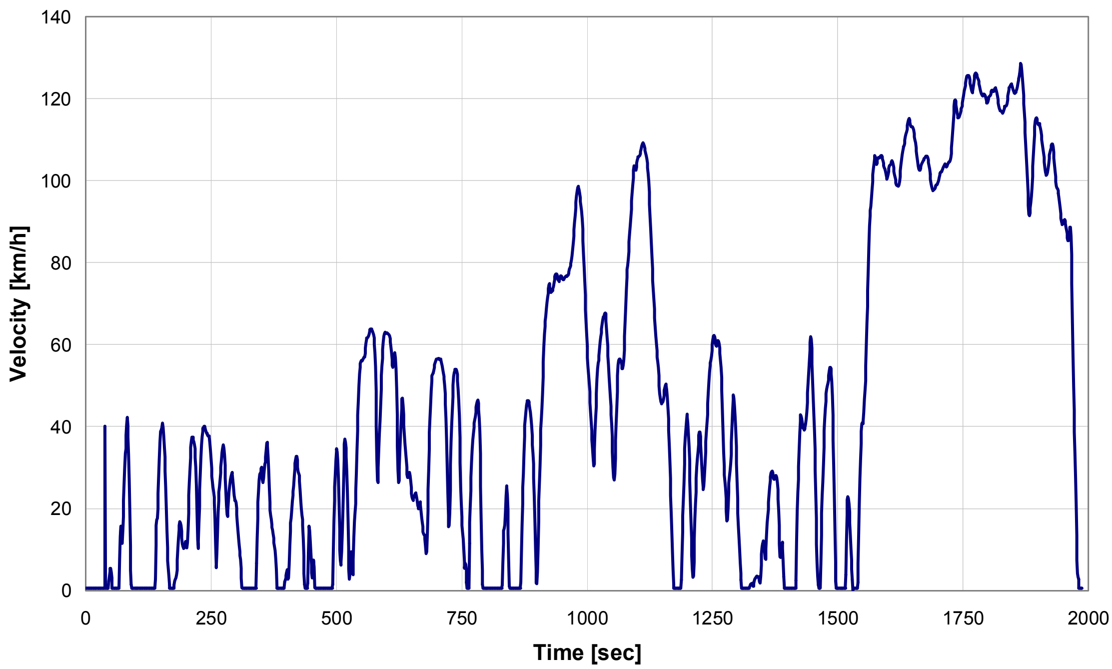
Annex B

Driving cycles

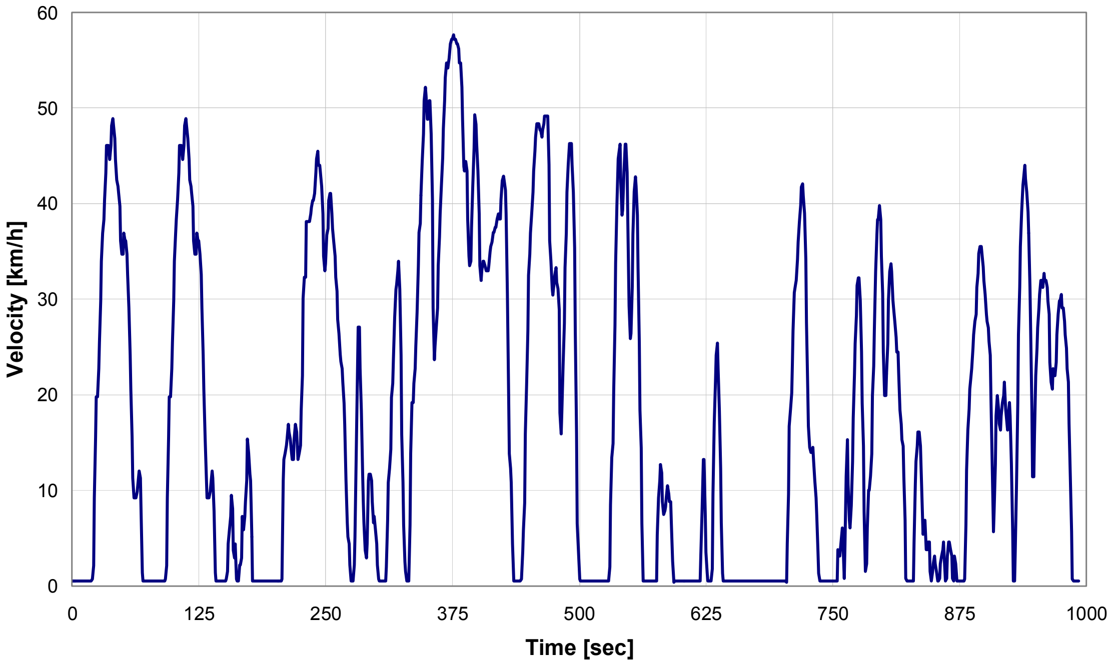
A. New European Driving Cycle (NEDC)



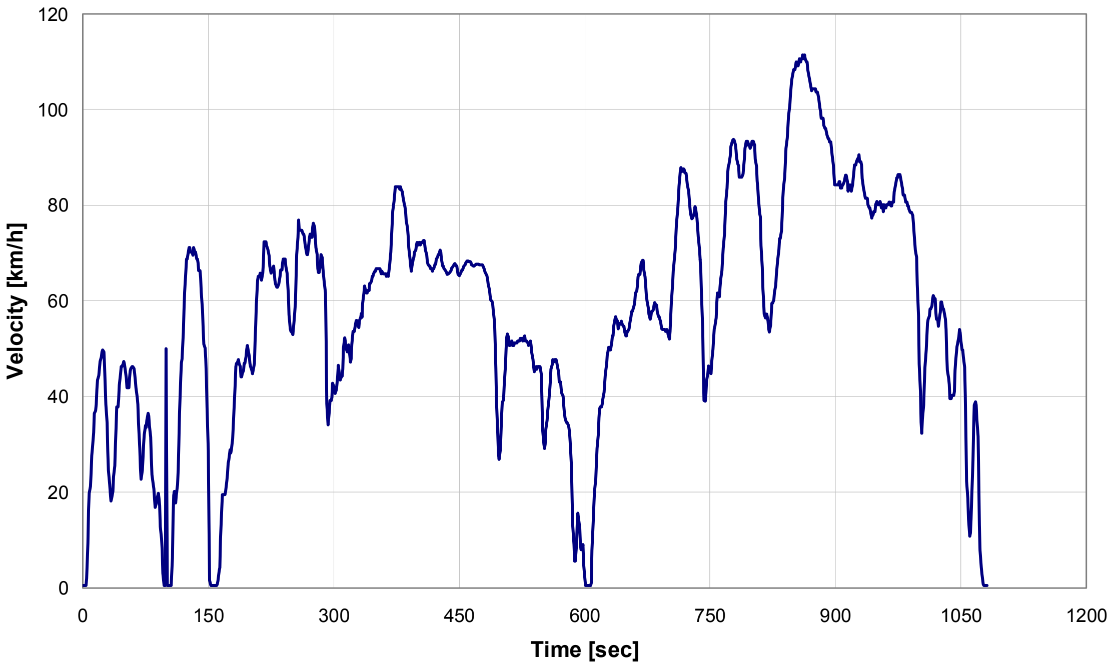
B. Modem



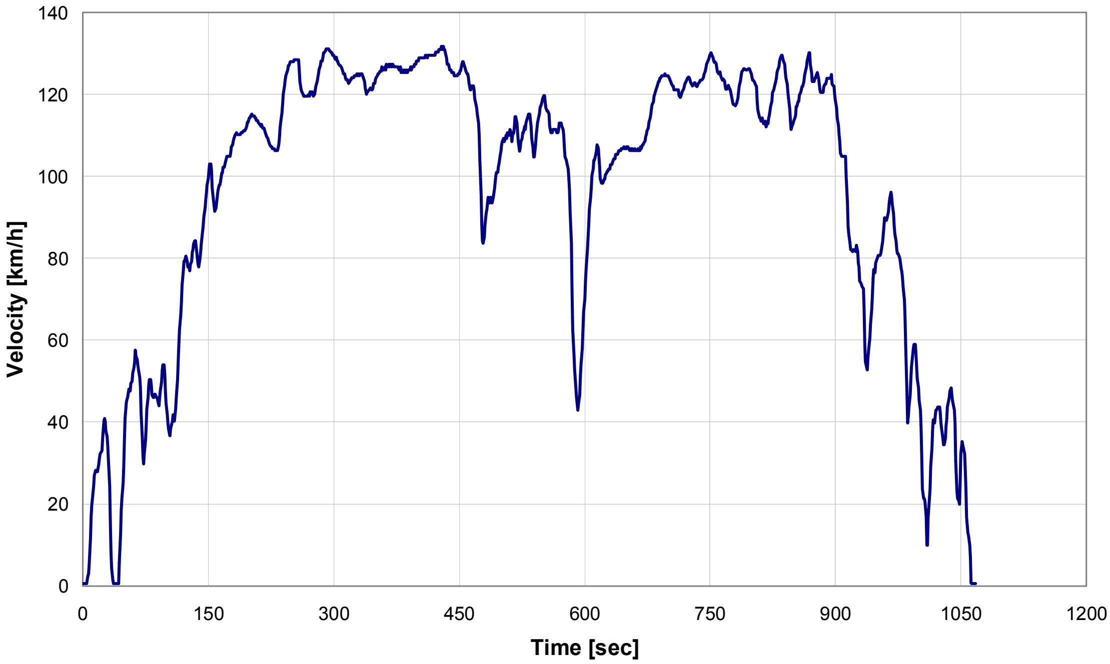
C. Artemis urban



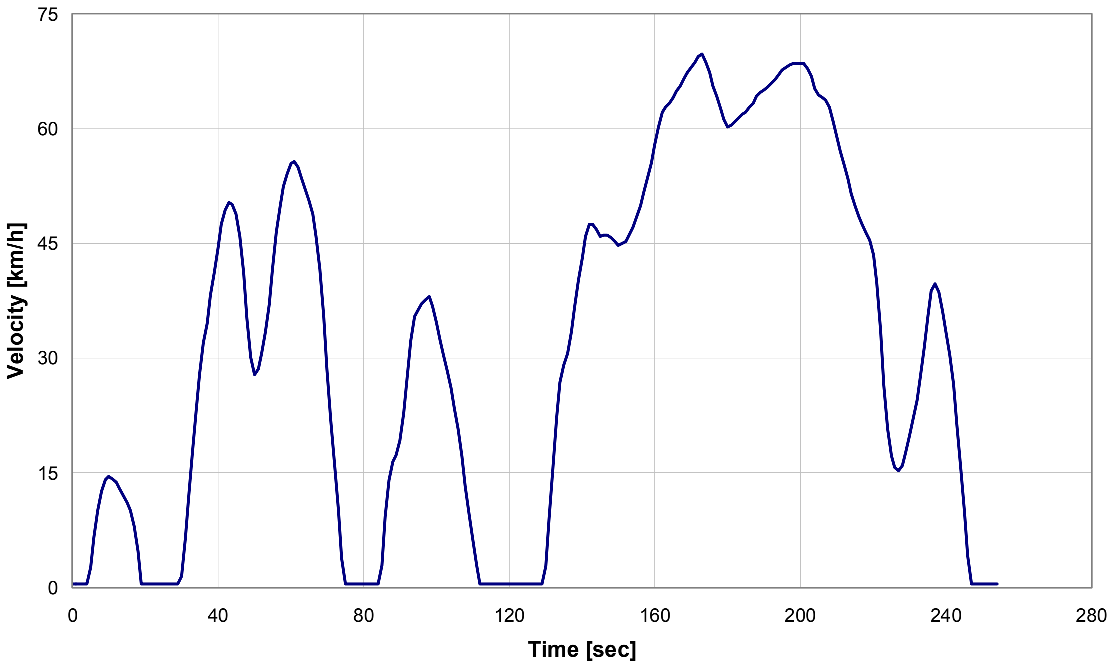
D. Artemis road



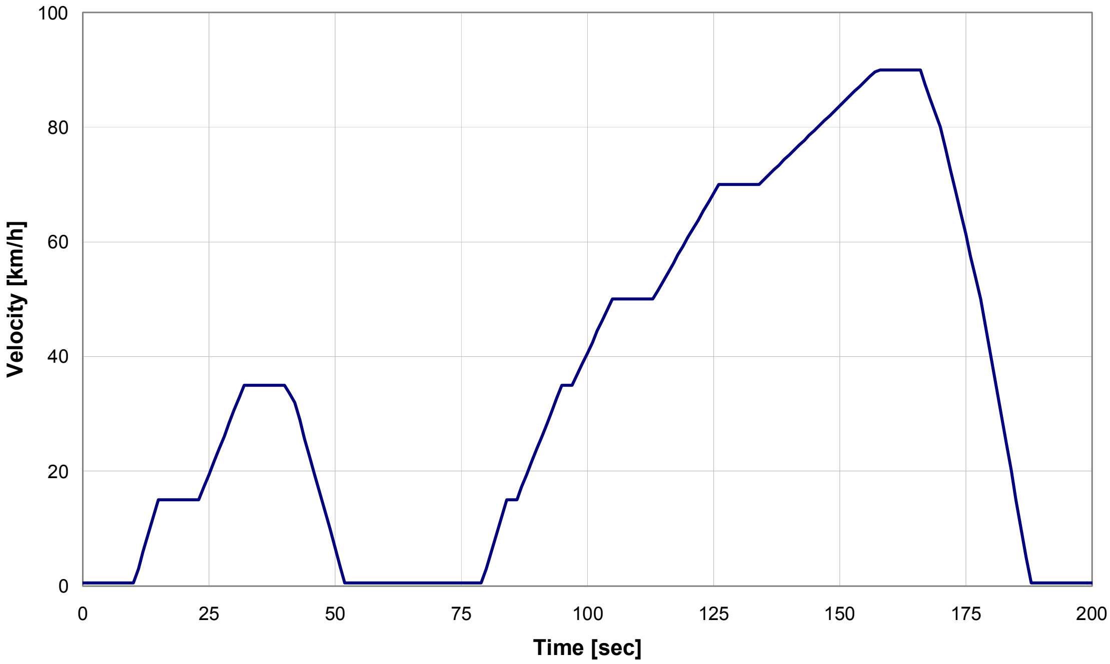
E. Artemis motorway



F. Modem short



G. TÜV short



Velocity [km/h]
Time [sec]
0
20
40
60
80
100
0
25
50
75
100
125
150
175
200

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