EMISSIONS AND FUEL CONSUMPTION FROM HEAVY DUTY VEHICLES

COST 346 – Final Report

including Final Report of Working Group A

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COST – the European **CO**operation in the field of **S**cientific and **T**echnical Research (http://www.cost.esf.org/) – is the widest European intergovernmental network for cooperation in research. Established by the Ministerial Conference in November 1971, COST is presently used by the scientific communities of 35 European countries to cooperate in common research projects supported by national funds. The funding provided by COST of around € 20 million per year, which is less than 1% of the total value of the nationally funded projects of annually exceeding € 2 billion, supports the COST cooperation networks (COST Actions) of more than 30,000 European scientists. A "bottom up approach" (the initiative of launching a COST Action comes from the European scientists themselves), "à la carte participation" (any country voluntary interested in the Action to participate); "equality of access" (e.g. participation is also open to the scientific communities of non-EU countries) and "flexible structure" (easy implementation and light management of the research initiatives) are the main characteristics of COST. As precursor of advanced multidisciplinary research, COST has a very important role for the realization of the European Research Area (ERA) anticipating and complementing the activities of the EU's Framework Programmes, while constituting a "bridge" towards the scientific communities of emerging countries, increasing the mobility of researchers across Europe and fostering the establishment of "Networks of Excellence" in many key scientific domains, such as: Biomedicine, Chemistry and Molecular Sciences, Earth System Science and Environmental Management, Food and Agriculture, Forests, Cultures and Health, Information and Communication Technologies, Transport and Urban Development, Materials, Physics and Nanosciences. COST intends to support analysis and dissemination of innovative cross-border European basic and applied research of public concern. Thereby, it also addresses issues of pre-normative nature and societal importance.

Action 346: Emissions and fuel consumption from heavy duty vehicles

The primary objective of the Action was to develop an improved methodology for estimating pollutant emissions and fuel consumption from commercial road transport operated with Heavy Duty Vehicles (HDV's) in Europe. The methods should make it possible to estimate the emissions [g/km] from single vehicles, as well as, from vehicle fleets. The activities were concentrated on improving the amount and quality of basic data on emissions and transport activity, as well as, on validating and enhancing existing models.

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COST 346

Emissions and Fuel Consumption from Heavy Duty Vehicles

Final Report of the Action

This publication is based on a support by COST. COST is an intergovernmental European framework for international cooperation between nationally funded research activities. COST creates scientific networks and enables scientists to collaborate in a wide spectrum of activities in research and technology. COST Activities are administered by the COST Office. Please consult the COST homepage for further information: http://www.cost.esf.org/

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Preface

Air pollution is a global environmental problem, although its scale and scope have a strong regional and local orientation. Transport in general and vehicle traffic in particular are an essential source of air pollution problems, especially in urban areas. When considering road traffic heavy duty vehicles play a major role. They are supposed to contribute strongly to the overall CO_2, NO_x and PM_{10} emissions.

Motivation of setting up this COST action was the poor data bases on emissions and activity data for HDV, which existed before the Action started. Within the 6 working years the COST 346 Action of the COST Transport and Urban Development Domain has definitely improved the knowledge on emissions and fuel consumption of heavy duty vehicles under real world conditions. In addition a methodology for an emission factor database has been developed which can be adapted to each individual country on bases on their own fleet distribution.

However, the work is not finished yet and topics for further activities have been identified. The measurement programme covered engines up to EURO 3 technology and a few EURO4/5 prototypes. EURO 4 and 5 engines will have to utilize high end technology in order to achieve the required low emission levels. The high technical standard might open the gap between type approval tests and real world emission behaviour. This fact calls for intensive monitoring of real world situations, which itself require improved field test possibilities and effective short tests in I/M procedures.

In total 17 COST countries and one organisation have joined the COST 346 Action. These are listed in the report. The intensive work of the individual members of the COST 346 Action resulted in a very valuable product. The final report tries to summarise the main results. More detailed information may be found on the COST 346 web page.

Attached to the final report is the report of working group A, dealing with the vehicle emission model and the emission data base. A major part concerning the fleet model, the activity data and the driving behaviour was performed in cooperation with the FP5 framework project ARTEMIS.

Over the duration of COST 346 (1999 – 2005) the Action was followed by Mr. Jan Spousta as scientific secretary and Mr. Olav Eidhamer as COST rapporteur. Their support for the action as well as their efforts are appreciated by the COST 346 participants. Thanks also to Mr. Erwin Cornelis for maintaining the COST 346 web site.

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1. General framework of COST

COST – the European Cooperation in the field of Scientific and Technical Research (http://www.cost.esf.org/) – is the widest European intergovernmental network for cooperation in research. Established by the Ministerial Conference in November 1971, COST is presently used by the scientific communities of 35 European countries to cooperate in common research projects supported by national funds. The funding provided by COST of around € 20 million per year, which is less than 1% of the total value of the nationally funded projects of annually exceeding € 2 billion, supports the COST cooperation networks (COST Actions) of more than 30,000 European scientists. A "bottom up approach" (the initiative of launching a COST Action comes from the European scientists themselves), "à la carte participation" (any country voluntary interested in the Action to participate); "equality of access" (e.g. participation is also open to the scientific communities of non-EU countries) and "flexible structure" (easy implementation and light management of the research initiatives) are the main characteristics of COST. As precursor of advanced multidisciplinary research, COST has a very important role for the realization of the European Research Area (ERA) anticipating and complementing the activities of the EU's Framework Programmes, while constituting a "bridge" towards the scientific communities of emerging countries, increasing the mobility of researchers across Europe and fostering the establishment of "Networks of Excellence" in many key scientific domains, such as: Biomedicine, Chemistry and Molecular Sciences, Earth System Science and Environmental Management, Food and Agriculture, Forests, Cultures and Health, Information and Communication Technologies, Transport and Urban Development, Materials, Physics and Nanosciences. COST intends to support analysis and dissemination of innovative cross-border European basic and applied research of public concern. Thereby, it also addresses issues of pre-normative nature and societal importance.

The contribution to European competitiveness in the global market is testified by the many contributions to normative and standardisation bodies where results, COST models COST, COST methods are commonly referred to and recommended.

The societal importance of COST results is particularly relevant in the case of delicate issues arising from new technologies. With COST, the public is reassured that the solution of these issues is not restricted to individual countries and that it is obtained in a high-standard, industry-independent, environment. COST has relations with a series of International and European bodies.

Transport is one of the oldest COST domains. Throughout more than 30 years, there have been a huge number of transport research Actions within the newly unified COST Transport and Urban Development Domain, contributing to the common European transport policy. Considerable importance is given to the environmental issues of transport, which have been dealt with in the COST 346 Action.

In total 17 COST countries and one organisation have joined the COST 346 Action. These are:
Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, Lithuania, Spain, Sweden, Switzerland, United Kingdom, and as associated partner the Moscow State Automobile and Road Technical University.

Detailed information on the COST Actions related to transport can be found at: http://www.cost.esf.org/index.php?id=239

2. Background for the COST 346 Action

The greenhouse gas emission reduction targets agreed at Kyoto represent a first step to reduce emissions in the long term in order to stabilise the Earth's climate. The European Union (EU) has made an important contribution to the Kyoto agreement and the European Commission (EC) intends to develop a strategy to reach the Union's Kyoto target. This will require action in all sectors of the economy including the transport sector.

Of the six gases covered by the Kyoto protocol, carbon dioxide (CO_2) is the most important as it accounts for about 80% of the total global warming potential of all six greenhouse gases. In the EU the share of transport CO_2 emissions in total increased from 19% in 1985 to 26% in 1995. Road traffic is the most important source, and largely determines the trend in the transport sector; and road freight accounts for about 35% of transport CO_2 emissions.

As well as CO_2, road freight transport causes considerable amounts of other pollutant emissions. With a share of approximately 75% of combustion related particulate (PM) emissions and about 60% of oxides of nitrogen (NO_x) emissions, road freight transport is the most important source of these pollutants within the total transport sector.

To forecast and monitor the development of heavy duty vehicle (HDV) emissions and the effect of emission reducing measures, calculation methods must be provided. COST 346 deals with the subject of estimation of air pollutant emissions caused by heavy duty vehicles. International research should be structured to today's needs and a European data base of emission related information for heavy duty vehicles should be developed. Basic data for emission estimates, emission models and activity data shall be collected and mapped with the results from national research activities as well as those from the EU framework research programmes ARTEMIS and Particulates. The web sites of these two FP5 projects are:
http://www.trl.co.uk/artemis/introduction.htm (August 2005)
http://lat.eng.auth.gr/particulates/ (August 2005)).

The COST 346 Action started in October 1999 and closed in October 2005.

3. Objectives and Benefits

3.1. Objectives

The main objective of the Action was to improve the knowledge of real world emission behaviour of the heavy duty vehicle fleet in Europe. This includes the enlargement of the emission data base, the activity figures and the development of an improved methodology for estimating pollutant emissions and fuel consumption. The methods should make it possible to estimate the emissions [g/km] from single vehicles as well as from vehicle fleets.

The activities are concentrated on improving the amount and quality of basic data on emissions and transport activity, as well as validating and improving existing models.

To achieve these objectives the following actions were set:

- Establishment of a protocol for HDV emission and fuel consumption testing. The protocol includes provisions for ensuring comparability between measurements made in different laboratories (quality assurance procedures, etc.).
- Production of engine maps for calculating emissions and fuel consumption from HDV's. This covers both static and dynamic operating conditions and a representative range of engines.
- Because of the lack of existing data on particulate matter (PM) emissions and their important impact on health, the Action includes measurements of PM size and number distributions.
- Development of vehicle simulation models in order to calculate emissions for single vehicles. For this task existing, improved or totally new models are used and validated.
- The use of aggregated emission models, aimed at the assessment of the overall emissions from a HDV fleet, requires detailed information on vehicles and vehicle operation (e.g. driving statistics) and more general traffic statistics (e.g. loading factors, fleet composition, mileage). COST 346 considers this aspect and makes recommendation on sources of information and methods of data acquisition.

3.2. Benefits

The main benefit of COST 346 will be the improvement of emission estimates for HDV's.

As a consequence the modelling of HDV emissions and the differentiation of vehicle types and driving conditions provides an effective tool for political decisions within the EU, as well as for traffic and transport engineering purposes. Furthermore, the database gives a comprehensive view of emissions under various driving conditions for HDV´s of different emission standards. The close co-operation between laboratories in different countries improves the harmonisation of European scientific knowledge and testing facilities. The focus is on the quality and extension of HDV emission and activity data.

- COST 346 offered a forum for dissemination of the results of national activities and research in the area of HDV and utilizing these results in a European wide initiative.

Moreover, the results and conclusions from COST 346 could be used in the context of legislative proposals by national authorities or by the EC, such as:

- Consolidation of European measurement facilities and programmes for HDV or other vehicle categories.
- Regulations regarding PM size and number distributions.
- Future emission legislation for HDV.
- Inspection and maintenance and field inspection programmes for HDV.

4. Scientific Programme and Structure

4.1. SCIENTIFIC PROGRAMME

The scientific work programme was designed to improve emission estimates for HDV's. Therefore the quality and quantity of emission data and statistical data on the activities of HDV's was to be improved. In order to achieve these tasks the following steps were undertaken:

- Definition of the detailed work programme
- Preparation of measurement programme
- Measurement programme on emissions
- Data definition and collection programme - statistics
- Development of models and validation
- Analysis of in-use emission and driving behaviour data
- Derivation of road type traffic situation classification matrix

4.2. WORKING GROUPS

The work within COST 346 has been split into different working groups according to the tasks to be fulfilled. A detailed report on the activities will be given in the individual working group presentations.

4.2.1. Working group A: Vehicle model

Aim of this working group is to develop a vehicle model which is capable to estimate vehicle emissions on bases of engine emission and fuel consumption maps. All the measurements performed on HDV and engines are covered within this working group. The results of this group are emission factors for given driving cycles according to different engine types and emission standards.

The goals stipulated in 1999 have mostly been achieved. The measurement and data collection activities were performed together with the ARTEMIS work package 400, the German - Austrian – Swiss-Dutch co-operation (D.A.CH-NL) and other national COST 346 activities, e.g. in Sweden, Finland and Hungary. The commonly established measurement protocol and test programme allowed for a wide spread of measured engines, vehicles and operation conditions. This co-operation resulted in the most extensive European data base on emissions from HD engines and vehicles.

4.2.2. Working group AB: Driving behaviour

The driving behaviour is an important input parameter for the emission calculation. Aim of this group is to define measurement parameters for driving behaviour studies and to develop a classification system for influencing parameters for emission models.

One main input of the fleet emission model is the driving characteristics. This description of the driving situation on road is based on a classification matrix, whose parameters are road type, traffic load and speed limit. In order to derive the speed curves for heavy duty vehicles, driving behaviour data was be utilised, which was collected under the framework of an ECE-GRPE project for development of a worldwide harmonised certification procedure for heavy duty engines. For the assessment of the driving behaviour of urban busses additional representative driving cycles from Israel and France have been collected.

4.2.3. Working group B: Fleet model

Aim of the fleet model working group was to develop or improve emission models which shall be used for estimation of the emissions from the HDV fleet.

The work performed in this working group was also done jointly with the ARTEMIS project. The developed vehicle fleet model covers light duty vehicles (passenger cars and light commercial vehicles), motor cycles as well as heavy duty vehicles, as the topic of traffic emissions does not only concern HDV alone. The fleet model contains three main elements, which are: (a) the fleet composition model, (b) a traffic activity module, and (c) an emission concept module. Operationally the model is based on a MS ACCESS® database and will be distributed free of charge.

4.2.4. Working group C: Dissemination

This working group was created to ensure a dissemination of results from COST 346 within the scientific community. Room was given at two international conferences (5^{th} Conf. on ICE, Capri (I), Sept. 2001 and 14^{th} Symp. “Transport & Air Pollution”, Graz (A), June 2005) for presenting the objectives and the results of COST346 and a dedicated dissemination conference was organised in the course of COST346 (Antwerp (B), May 2004).

A website for internal use facilitated the distribution of notes, news, documents and papers among the COST346 participants. At the end of COST346, the website was transformed into a website with unrestricted access, presenting the outcomes of COST346 to the wide scientific world.

4.2.5. Working group D: Legislation

As COST 346 dealt exclusively with real world emissions of heavy duty vehicles, the results of this intensive work may have an impact on future legislation. This may cover inspection/maintenance (I/M) requirements as well as target values for certain pollutants. The working group legislation followed the legislation relevant output of the project.

5. Emissions and vehicle model (Working group A, S. Hausberger, M. Rexeis, TU-Graz, A)

5.1. INTRODUCTION

In the projects COST 346, ARTEMIS and D.A.CH-NL (www.hbefa.net/ (August 2005)) emission factors for all kinds of vehicles were elaborated. This chapter shall give an overview on the data, methods and results. Details can be found in the final report of COST 346 WG A (Rexeis, 2005 a) and Artemis work package 400 (Rexeis, 2005 b). The projects duration covered the years from 1999 until 2005 with a strong co-operation between the three projects. Scope of the work was to elaborate

- a model capable of simulating accurate emission factors for all types of HDV in any driving cycle for various vehicle loadings,
- the necessary model input from a measurement program, a data collection campaign and literature review, and
- the emission factors for the overall COST 346/ARTEMIS model using the model and data described before, including the influences of fuel properties as well as of inspection and maintenance.

In total, emission tests from 102 engines are used as model input data, representing the most extensive data base for HDV emission factors in Europe. Data from roller tests and from on board measurements on 50 HDVs were collected and used for model validation purposes.

Different modal vehicle emission models were compared during the COST action using similar input data from the measurement campaign. A main result was that very different fleet emission factors were simulated by the models at the beginning of COST 346. Reason was that information on average emission levels of the heavy duty vehicle fleet in terms of engine emission maps was very limited and different for each country. These differences should be eliminated in future due to the common data base elaborated in COST 346 and ARTEMIS. Differences will still remain if different models are used for the calculation of the emission factors due to different interpolation routines, gear shift models etc. Harmonizing not only the data but also the models could be a future task towards common European emission factors.

Several simulation models have been developed earlier or during the project (e.g. PHEM, Vehicle Motion Simulator VEMOSIM, ADVISOR, etc.). The models differ from each other in some respect. Some of these models are able to utilise the road alignment, traffic condition and traffic management data, and thus can create satisfactorily the driving pattern when a vehicle is moving on the road and can determine fuel and emission flows. Based on this some countries wanted to utilise their models as such and emphasised production of engine maps and standardised protocols for creating them and some other countries wanted to develop their simulation models further.

At the end of the COST 346 project, the model PHEM (Passenger car and Heavy duty Emission Model, Hausberger et al., 2003) was capable of making use of the data from all 102 engines. This model was developed at the Graz University of technology and improved and validated during the Artemis WP 400 activities. Due to the strong connection between COST 346 and Artemis WP400 the following section concerning the model PHEM serve as an example for the requirements to be put on HDV emission models.

For the elaboration of emission factors for COST 346 and ARTEMIS, the model PHEM was run with the data sets for average HDV according to certification level (EURO 0 to EURO 5), the size category (<7.5t up to 60t), different vehicle loadings, and a set of representative driving cycles (Rexeis et al., 2005). For the "Handbook Emission Factors for Road Transport, HBEFA" a different set of driving cycles was calculated with PHEM already in the year 2002 (Hausberger 2002).

The data structure and the model have proved to be capable of fulfilling all demands in a flexible and fast way until now. Validation of the results was performed via tunnel studies and on board measurements and showed a satisfying accuracy, e.g. Soltic et al. (2004).

After the finalization of the projects a stable platform for up to date and future assessments of emission factors for HDVs was created. A main open actual topic is a more extensive measurement program on relevant vehicle parameters such as the rolling resistance coefficients and the drag coefficients of some "typical" HDV. Due to the existing bandwidth in vehicle body geometry, tyre design and road surface, fleet emission factors should be based on a broader data than available yet.

A main concern is the update of the emission factors. During the projects it proved already to be difficult to get the EURO 3 engines running correctly on the engine test bed since the engine control strategies became more and more sophisticated, expecting correct CAN-bus signals from tyre revolutions, the gearbox and other vehicle components not existing on the engine test bed. For EURO 4 and EURO 5 engines, engine tests without special engine control units from the manufacturers may become nearly impossible. Additionally, the dismounting of the engine from an in-use vehicle to an engine test bed will be much more complex if a controlled after treatment system is present. Due to these difficulties it is assumed that costs for in-use tests at the engine test bed will clearly increase. Thus, alternative strategies for in-use tests have to be developed which are capable of detecting malfunctions as well as effects from potential type approval optimised exhaust behaviour and which are capable of providing the input data necessary for consistent and continuous updates of the emission factor model.

5.2. EMISSION DATA BASE

Mechanistical models based on the use of engine maps have been in use for many years. The use includes vehicle development, road planning and the assessment of emission factors. One problem with this type of model is the huge demand of data in order to reach representativity for vehicle fleets. One such type of data is engine maps. In an engine map fuel consumption or exhaust emissions as a function of engine speed and torque is described. The need of engine maps could be categorized after type of fuel, engine size, type of engine (turbo, intercooler, injection, exhaust gas aftertreatment), legislation class etc. In order to make a data base on engine maps useful some demands on the available data have to be fulfilled:

- A fixed structure for all data
- All data on engine model and type
- Legislation class
- Engine age/mileage
- Engine history, for example test engine from a manufacturer
- Both engine and chassis dynamometer measurements in parallel for validation (not necessary for all engines)
- Settings of the chassis dynamometer

- All background data of importance like: fuel quality parameters; the equipment of the engine (cooling fan connected or not etc.) etc.
- Both steady state and transient measurements
- Test protocol followed for each set of data

The engine map data bank developed in COST 346 includes this information. In total 33 engines and 48 vehicles have been measured within the work of COST 346, D.A.CH.-NL. and ARTEMIS WP400. Additional data on measurements from 69 engines and 3 vehicles was gained from the data collection campaign. All data is included in the data bank. Table 1 and Table 2 give an overview on the available tests.

Table 1: Overview on measured engines COST346, D.A.CH.-NL. and ARTEMIS WP400

Organisation	Engine / Vehicle	certification level	Description
TUG	SCANIA DSC 1201	EURO 2	engine test bed + chassis dynamometer
	FIAT 8060,45,B (in IVECO 120E18/FP Eurocargo)	EURO 2	chassis dynamometer including engine map
	SCANIA DC 1201	EURO 3	engine test bed + chassis dynamometer
	D2866 LF20/ MAN 19.403 Semitrailer	EURO 2	engine test bed + chassis dynamometer
	Volvo D6B220	EURO 3	engine test bed + chassis dynamometer
TNO Automotive	DAF PE183C	EURO 3	engine test bed
	DAF XE 280 C1	EURO 3	engine test bed
	DAF XF 355	EURO 2	engine test bed
	DAF XE 315 C	EURO 2	engine test bed
	Volvo D12D420	EURO 3	engine test bed + ESC on chassis dynamometer
RWTÜV	MAN D0826 LF11	EURO 2	engine test bed
	MAN DO836_LF04	EURO 3	engine test bed
	IVECO Cursor	EURO 3	engine test bed
EMPA	Mercedes OM 442 LA 6/1 V8	EURO 2	engine test bed
	Mercedes OM 441 LA 1/10 V6	EURO 2	engine test bed
	Scania DSC 1201 L01	EURO 2	engine test bed
	Volvo D12A380	EURO 2	engine test bed
	Iveco 120 E23	EURO 2	engine test bed
	Mercedes Benz Actros OM 501 LA	EURO 3	engine test bed
	Volvo FH12, MY2003 (Engine: D12D420EC01)	EURO 3	engine test bed + extensive on-board road measurements
KTI	RABA D10 UTSLL 190 E2	EURO 2	engine test bed + fuel quality influences
	RABA D10 UTSLL 190 E3	EURO 3	engine test bed + fuel quality influences
	RABA D10 TLL 225 E3	EURO 3	engine test bed + fuel quality influences
MTC	Scania DC 1291 420	EURO 3	engine test bed + fuel quality influences
	Scania DC 1201	EURO 3	engine test bed
	VOLVO D12C 01 420	EURO 3	engine test bed + fuel quality effects
	SCANIA DT12 02 470	EURO 3	engine test bed

VTT	Catarpillar C-18 MDP00141	EURO 3	engine test bed
	Cummins N425E20	EURO 2	engine test bed
	Cummins N475E20	EURO 2	engine test bed
	Cummins N525E20	EURO 2	engine test bed
	SCANIA DC 11 03 340	EURO 3	engine test bed
	Volvo DH 10A-285	EURO 2	engine test bed

Table 2: Overview on measured vehicles , D.A.CH.-NL. and ARTEMIS WP400

VITO	FIAT 8060,45,B (in IVECO 120E18/FP Eurocargo)	EURO 2	on-board measurements
	D0826 LUH05 (in MAN bus, NL 202 F)	EURO 1	on-board measurements
	D0826 LUH12 (in Van Hool bus, A600)	EURO 2	on-board measurements
INRETS	Iveco Daily 35-8	EURO 1	chassis dynamometer
	Iveco Solo	EURO 1	chassis dynamometer
	Renault VI R340	EURO 1	chassis dynamometer
	IVECO 100E15	EURO 2	chassis dynamometer
	Renault VI M250.12/c	EURO 2	chassis dynamometer
	Renault VI Premium 340.18T	EURO 2	chassis dynamometer
	VOLVO FH12	EURO 2	chassis dynamometer
	Iveco Daily 35-8	EURO 2	chassis dynamometer
	Renault AGORA Citybus	EURO 2	chassis dynamometer
	Renault AGORA Citybus with 'Eminox-System'	EURO 3	chassis dynamometer
TRL	26 HDV	EURO 1, EURO 2	chassis dynamometer
TUG	MB O 405	Pre EURO 1	chassis dynamometer
	MB O 303	Pre EURO 1	chassis dynamometer
	MB 1324	EURO 1	chassis dynamometer
	D2866 LF20/ MAN 19.403 Semitrailer	EURO 2	chassis dynamometer
	IVECO 120E18/FP	EURO 2	chassis dynamometer
	Scania 400 E2	EURO 2	chassis dynamometer
	SCANIA R124 LA 4x2 NA 420	EURO 3	chassis dynamometer
	VolvoD6B220	EURO 3	chassis dynamometer
EMPA	Volvo FH12, MY2003, Euro-3	EURO 3	on-board measurements

Thus, the steady state engine emission maps are based on measurements on 102 HD engines, most of them including a reasonable number of points measured additionally to the type approval test. The average transient correction functions for EURO 0 to EURO 3 were elaborated as empirical functions based on measurements on 27 engines, where at least 3 different transient tests and complete steady state emission maps are available. Fuel quality and cold start tools are described in the Final report of WG A (Rexeis et. al., 2005a).

The engine map points measured proved to be sufficient for the simulation of real world emissions of HDV in most driving cycles. For some low load cycles the accuracy of the model could be improved by adding additional test points at low or zero engine loads with engine speed levels above idling speed.

5.3. METHODOLOGY FOR EMISSION FACTOR SIMULATION

Within the framework of COST 346 several models were applied by the different participating organisations. As there was already at the beginning of COST 346 an agreement between the COST346 group and the Artemis WP 400 activists to combine the resources COST 346, ARTEMIS and D.A.CH-NL. used the model PHEM for the simulation of HDV emission factors. For a given driving cycle (defined by the course of vehicle speed and road gradient over time) PHEM calculates the necessary engine power second per second according to the driving resistances and losses in the transmission system. The actual engine speed is simulated by the transmission ratios and a driver's gear shift model. The actual emission level is then interpolated from engine emission maps. To take transient influences on the emission level into consideration, the results from the steady state emission map are corrected by using transient correction functions. Average engine emission maps for the engine certification levels EURO 0 to EURO 5 have been elaborated. Also a data set on the relevant vehicle characteristics of EURO 0 to EURO 5 HDV has been defined, where each EURO-category is separated into HDV-classes according to vehicle type, maximum allowed gross weight and loading factor. This data set allows the detailed simulation of HDV fleet emissions for any traffic situation with a high accuracy. A scheme of the model is shown in Figure 1.

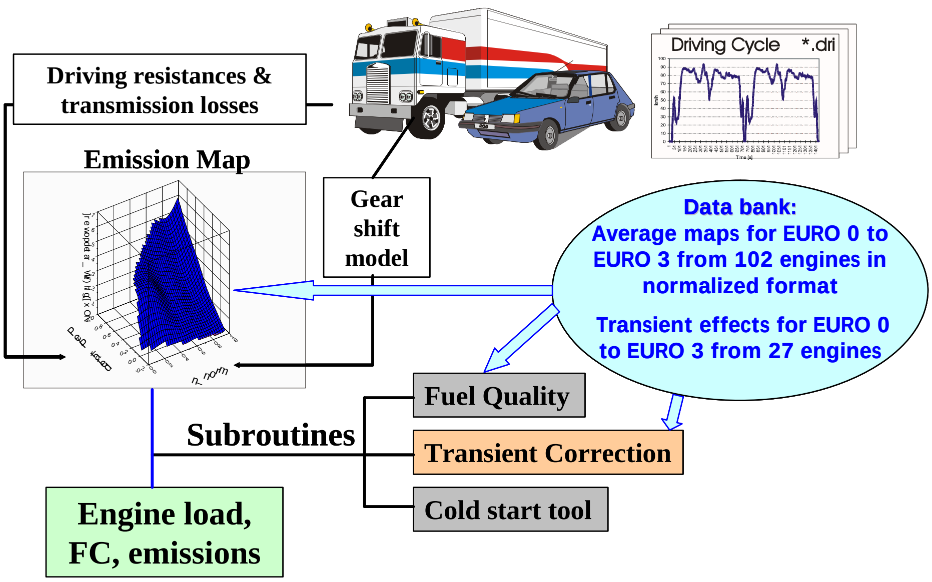


Figure 1: Schematic picture of the model PHEM

The steady state engine emission maps are based on measurements on 102 HD engines, all of them including a reasonable number of points measured additionally to the type approval test. The average transient correction functions for EURO 0 to EURO 3 were elaborated as empirical functions based on measurements on 27 engines, where at least 3 different transient tests and complete steady state emission maps are available (Rexeis et al. 2005). Fuel quality and cold start tools are described in the WG A report.

5.4. RESULTS

The measurement campaign, the data collection and the emission factors calculated show, that HDV manufacturers design the engines and vehicles for highest economy, thus robustness and low fuel consumption at reasonable vehicle costs. As a pleasing result for the emission simulation, the diesel engines up to EURO 3 proved to have very stable emission levels over their lifetime. From in-use tests in the Netherlands (Riemersma

2000), (Rijkeboear, 1998) and Germany (Motzkau, 2001), the conclusion was drawn, that no increase in emissions with mileage could be confirmed by the analysis. More details on the subject of deterioration can be found in section 0.

A less pleasing result for emission inventories was the finding that meeting the exhaust gas limits in type approval is a necessary boundary condition for manufacturers but reaching high fuel efficiency clearly has a much higher market value than low real world emissions. This result is not astonishing at all, but the effects on the real world emission levels of HDV have not been anticipated. Since the market situation encourages manufacturers to optimize fuel consumption wherever possible, the old ECE R 13 mode test was not able to guarantee low NO_x-emissions for the new generation of electronically-controlled engines from approximately the year 1996 on. The reason lies in the known trade-off between fuel efficiency and NO_x emissions. For a given engine the fuel efficiency can be increased (and particulate emissions decreased) by earlier fuel injection, in return the NO_x emission levels increase.

The effects on real world emissions depend very much on the design of the relevant type approval test. Figure 2 shows the ECE R 49 and the ESC (European Steady State Cycle) as well as the additional off-cycle points measured in the ARTEMIS-COST 346 program.

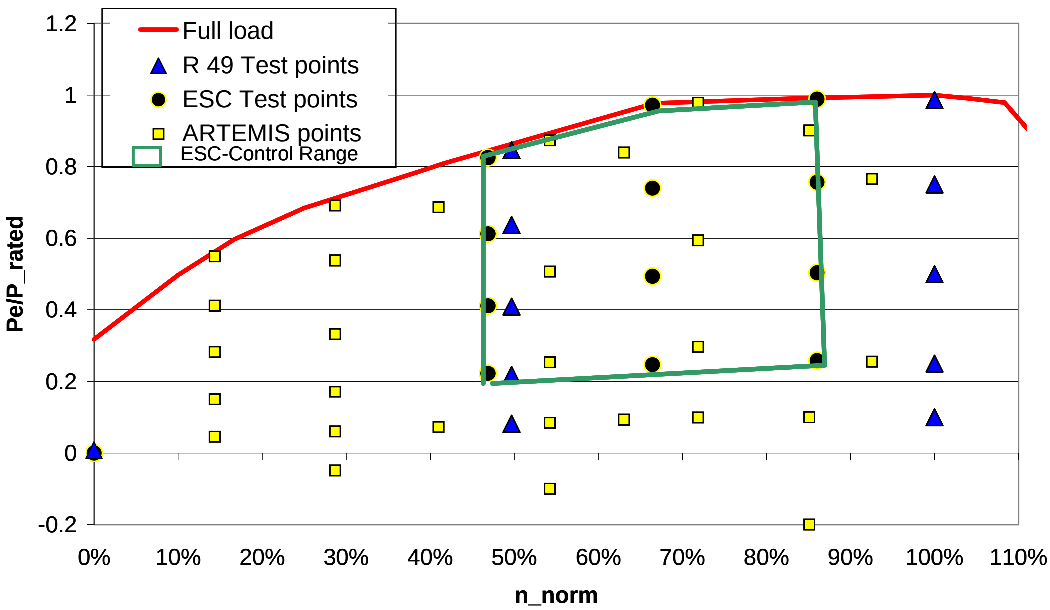


Figure 2: Steady-state points measured in the COST 346-ARTEMIS program (example)

Since the ECE R 49 tested 11 single points in the map only, optimisation of fuel consumption everywhere else in the engine map was possible due to the introduction of electronically-controlled fuel injection systems with the EURO 2 technologies. The ESC improved the situation since it has a “control area” where three points are randomly tested. The NO_x emissions in these three points must not exceed the levels of the surrounding type approval points by more than 10%.

As a result, EURO 2 engines only have lower NO_x levels than EURO 1 at the ECE R 49 test points. Off-cycle the levels are higher than for EURO 1 engines. The tested EURO 3 engines show a different setting according to the new ESC. Outside of the control range, also for EURO 3 engines, an optimization for the specific fuel consumption with increased NO_x-emissions can be observed (Figure 3).

Since vehicles in real traffic most likely do not match the load of the test points but drive in all areas of the engine map, real world NO_x emissions from HDV can differ from type approval values significantly.

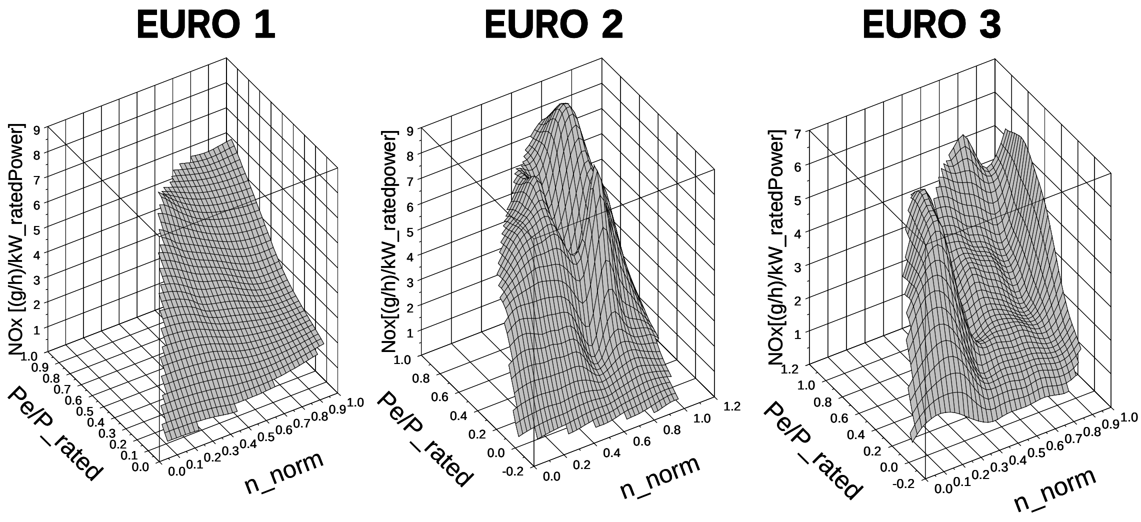


Figure 3: Typical NOx-emission map designs for EURO 1 to EURO 3 HD engines

The simulated NO_x emission factors correspond to the findings from the engine tests. The calculated NO_x emissions of EURO 2 engines are on average nearly on the same level than for EURO 1 engines. The NO_x emission level of the EURO 3 vehicles are below EURO 2 again, but the trend depends on the driving cycle (Figure 4 exemplarily shows a comparison of calculated emission factors for the emission standards Pre EURO 1 to EURO 5 for 20 different driving cycles[1].). While on fast highway cycles EURO 3 is approximately 20% below EURO 2, in slow stop & go traffic the NO_x-emission levels of EURO 2 and EURO 3 engines are nearly equal. This results from the different engine loads of the cycle. In the stop & go cycle a high share of low engine speeds occurs where the ESC has no test points.

[1] This picture aims only in a comparison of the emission levels of different emission standards. An evaluation of other effects like speed limits on the HD emissions can only be performed based on a special selection of driving cycles.

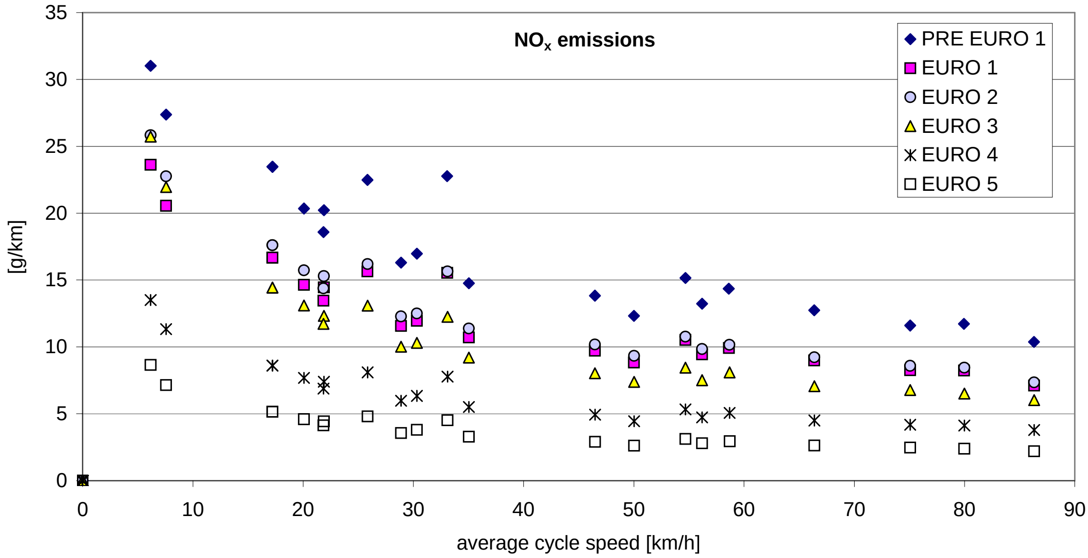


Figure 4: Simulated NOx-emission factors for truck trailers and articulated trucks 34 to 40 tons, 50% loaded, 0% road gradient

The emission behaviour of EURO 4 and EURO 5 HDV is very hard to predict at the moment since the technologies used are new and no production vehicle with these technologies was available for measurements within the duration of the projects. Most likely emissions will drop clearly, but in-use tests seem to be necessary to prevent that emission levels in real world driving exceed the type approval values significantly. Assuming rational engine control mechanism over the complete engine map, the NO_x emissions of EURO 4 may be on average 40% lower and for EURO 5 more than 60% lower than for EURO 3.

In contrast to NO_x, particulate emissions dropped by approximately 60% from “pre EURO 1” to EURO 2 vehicles. For the EURO 3 vehicles on average about the same PM emission level is simulated as for EURO 2. For EURO 4 and EURO 5 a reduction of more than 80% is predicted compared to EURO 3.

Most of the former HDV emission factors for EURO 2 and 3 were based on extrapolation according to reductions of the type approval limits compared to EURO 1. Reason was, that the last extensive measurement program was performed in the early 90ies (Hassel et al. 1995) and included measurements on EURO 0 and some EURO 1 engines only. Therefore the actual emission factors for NO_x are clearly higher than those in previous models, e.g. Rexeis et al. (2005), Hausberger et al. (2003). The actual measurements show, that emission factors have to be based on a sufficient sample of measured engines or vehicles. Assumed emission factors may result in reduced emissions in the inventory but not necessarily in real life.

5.5. RECOMMENDATIONS

There are several models on the national level which deliver fuel consumption and emission factors quite accurately. However, at the moment all data indicates that the emission model PHEM, comprising also the input data for delivering fleet emission factors, is quite accurate for predicting the emissions of HDV in any traffic situation. The model has been used in several applications since the year 2002. The experience gained from both, the point of model developer and from the view of the model user leads to conclusions and recommendations summarized in the following.

5.5.1. Application of emission factors for HDV

The effort necessary for elaborating emission factors depends on the accuracy and flexibility needed from the results. Here some experiences from developer and users of PHEM are given, where the model PHEM was used for simulation of single streets as well as for delivering average emission factors for HDV in Europe.

An advantage of PHEM compared to emission factors measured directly on the roller test bed proved to be the flexibility concerning the input data to be handled. Since the knowledge on "average traffic situations" improved, the basic driving cycles for the emission factors changed in the last years. Such changes cannot be taken into consideration in a finalised measurement program as the model input data can be changed whenever necessary.

Using the model PHEM and the resulting emission factors can be done on different levels:

a) Highest accuracy can be reached when the driving cycles used as model input are measured directly for the traffic situation under consideration. Uncertainties still remain from the model itself (approx. +/-5% for fuel consumption, less than +/- 20% for NO_x, PM, HC in single cycles for known vehicles) and from the data on the fleet composition. In standard applications the share of HDV with different size and shape is most often not known and also the loading usually is not measured. ARTEMIS provides default values for these parameters but the local situation can differ significantly. Thus, the accuracy of the absolute emission level will be determined rather by the data on the fleet composition than by the accuracy of the driving cycle. Thus, for most accurate results also the fleet composition has to be recorded. For more reliable vehicle characteristics a measurement program on driving resistances of HDV would be necessary since no actual data can be found in the literature. However, if effects of measures influencing the driving behaviour shall be estimated, a detailed simulation based on the "average fleet composition" shall give quite accurate relative changes of emissions.

b) Using the emission factors already prepared for ARTEMIS or for the HBEFA saves the effort for measuring driving behaviour and for extra simulation runs with PHEM but increases the uncertainties since it is not possible to exactly cover all potential real world traffic situations with predefined driving cycles. Already the interpolation between the stepwise defined road gradients (0%, 2%, 4%...) can result in several percent inaccuracies, e.g. Hausberger et al. (2003). Uncertainties arising from choosing a not very well suited cycle from the ARTEMIS set are in the range of approx. 10% for highway driving to more than 30% at slow urban traffic and may depend very much on the experience and the carefulness of the user. Experience with the huge set of traffic situations predefined in ARTEMIS is very limited yet. Still the uncertainties of the fleet composition may be dominant for assessing the absolute emission level. For $NO_{x,}$ also the influence of the ambient temperature and humidity can contribute to the uncertainty (Hausberger et al. (2003).

As a summary it can be said, that for most applications the emission factors already calculated for the huge set of traffic situations defined in ARTEMIS shall be appropriate. For special situations model runs with PHEM can quickly produce emission factors for new traffic situations. Users should have the unavoidable uncertainties in the data on the fleet composition, in the selected driving cycle and in the model itself in mind when making interpretations of their results.

5.5.2. Updates of Emission Factors for Future Technologies

As mentioned before, the emission factors for EURO 4 and 5 HDV are estimations not based on any measured production engine. Learning from the past it can be stated that such estimations have a very high uncertainty. The actual estimations may be rather optimistic since rational electronic engine control strategies and a restrictive OBD are assumed for all vehicles everywhere in the engine map. These assumptions are not completely reflected in the actual type approval directive for EURO 4 and 5.

Potential errors in the prospects on future vehicle emission factors would not affect the accuracy for the complete model when predicting 2006 or 2007 very much since wrong emission factors would be attributed only to the part of the new registered vehicles. For views beyond 2008, updated emission factors based on measured EURO 4 and 5 HDV are crucial. Especially for monitoring the compliance with existing European emission and air quality targets for NO_x and PM10 regular updates with emission factors of the actual HD technologies seem to be highly relevant.

The measurement program for ARTEMIS and COST 346 was designed to improve the understanding of transient effects and to provide basic data to be in the position to make use of as much of the existing measurements as possible. Both tasks will still be valid for future updates since effects of transient engine loads can be completely different for EURO 4 and 5 engines than for the EURO 3 ones and certainly all the data already elaborated shall still be useful.

Since the knowledge on driving behaviour and traffic situations will improve and emission factors for different cycles may be necessary in future, the data and model approach from PHEM seem to be useful also in future for the EURO 0 to EURO 3 HDV. Thus, updates should rather try to fill new data into the model than to invent a new model (as long as the existing model works sufficiently). This would require the measurement of engine emission maps for EURO 4, 5 etc..

To dismount the engine and the after treatment system with all their electronic control devices from a vehicle and to assemble the system on the engine test bed and to allocate the correct signals to all inputs of the electronic control unit (ECU) would be very difficult, time consuming and expensive without the support of the manufacturers. Being dependent on special ECUs for the test bed provided by the manufacturer of the engine would not fulfil basic requirements of independent testing. Even with support of the manufacturers, emission measurements of future HD in-use engines most likely will be much more expensive than the actual ones. This makes measurements of the complete HDV attractive. Until today HDV emission measurements, either on-board or on roller test beds, rather have been used to set up emission factors directly, e.g. as speed dependent emission curves. To be compatible with the actual emission factor model a different approach is necessary, since engine maps have to be produced. This leads to the following possibilities:

a) Measure steady state engine emission maps + transient cycles at the roller test bed.

b) Measure transient cycles only and calculate transient engine maps from the tests.

Both methods are feasible. a) is very similar to the actual method used in ARTEMIS/COST 346. Only the accuracy of meeting the engine torque exactly on a roller test bed is somewhat lower than on the engine test bed. But steady state engine maps would be available and transient correction functions could be gained from the transient tests.

When applying on-board emission measurements, method a) is not feasible since it would be hard to drive several defined steady state engine loads long enough to get reliable emission values. Thus, for on-board measurements the engine map has to be filled from the transient test cycles driven on the road. A similar method is already used in the model PHEM for simulating passenger cars. In this application engine emission maps are gained from the transient CADC (Common ARTEMIS Driving Cycle) measured on the roller test bed. The principle is rather simple, the instantaneous measured emissions (e.g. 1 Hz) are allocated to the associated engine power and engine speed. This already gives an engine map. To be able to take transient effects into consideration, for each point in the engine map the relevant information of "how transient" this point was in the measurement has also to be stored. This is done via the transient parameters, e.g. the derivation of torque and engine speed and the number of load changes per time unit. For each point in the map the emission value and the transient parameters are stored. When calculating a new cycle, emissions are interpolated from the map according to the actual engine power and engine speed as usual. Effects of transient loads on the emission level are calculated relative to the transient level of the points in the map. This is similar to the actual method for HD engines but the transient level of the map is actually zero since the emission maps are gained from steady state tests.

Figure 5 gives an example for the resulting mapping of CO and for one of the transient parameters for a passenger car. Details are described in Zallinger et al. (2005).

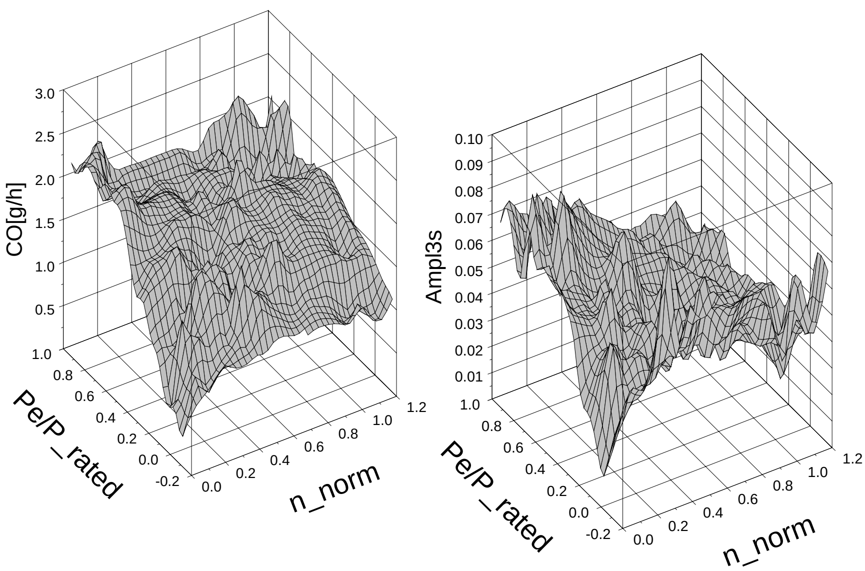


Figure 5: Engine map for CO emissions of a EURO 3 passenger car diesel engine and corresponding engine map of one of the transient parameters

Such a method would be fully compatible with the existing input data of the model PHEM. Advantages would be that engine tests, roller tests and on-board measurements could be used to gain input data for the model. This would save costs and/or increase the sample of HDV measured. One prerequisite for setting up transient engine maps is the exact knowledge of the time delays and smoothening effects in the emission measurement system and the elaboration of functions for compensating those effects. Otherwise, emissions would be allocated systematically wrong to engine loads. Corresponding methods were elaborated already in ARTEMIS, e.g. Tuan Leh Ahn (2005).

Since HDV emission measurements, even with such alternative methods, would not be cheap, a European cooperation in this task would be very advantageous. To gain the results as long as the vehicles are still under production would allow to react on potential discrepancies in time and to find mechanisms to change control strategies in the production. This would need a quite immediate start of a project.

5.6. SUMMARY

European projects on HDV emission factors like Artemis are finalised, providing results for EURO 0 to EURO 3 based on a large number of measured engines and vehicles, while the emissions of EURO 4 and 5 are based on assumptions only.

The emission behaviour of the modern HD engines measured in the projects as well as the emission factors calculated showed that real world emission levels can differ significantly from the type approval levels. Mainly NO_x emissions proved to be higher in real world cycles than in the R 49 or ESC from EURO 2 on. This is due to the trade-off between fuel consumption and NO_x emissions. Since engines have to be robust and fuel efficient to be competitive on the market, engines are optimized towards low fuel consumption whenever possible. This resulted in rather high NO_x-emissions outside of the type approval tests. Even an ideal type approval system for actual technologies may soon have gaps for future technologies.

Thus in-use tests based on real world driving with the complete vehicle using on board emission measurement equipment or roller test bed measurements may be an important tool in future when low emissions shall be guaranteed. Such in-use tests could also check the durability of the new technologies introduced with EURO 4 and EURO 5. Such tests would have to be performed in time to be able to react as long as the vehicles are still produced. This means that such a program has to be started immediately.

Such in-use tests could also be used to feed emission factor models like PHEM with data for easy updates if the test program is designed correspondingly. In ARTEMIS WP 300 it has been shown that the model PHEM can transfer instantaneous emission measurements from transient cycles on the roller test bed into useful engine emission maps to produce emission factors. Such a method could lower the costs for updates significantly since measurements on the engine test bed for in-use EURO 5 HDV may become very expensive due to the complex technology. Even more, engine tests without special engine control units may become quite impossible for future HD engines, thus new methods are necessary if tests independent from the manufacturers shall be preformed.

6. Driving behaviour of heavy goods vehicles (working group AB, H. Steven RWTÜV, D, M. André, INRETS, F)

6.1. INTRODUCTION

The emission estimation for heavy duty road vehicles (HDV) is based on the emission model presented in the previous chapter. This programme calculates emission factors for driving cycles and needs then vehicle speed pattern versus time with 1 Hz resolution as input data. The resulting emission data are then used as a database for the overall emission model, whose main branch is based on road types and traffic situations.

In this chapter, a conceptual framework for the estimation of the emissions at this level is defined as a first step. The analysis of the existing road classifications and the taking into account of the emission parameters enable the definition of a classification matrix into traffic situations, combining road types and characteristics and traffic conditions.

Driving behaviour data is then collected and analysed to produce driving patterns (i.e. speed versus time curves) for each of the predefined traffic situations.

6.2. CLASSIFICATION MATRIX AND DRIVING BEHAVIOUR DATABASE

6.2.1. The road type/traffic situation classification matrix

The estimation of the pollutant emissions from the road transport is needed at a low spatial scale for detailed inventories or impact studies. Such a local approach implies the definition of a structure in traffic situations, which should be understandable across the different countries and users, and preferably close to the classifications usually implemented by traffic engineers (André et al. 2005b, Fantozzi et al. 2005). A traffic situation scheme (TSS) should cover the road characteristics (width of the lanes, sinuosity, gradient, speed limit, junctions, etc.) and the traffic conditions.

The existing road classifications generally distinguish urban and rural situations. In the following of international works, the definition of “urban” should follow a “morphological” point of view (i.e. continuity of the buildings around a centre and coherence) or a functional point of view (Functional Urban Area). Indeed, the city and the road network are generally managed at this scale, and mobility, traffic conditions and speeds are to a large extent linked to these structural aspects. According to such views, isolated villages and small towns are considered as rural, while there can be rural territories within an urban area and indeed crossed by the urban traffic.

It was proposed to consider a road classification based primarily on the function (access / distribution / through) and on the road network hierarchical organization (Figure 6). The distinction between motorway and normal road and the road characteristics – generally linked to the function (lane wide, parking, junctions type and density) – were then considered according to the most usual practices in Europe to propose a common urban and rural road typology (Table 3, Table 4). Obviously, local specificities and exceptions can occur.

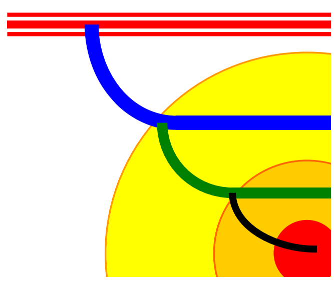


Figure 6: Hierarchisation of the road network (Artists, 2004)

Table 3: Urban roads typology

Main function	Comments	Characteristics	Speed limit (km/h)
National and regional network - Through-traffic	High-speed or major road through an urban area. - Regional or national traffic	5a - Motorway	80 - 130
		5b - Not motorway	70 - 100
Agglomeration primary network - Primary distributors, primary roads	High-speed or major roads through the urban area major. Quick exchanges at city scale	4a - Motorway (ring, etc.)	60 - 110
		4b - Not motorway	50 – 90
Districts distributors	Connection between districts or poles and access to/from primary distributors	3 - Road	50 - 80
Local distributors - Inner exchange and local traffic	Connection between communities and within districts. Access to/from district distributors	2 - Road	50 – 60
Access roads - Local traffic.	Access to housing and business places.	1 - Road, cul-de-sac, side road	30 - 50

Table 4: Rural roads typology

Main function	Comments	Characteristics	Speed limit (km/h)
National and regional network - Through and distribution	High speed or major road through the rural area. Regional or national traffic, and connection between villages, towns	5 - Motorway	80 - 150
		4 - Trunk road	60 - 110
Distributors	Connection between villages, towns and access to/from national/regional network	3 - Road	50 - 100
Local distributors - Inner exchange and local traffic	Roads through villages, and occasional access to properties such as farms	2 - Road	50 - 80
Access roads - Local traffic	Access to properties, residential roads	1 - Road, cul-de-sac, side road	30 - 50

The road gradient and the sinuosity (due to their significant influence on the HDV driving conditions, emissions and fuel consumption) should also be considered. These 2 parameters are linked as sinuosity is generally observed in mountainous area. For large scale estimation, a qualitative approach was proposed (Table 5) possibly associated with macroscopic indicators (sum of angle changes per kilometre in radians/km, sum of changes in height in m/km). Indeed the local gradient, (one or both directions, i.e. +4% or ± 4%) should be only applied to a very local scale (a short road section), and has no meaning at a large scale (one trip, one itinerary or a part of a road network). Because of the poor information about the sinuosity in the driving behaviour database the classification matrix contains this parameter only for rural distributor and local roads. The same applies for the macroscopic indicators.

Table 5: Gradient and sinuosity typology

1	Flat and non-sinuous	Low sinuosity without influence on the speed
2	Flat and sinuous	Sinuosity with influence on the speed
3	Hilly straight roads	Long ramp on main roads and motorways
4	Hilly and sinuous,	
5	Mountainous and strongly sinuous	of which the Alps are a particular case

The existing traffic conditions "scales" (from free-flow to congestion) are not really coherent. The worst condition (level F) of the well-known Highway Capacity Manual (HCM, 2000) (speed in the order of 50% of the free speed, vehicle density about 30 veh/km/lane) seems quite far from the stop-and-go condition. For a good coverage of the actual traffic conditions, a structure in 4 levels was proposed (Table 6, Figure 7), with free-flow traffic (levels A-B of the HCM, average speed between 85-100% of the free speed), heavy traffic (constraint speed in the range 65-85% of the free speed, HCM levels C-D), unsteady quite saturated traffic (HCM Level E or even worst, variable speed with possible stops in the range of 30 to 60% of the free speed) and the stop-and-go (speed in the range of 10 km/h). To avoid misunderstandings it must be mentioned that the vehicle speeds in Table 6 are related to the whole fleet while the vehicle speeds in the following chapter are related to HDV's only.

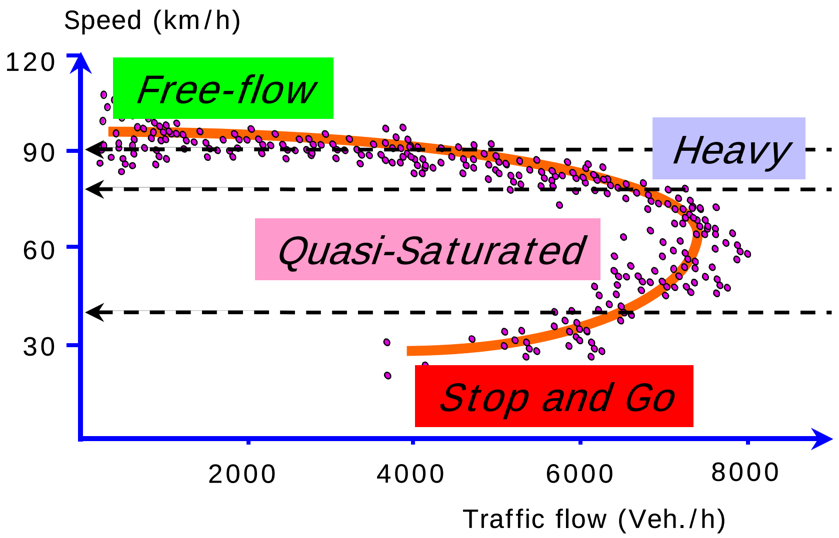


Figure 7: Four levels of service as regards speed and traffic capacity

Table 6: Traffic conditions and typical speed ranges for 2 contrasted cases

Traffic level and conditions		Indicative speed range (km/h)	
		Motorway, 110 km/h	Road, 50 km/h
1	Free flow (free flowing conditions, low and steady traffic flow. Constant and quite high speed).	90 - 120	45 - 60
2	Heavy traffic (free flowing with heavy traffic. Constraint but quite constant speed.)	70 – 90	30 - 45
3	Saturated traffic (heavy and unsteady flow, quite saturated traffic. Variable intermediate speeds, with possible stops.)	30 – 70	15 - 30
4	Stop and go (heavily congested flow, stop and go or gridlock. Variable and low speed and stops.)	5 – 30	5 - 15

The resulting classification matrix for road types and traffic situations developed in coordination between the working groups B and AB and ARTEMIS is recapitulated in Annex I.

6.2.2. Description of the Database

In order to derive appropriate vehicle speed pattern curves for each cell of the road type and traffic situation matrix, in-use driving behaviour data for HDV was analysed. This data was the European part of the extensive HDV in-use driving behaviour data from different regions of the world analysed within the ECE-GRPE ad hoc working Group WHDC to derive a worldwide harmonised engine test cycle for the emissions certification procedure of heavy-duty engines (work by RWTUEV, Germany and TNO Automotive, Netherlands). The RWTÜV database (Table 7) contains driving behaviour data of

- 13 rigid trucks with gross vehicle mass (GVM) between 5600 kg and 28000 kg,
- 11 trailer/semitrailer trucks with GVM between 28000 kg and 40000 kg,
- 7 urban buses (standard and articulated) and
- 1 coach.

Complementary in-use driving behaviour data were made available by TRL (a truck and an urban bus, see Table 8), INRETS, TECHNION and TNO (urban buses data and cycles, see Table 9 to Table 11). These data were however not taking into account in the analysis.

Table 7: Vehicles and mileage of the in-use driving behaviour database (RWTÜV)

Region	veh. No	vehicle	gross vehicle mass in kg	engine type	engine capacity in cm³	rated power in kW	rated speed in min^{-1}	distance driven in km
Germany	1	rigid truck	7490	naturally aspirated	5917	100	2800	237
Germany	2	rigid truck	5800	naturally aspirated	3927	50	2600	380
Germany	3	rigid truck	5600	naturally aspirated	3972	63	2800	331
Germany	4	rigid truck	13300	turbocharged	5638	112	2800	129
Germany	5	rigid truck	16000	turbocharged	5917	125	2600	291
Germany	6	rigid truck	24000	naturally aspirated	10888	143	2300	315
Germany	7	rigid truck	17000	turbocharged	6550	148	2600	343
Germany	8	rigid truck	17000	turbocharged	5917	125	2600	412
Germany	9	rigid truck	18000	naturally aspirated	11309	153	1800	230
Germany	10	rigid truck	24000	air cooled turbocharged	9973	198	2000	324
Germany	11	rigid truck	9650	naturally aspirated	6560	92	2300	408
Germany	12	trailer/semitrailer truck	30500	naturally aspirated	14517	162	2300	303
Germany	13	trailer/semitrailer truck	28000	naturally aspirated	10888	151	2300	538
Germany	14	trailer/semitrailer truck	30000	air cooled turbocharged	6871	169	2400	321
Germany	15	trailer/semitrailer truck	40000	air cooled turbocharged	11967	265	2200	1007
Germany	16	trailer/semitrailer truck	40000	air cooled turbocharged	11884	198	2200	352
Germany	17	trailer/semitrailer truck	40000	air cooled turbocharged	14618	326	2100	847
Germany	18	trailer/semitrailer truck	40000	air cooled turbocharged	13798	277	1800	1192
Germany	19	urban bus	22500	naturally aspirated	10350	142	2100	262
Germany	20	urban bus	16000	naturally aspirated	10350	142	2100	261
Germany	21	urban bus	27600	air cooled turbocharged	11884	177	2200	312
Germany	22	urban bus	17600	naturally aspirated	11334	150	2200	132
Germany	23	urban bus	12300	turbocharged	6596	137	2600	66
Germany	24	urban bus	17600	naturally aspirated	11334	157	2400	241
Switzerland	25	rigid truck	13000	air cooled turbocharged	5958	177	2600	1008
Switzerland	26	rigid truck	28000	turbocharged	11950	232	2000	350
Switzerland	27	trailer/semitrailer truck	28000	turbocharged	11970	240	2200	1631
Switzerland	28	trailer/semitrailer truck	28000	air cooled turbocharged	11000	252	2000	1233
Switzerland	29	urban bus	17000	naturally aspirated	11967	177	2200	402
Switzerland	30	coach	16000	turbocharged	14618	309	2100	503
Europe	31	trailer/semitrailer truck	40000	air cooled turbocharged		390	1800	10075
Netherlands	46	trailer/semitrailer truck	41380	air cooled turbocharged	8660	191	2300	2243
							sum	**26679**

Table 8: In-use driving behaviour (TRL)

vehicle cat	route no	route	average speed in km/h	time in s	distance in km	percentage of standstill
HDV	1	Traffic Calming - Speed Humps Cycle	20.5	1011	5.8	3.4%
HDV	2	Traffic Calming - Other Cycle	26.8	901	6.7	3.3%
HDV	3	Bus Lane Cycle	25.4	931	6.6	16.5%
HDV	4	Traffic Lights Cycle	19.1	955	5.1	22.1%
HDV	5	One-way Cycle	15.3	948	4.0	21.2%
HDV	6	Mini-roundabout Cycle	22.5	928	5.8	6.8%
HDV	7	Control: Congested Cycle	10.8	836	2.5	27.9%
HDV	8	Control: Non-congested Cycle	36.2	876	8.8	4.3%
HDV	9	Control: Suburban Cycle	23.3	791	5.1	5.2%
HDV	10	Cycle Lane Cycle	24.9	986	6.8	6.8%
urban bus	1	Traffic Calming - Speed Humps Cycle	20.2	945	5.3	5.8%
urban bus	2	Traffic Calming - Other Cycle	25.0	856	5.9	6.2%
urban bus	3	Bus Lane Cycle	25.2	1193	8.3	11.3%
urban bus	4	Traffic Lights Cycle	21.8	895	5.4	15.3%
urban bus	5	One-way Cycle	16.6	942	4.4	20.1%
urban bus	6	Mini-roundabout Cycle	26.3	1077	7.9	2.7%
urban bus	7	Control: Congested Cycle	10.5	1052	3.1	19.8%
urban bus	8	Control: Non-congested Cycle	27.8	984	7.6	10.0%
urban bus	9	Control: Suburban Cycle	26.0	887	6.4	7.6%

Table 9: In-use driving behaviour data and cycles for urban busses from INRETS

	Characteristics	average speed (in km/h)	time in hour or s	distance in km	percentage of standstill
Driving data					
1	**High density areas**	**13.9**	**357 h**	**4 985**	**40.5%**
2	**Remote housing area**	**19.4**	**497 h**	**9 623**	**23.3%**
3	**Remote and dense mixed housing area**	**19.3**	**278 h**	**5 419**	**22.0%**
4	**Concentrated council housing area (town centre)**	**11.5**	**432 h**	**4 970**	**42.6%**
All		***16.0***	***1 564 h***	***25 000***	***32.4***
Driving cycles					
1	**City centre driving cycle**	**13.0**	**1652 s**	**6.0**	**39.9%**
2	**Inner suburb (and link) driving cycle**	**29.1**	**1375 s**	**11.1**	**14.8%**
3	**Remote suburb driving cycle**	**19.2**	**1474 s**	**7.9**	**26.0%**

Table 10: In-use driving behaviour data for an urban bus from TECHNION

cycle	average speed in km/h	time in s	distance in km	percentage of standstill
1a	15.1	19771	82.8	35.4%
1b	17.8	3209	15.8	30.2%
2a uphill	19.6	2337	12.7	33.5%
2b downhill	24.8	1965	13.5	24.9%
3	7.1	8327	16.4	53.9%
4a	18.3	5783	29.5	41.5%
4b	21.1	5241	30.8	33.5%

Table 11: The Dutch urban bus transient cycle and the Braunschweig cycle

cycle	average speed in km/h	time in s	distance in km	percentage of standstill
Braunschweig cyle	22.5	1740	10874	28.7%
Dutch Urban Bus Transient Cycle (DBTC).	21.0	900	5241	29.2%

For all vehicles the following information is available as second by second data: vehicle speed, acceleration, engine speed and engine power. For vehicles 25 to 46 the vehicle mass was kept constant during the journeys, sometimes journeys with different vehicle load were performed. For vehicles 1 to 24 the vehicle mass was varying during the journeys, because these vehicles were measured during their normal use.

The altitude was recorded for vehicles 25 to 31 but even with extreme smoothing it was impossible to derive reliable road gradient values. Therefore an alternative approach was developed to get road gradient information. For all vehicles, whose mass was known and constant, the road gradient was derived from the difference of the measured engine power for a given driving condition and the power calculated for this driving condition and a level road. This provided quite good results for rural roads and motorways. It was however not essential to get a gradient signal for all in-use speed data as the PHEM model manage speed and gradient independently (the vehicle speed pattern remains unchanged as long as the vehicle can follow the speed curve, otherwise the model reduces the vehicle speed in accordance with the required power).

The power to mass ratio, which depends very much on the vehicle mass and thus the vehicle load is also considered by the PHEM model. Since it is known from earlier analyses that the vehicle speed pattern is more influenced by road type and traffic condition than by power to mass ratio or even vehicle size, these parameters were not considered for the further analysis of the in-use driving behaviour database.

6.3. ANALYSIS OF IN-USE DRIVING BEHAVIOUR DATA

The driving behaviour (= driving pattern) of the professional drivers of HDV´s in urban areas is determined mainly by the following factors: the goal speed which is normally the speed limit, the road vertical alignment, the junction density, the traffic management (traffic signals), and the power/load ratio of the vehicle. In rural areas the factors are normally only the goal speed (the speed limit for HDV´s), the road vertical alignment and the power/load ratio of the vehicle. In some models the driving behaviour or driving pattern can be generated by using the influencing parameters mentioned above. But in most of the models it is not possible for the time being. That is why another approach has been used in this project and it will be described in the following.

Concerning road category information the data could be separated into urban, rural and motorway parts. The more specific information needed to assign the in-use data to the different road types of the classification matrix was not available for the major part of the vehicles. For vehicles 25 to 30 the posted speed was also given, but this could only partly be used for the analysis, because it was not always reliable.

Therefore the following approach was chosen in order to derive the appropriate vehicle speed pattern: For the whole database the vehicle speed, the normalized engine speed, the engine load and the road gradient (where possible) were plotted versus time. The engine speed was normalized to the difference between rated speed and idling speed (norm. eng. speed = (eng. speed – idling speed) / (rated speed – idling speed)), so that idling speed is 0% and rated speed is 100%. The engine load was calculated by dividing the actual power by the maximum power, available at the actual engine speed. This calculation requires the full load power curves of the engine.

The vehicle speed pattern was then separated into "homogeneous" parts representing a particular road type/traffic situation. Figure 8 to Figure 10 show examples of such homogeneous parts. The engine load signal is not shown on urban and rural roads, because it is a continuous line up and down which would camouflage the other signals. Figure 11 shows an example of a steep gradient on a motorway. The vehicle speed decreases drastically from nearly 90 km/h, while the engine load goes up to 100%. On a level road the engine load would be typically between 20% and 40% (see Figure 10).

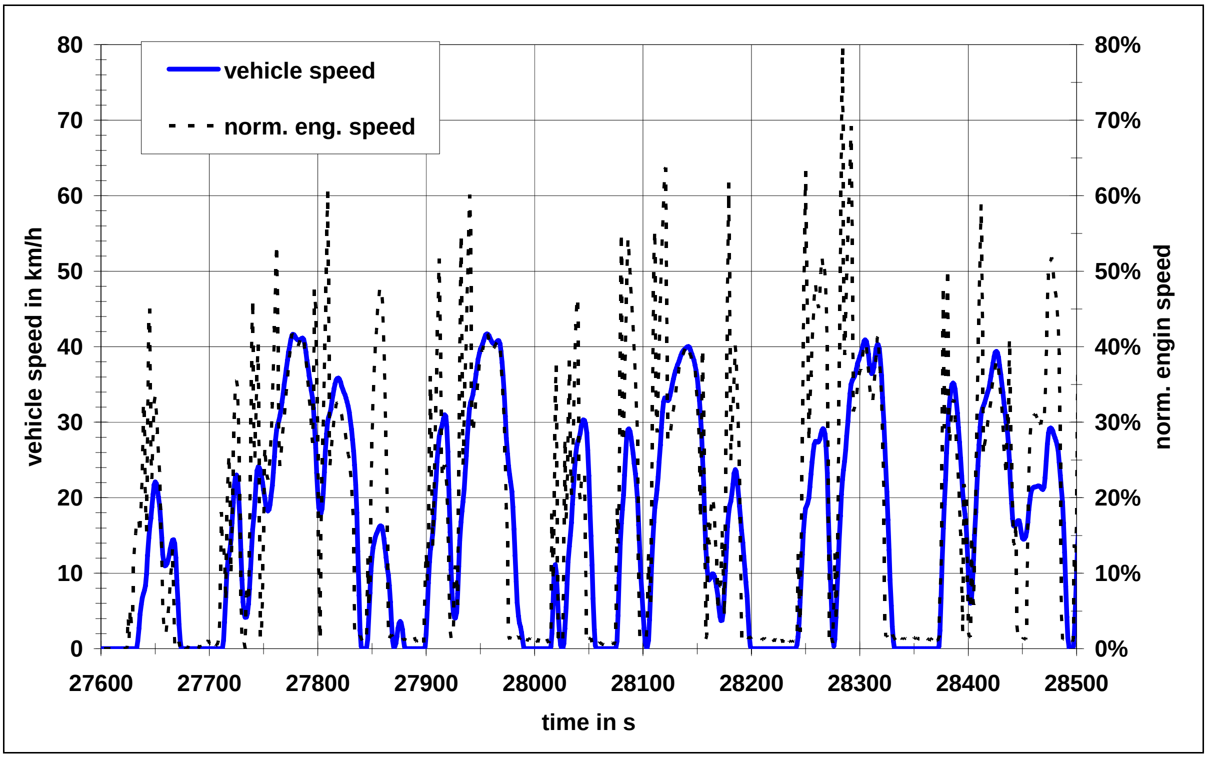


Figure 8: Speed pattern for an urban road with top speed of 40 km/h

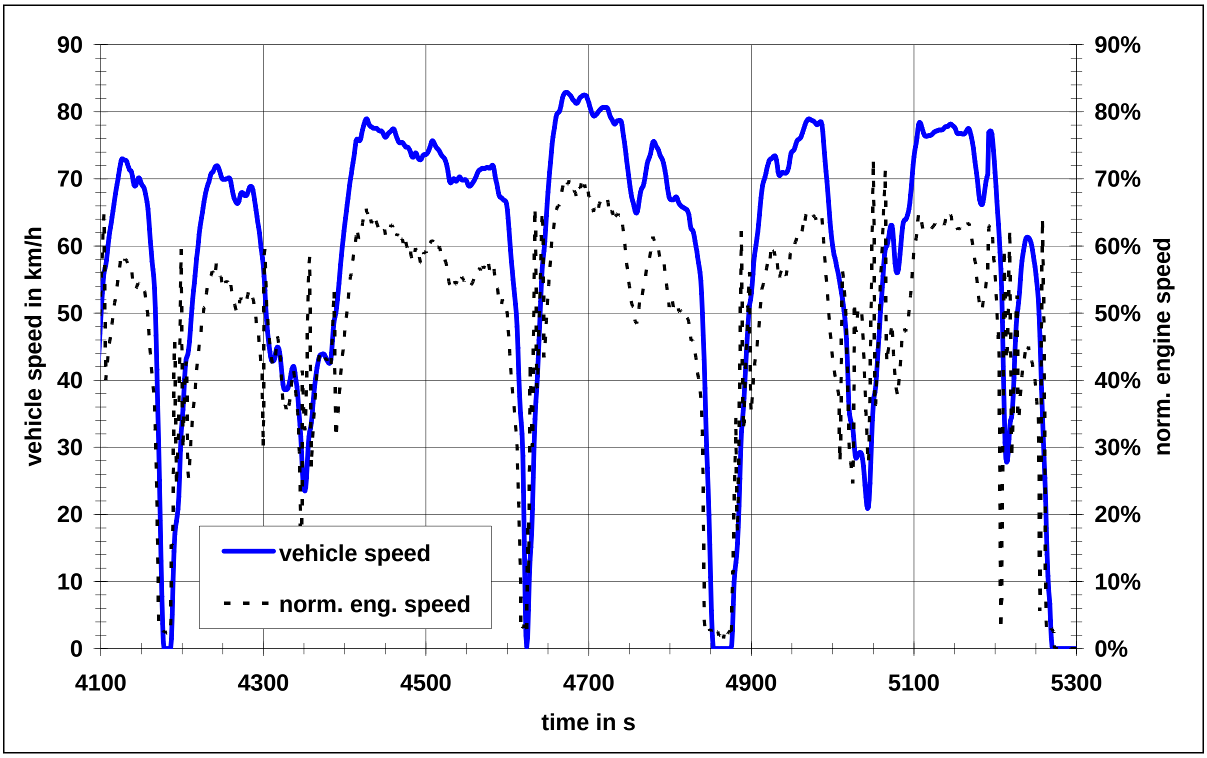


Figure 9: Speed pattern for a rural road with top speed of 80 km/h

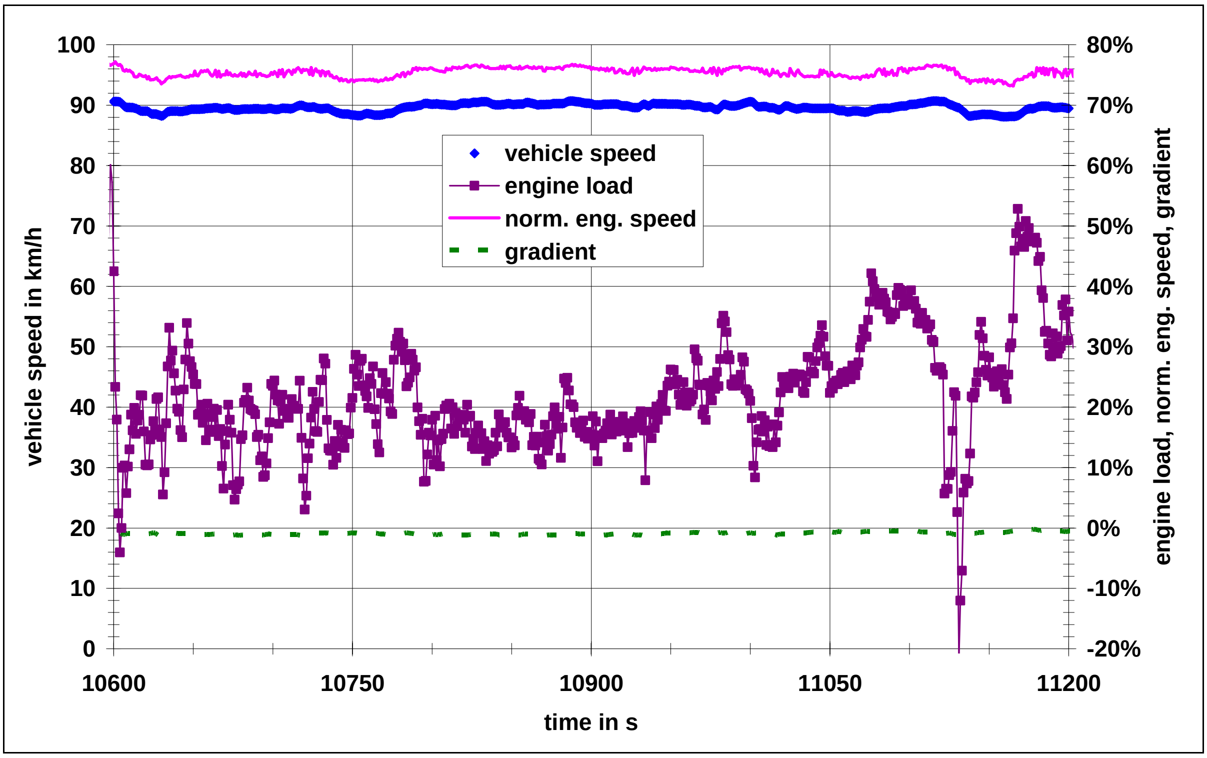


Figure 10: Speed pattern for a level motorway with free flowing traffic

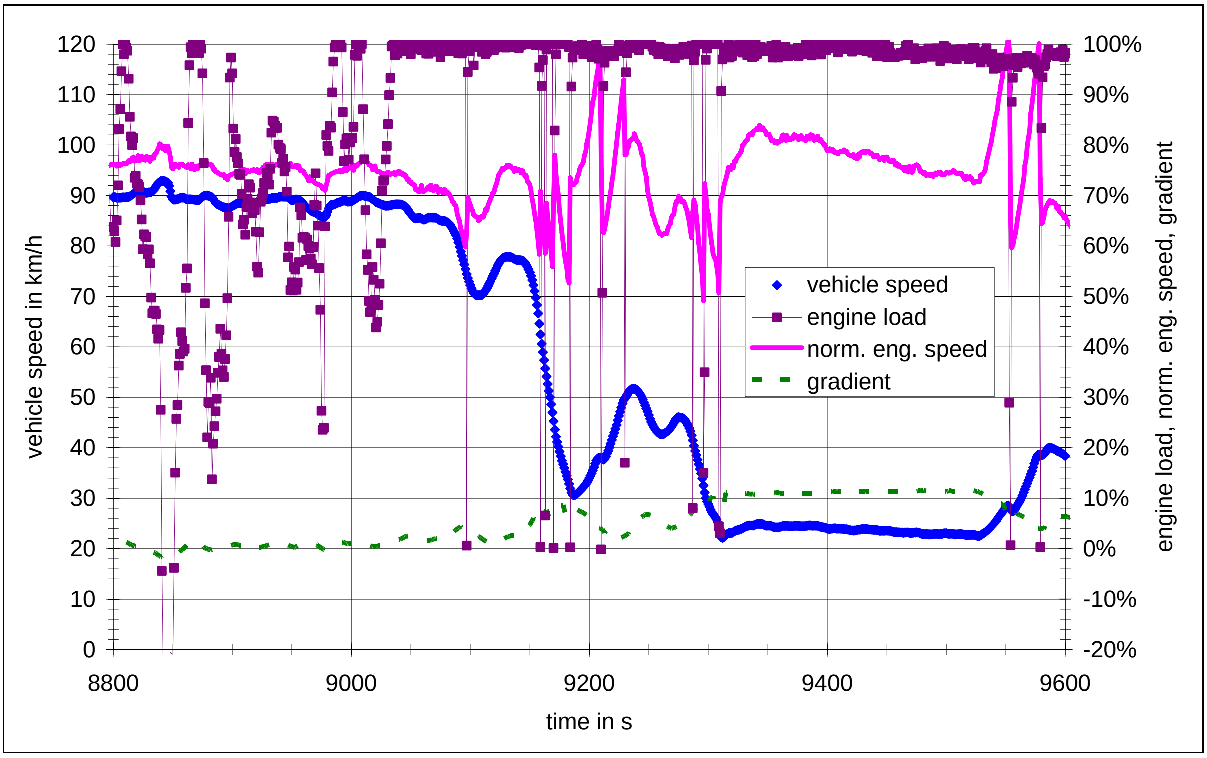


Figure 11: Speed pattern for a motorway with gradient

In order to cluster the homogeneous vehicle speed patterns, the following parameters were calculated for each part:

- average speed with and without stops,
- v_10 and v_90 with and without stops, (v_10 describes the 10% percentile of the vehicle speed distribution)
- v_30, v_50 and v_70 without stops,
- percentage of stop time, number of stops per km:

In addition to that the following parameters were calculated for periods with positive acceleration ($a > 0.1$ m/s²):

- percentage of time and distance in relation to the whole part,
- average positive acceleration,
- a_10, a_90,
- average of the positive acceleration multiplied by the vehicle speed (vma, i.e. the power to mass ratio that is necessary for the acceleration),
- vma_10 and vma_90.

These parameters were then classified (e.g. the vehicle speed in 5 km/h steps) and clustered. Appropriate vehicle speed pattern were then assigned to the different cells of the classification matrix on the basis of these clusters and long-standing experience. In a second step the average speed values and stop percentages were checked for plausibility and consistency. Where necessary, the speed pattern was modified. The results for a part of the classification matrix are shown in Table 12 and Table 13.

Table 12: Average vehicle speeds for the rural and urban traffic situations

area	road type	curvature	level of service	speed limit in km/h									
				30	50	60	70	80	90	100	110	120	130
rural	motorway	low	free flow			58	72	80	80	80	86	86	86
rural	motorway	low	heavy traffic			50	60	75	75	75	80	80	80
rural	motorway	low	saturated traffic			34	39	50	50	50	50	50	50
rural	motorway	low	stop+go			8	8	8	8	8	8	8	8
rural	primary road	low	free flow			56	65	75	75	75	75		
rural	primary road	low	heavy traffic			48	59	66	66	66	66		
rural	primary road	low	saturated traffic			30	30	46	46	46	46		
rural	primary road	low	stop+go			8	8	8	8	8	8		
rural	secondary road	low	free flow		40	48	59	70	70	70			
rural	secondary road	low	heavy traffic		36	43	55	66	66	66			
rural	secondary road	low	saturated traffic		27	30	30	39	39	39			
rural	secondary road	low	stop+go		8	8	8	8	8	8			
rural	secondary road	curved	free flow		34	42	56	65	65	65			
rural	secondary road	curved	heavy traffic		30	39	49	60	60	60			
rural	secondary road	curved	saturated traffic		20	22	22	34	34	34			
rural	secondary road	curved	stop+go		8	8	8	8	8	8			
rural	collector road	low	free flow		34	42	56	65					
rural	collector road	low	heavy traffic		31	39	51	60					
rural	collector road	low	saturated traffic		22	25	25	34					
rural	collector road	low	stop+go		8	8	8	8					
rural	collector road	curved	free flow		33	40	49	59					
rural	collector road	curved	heavy traffic		30	34	45	56					
rural	collector road	curved	saturated traffic		22	22	22	27					
rural	collector road	curved	stop+go		8	8	8	8					
urban	motorway	low	night time			54	66	75	75	75	75	75	75
urban	motorway	low	off rush hours			49	60	66	66	66	66	66	66
urban	motorway	low	rush hours			31	31	45	45	45	45	45	45
urban	motorway	low	stop+go			8	8	8	8	8	8	8	8
urban	primary road	low	night time		35	43	56	65	65	65	65		
urban	primary road	low	off rush hours		29	41	50	60	60	60	60		
urban	primary road	low	rush hours		17	22	22	35	35	35	35		
urban	primary road	low	stop+go		6	8	8	8	8	8	8		
urban	secondary road	low	night time		33	40	48	59					
urban	secondary road	low	off rush hours		26	36	45	55					
urban	secondary road	low	rush hours		17	22	22	27					
urban	secondary road	low	stop+go		6	7	7	8					
urban	collector road	low	night time		30								
urban	collector road	low	off rush hours		22								
urban	collector road	low	rush hours		17								
urban	collector road	low	stop+go		7								
urban	residential street	low	night time	26	39								
urban	residential street	low	off rush hours	20	29								

Table 13: Percentages of stops for the rural and urban traffic situations

area	road type	curvature	level of service	speed limit in km/h									
				30	50	60	70	80	90	100	110	120	130
rural	motorway	low	free flow			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
rural	motorway	low	heavy traffic			3.0%	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
rural	motorway	low	saturated traffic			11.0%	6.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
rural	motorway	low	stop+go			22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%
rural	primary road	low	free flow			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		
rural	primary road	low	heavy traffic			3.0%	1.0%	0.0%	0.0%	0.0%	0.0%		
rural	primary road	low	saturated traffic			12.0%	12.0%	5.0%	5.0%	5.0%	5.0%		
rural	primary road	low	stop+go			22.0%	22.0%	22.0%	22.0%	22.0%	22.0%		
rural	secondary road	low	free flow		2.0%	0.0%	0.0%	0.0%	0.0%	0.0%			
rural	secondary road	low	heavy traffic		5.0%	4.0%	2.0%	1.0%	1.0%	1.0%			
rural	secondary road	low	saturated traffic		13.0%	12.0%	12.0%	6.0%	6.0%	6.0%			
rural	secondary road	low	stop+go		22.0%	22.0%	22.0%	22.0%	22.0%	22.0%			
rural	secondary road	curved	free flow		2.0%	1.0%	2.0%	2.0%	2.0%	2.0%			
rural	secondary road	curved	heavy traffic		7.0%	6.0%	3.0%	3.0%	3.0%	3.0%			
rural	secondary road	curved	saturated traffic		16.0%	12.0%	12.0%	11.0%	11.0%	11.0%			
rural	secondary road	curved	stop+go		22.0%	22.0%	22.0%	22.0%	22.0%	22.0%			
rural	collector road	low	free flow		2.0%	2.0%	2.0%	1.0%					
rural	collector road	low	heavy traffic		6.0%	6.0%	3.0%	3.0%					
rural	collector road	low	saturated traffic		15.0%	15.0%	15.0%	11.0%					
rural	collector road	low	stop+go		22.0%	22.0%	22.0%	22.0%					
rural	collector road	curved	free flow		3.0%	2.0%	1.0%	1.0%					
rural	collector road	curved	heavy traffic		7.0%	4.0%	4.0%	3.0%					
rural	collector road	curved	saturated traffic		13.0%	12.0%	12.0%	11.0%					
rural	collector road	curved	stop+go		22.0%	22.0%	22.0%	22.0%					
urban	motorway	low	night time			2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
urban	motorway	low	off rush hours			3.0%	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
urban	motorway	low	rush hours			13.0%	13.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%
urban	motorway	low	stop+go			22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%
urban	primary road	low	night time		1.0%	1.0%	2.0%	0.0%	0.0%	0.0%	0.0%		
urban	primary road	low	off rush hours		14.0%	7.0%	5.0%	2.0%	2.0%	2.0%	2.0%		
urban	primary road	low	rush hours		26.0%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%		
urban	primary road	low	stop+go		40.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%		
urban	secondary road	low	night time		2.0%	2.0%	1.0%	0.0%					
urban	secondary road	low	off rush hours		11.0%	8.0%	8.0%	4.0%					
urban	secondary road	low	rush hours		26.0%	22.0%	22.0%	11.0%					
urban	secondary road	low	stop+go		40.0%	35.0%	30.0%	22.0%					
urban	collector road	low	night time		3.0%								
urban	collector road	low	off rush hours		12.0%								
urban	collector road	low	rush hours		23.0%								
urban	collector road	low	stop+go		35.0%								
urban	residential street	low	night time	3.0%	2.0%								
urban	residential street	low	off rush hours	9.0%	6.0%								

6.4. PUBLIC TRANSPORT BUS CYCLES

Figure 12 shows the main kinematic parameters average speed and percentage of stops for the in-use driving behaviour data of urban buses and for different available urban bus driving cycles. The percentage of stops is about 40% at an average speed of 15 km/h, 28% at 20 km/h, 20% at 25 km/h and goes down to 10% at 40 km/h.. City centre driving routes have average speeds below 17 km/h, liaison and suburb routes have average speeds between 17 and 25 km/h. The average speeds for distant suburb routes are between 25 and 35 km/h and town to town service has average speeds around 40 km/h.

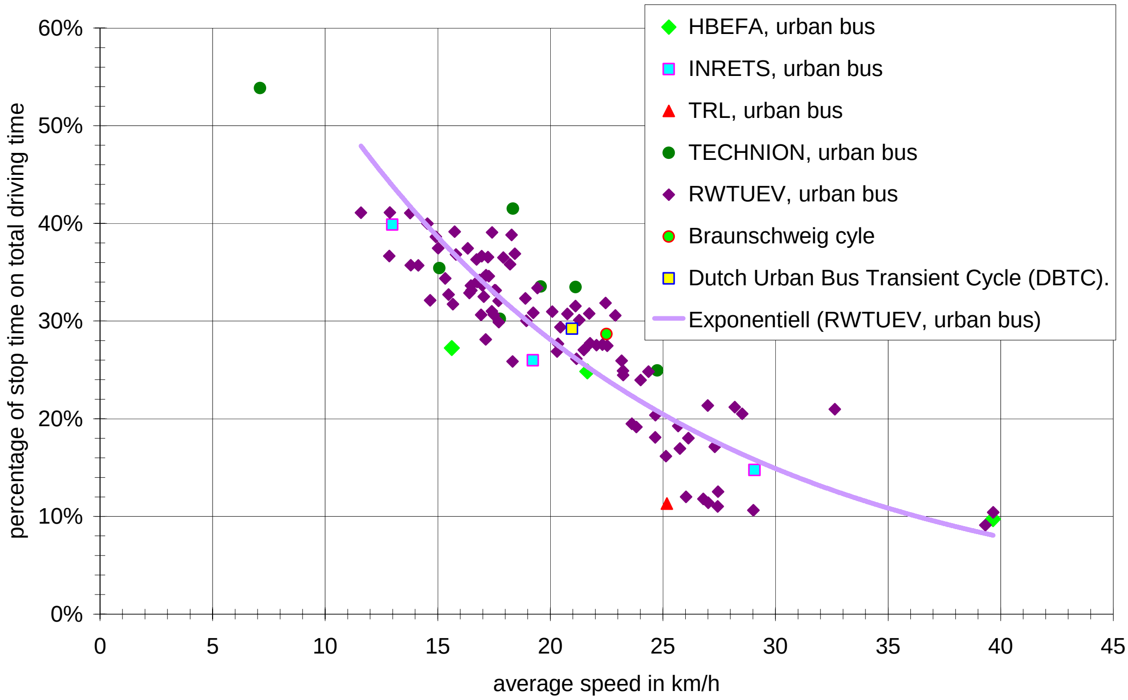


Figure 12: Average speed and percentage of stops for urban busses

7. ARTEMIS/COST 346 Fleet Emission Model (M. Keller, INFRAS, CH)

7.1. Introduction

The objectives of the COST 346 / ARTEMIS projects of the EU Commission are to improve the knowledge about the emission behaviour of the different transport modes. Therefore several basic research activities including a large set of emission measurements have been undertaken in order to gain the relevant data. However, knowing the emissions at the engine level is just one element if one wants to draw a picture of the present and in particular of the future situation of the emissions due to the transport system. The other element is the amount of traffic causing these emissions in different operational conditions. Furthermore, since the emission behaviour changes over time, the composition of the fleets and its development over time play a crucial role. Therefore both projects had the task not only to develop emission factors at the vehicle level but also to provide tools to calculate emission over a certain time period and at different levels of spatial resolutions, i.e. at local, regional, national and international level. The projects want to compile the vehicle emission data into an emission model in order to make them available to users and to allow emission calculations.

While ARTEMIS focuses not only on road emissions, COST 346 concentrates on the emissions of the heavy duty vehicles. The basic questions however are similar. Since this chapter deals with the "COST 346 emission model", it concentrates on the road emission fleet model.

7.2. Objectives

One can distinguish three objectives of the projects of the projects with respect to the models:

- To provide calculation methodologies, which are coherent for emission estimations between modes as well as for different temporal and spatial resolution.
- To provide data, i.e. to come up with a database allowing emission calculations. This not only concerns emission factors (at vehicle level) but also provide empirical data about the relevant parameters influencing the emission estimates, in particular fleet compositions and traffic activity parameters.
- To develop tools which allow the access to data mentioned as well as to calculate emissions in particular circumstances.

These objectives basically are valid for ARTEMIS as well as for COST 346. And since – with respect to the road part – the two projects overlap to a large extent, it was decided to develop a single model for both projects.

7.3. Approach

As driving forces behind the development of an emission model we considered basically three elements: (i) the regulatory tasks aiming at reducing the environmental load due to pollutant emissions as well as greenhouse gas emissions, (ii) evaluations of projects, programmes and measures, and (iii) reporting mechanisms (like CORINAIR, TERM) describing status and development of the environmental situation.

This can be translated in different forms of applications of the emission models, like:

- Classical emission inventories at different levels of spatial resolution (regional, national).
- Scenario calculations, making assessments of the impact of alternative developments or measures.
- Providing inputs to air quality models which have the same or similar objectives in describing and assessing the quality of the environment as tools for corresponding policies.

The ARTEMIS / COST 346 emission model was designed with these types of applications in mind. In particular it was decided that it should allow access to emission factors in a flexible way (as other tools like the German/Swiss/Austrian handbook (Infras 2004a) and at the same time it should allow to calculate emissions on an aggregate level (e.g. regions, nations) as well as on a street level.

The basic approach underlying emission calculations is comparatively trivial, i.e. emissions are a product of "activities" and "emission factors". However, since emission factors vary to a large extent, the crucial point is the "segmentation" along (at least) two dimensions:

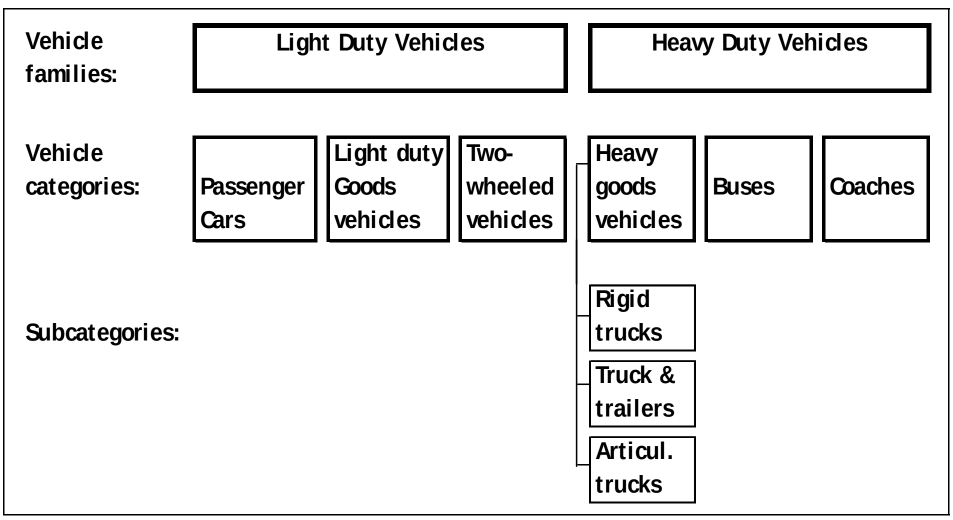
- the classification of the fleet, since it is known that different generations of vehicles and technologies emit considerably different amounts of pollutants, and
- the "operational conditions"; this refers to different driving behaviour in varying traffic situations, but also to particular situations or effects like cold start behaviour.

Therefore the emission model has first to characterize these classifications and secondly to provide the data (or data structures) in such a way that the users are able to prepare and provide their own data accordingly in order to make emission estimates for a particular case.

7.4. THE FLEET SEGMENTATION

A central element of any fleet model is the fleet segmentation. The ARTEMIS / COST 346 road emission model uses the following fleet segmentation (**Figure 13**).

Figure 13: Fleet segmentation of the ARTEMIS / COST 346 model



The “base emission factors” however are provided on a more detailed level. This means that each vehicle category is subdivided in a first step in “segments” which are vehicle groups of equal size and fuel types. In the case of heavy duty vehicles for instance the segments contain the following vehicle groups:

Table 14: HDV and Bus Segments of the ARTEMIS/ COST 346 model

RIGID TRUCK <=7.5t
RIGID TRUCK >7,5-12t
RIGID TRUCK >12-14t
RIGID TRUCK >14-20t
RIGID TRUCK >20-26t
RIGID TRUCK >26-28t
RIGID TRUCK >28-32t
RIGID TRUCK >32t
TRUCK+TRAILER/ARTICULATED TRUCK >14-20t
TRUCK+TRAILER/ARTICULATED TRUCK >20-28t
TRUCK+TRAILER/ARTICULATED TRUCK >28-34t
TRUCK+TRAILER/ARTICULATED TRUCK >34-40t
TRUCK+TRAILER/ARTICULATED TRUCK >40-50t
TRUCK+TRAILER/ARTICULATED TRUCK >50-60t
COACH Midi < = 15 t
COACH Standard 15 t - 18t
COACH 3-Axes >18t
URBAN BUS Midi <=15t
URBAN BUS Standard >15-18t
URBAN BUS Articulated >18t

These segments are further split into “sub-segments” according to different emission concepts, like Pre-Euro, Euro-1, Euro-2, Euro-3, Euro-4, Euro-5. In addition, some additional sub-segments are defined in order to take into account particular devices like particle traps. Emission factors will also be provided for some special vehicle groups like CNG buses even if the underlying emission measurements are limited.

7.5. THE FLEET MODEL

7.5.1. The approach

The aim of a fleet model is to provide an adequate description of the fleet and traffic activity in a particular region for a particular point in time (or timeseries). This obviously requires specific input data of that region. With the ARTEMIS / COST 346 model it was not intended to provide a full description of e.g. the European fleet. It rather was intended to provide a “shell” with data structures needed to calculate emissions adequately. Illustrations will be given for a couple of countries. In this presentation Austrian fleet data are used to illustrate the components of the fleet model.

The fleet model is designed for describing full time series but allows a description of the situation in one particular year as well. It distinguishes three parts and expects a description of fleets and traffic activities accordingly:

- The fleet composition,
- the traffic activity,
- the introduction scheme of emission concepts over time.

7.5.2. The Fleet composition

The fleet composition part distinguishes between the past and the future. For the *past* the model expects a description of the fleet according to statistical data e.g. of the registration offices, in particular nr of vehicles (by segments) and corresponding age distributions. For the *future* the model calculates the vehicle turnover. Therefore it requires a description in form of expected new registrations entering the market. In addition, the model expects survival probabilities. By these means, the model will simulate the new and scrapped vehicles from year to year over a user-defined period of time. At the same time it "links" the past and the future to build consistent time series of the fleet. Figure 14 shows the past and the expected future HDV fleet of Austria – differentiated by segments. The figure shows also the (modelled) age distribution of the aggregate fleet.

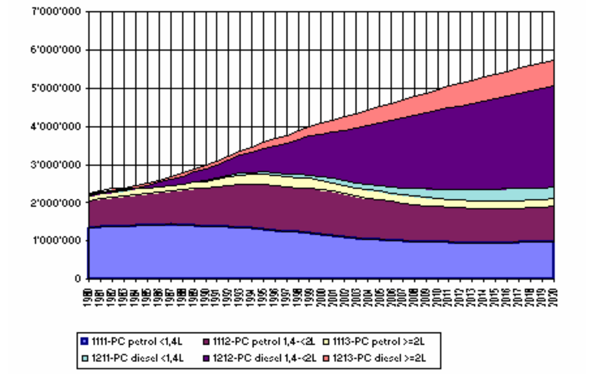
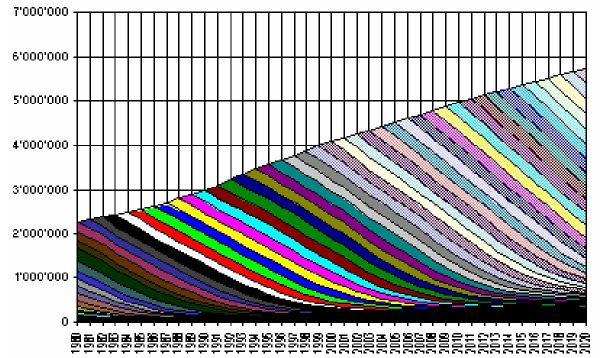
Development of the Austrian passenger car fleet	
By "segments" (size/fuel-type)	Age distribution
	

Figure 14: Description of the Austrian passenger car fleet

7.6. TRAFFIC ACTIVITY

Traffic activity data are needed in order to weight the different segments against each other since not every segment has the same share and relevance for the emissions. For instance bigger HDV vehicles tend to drive more Km and are more present on motorways, at the same time newer vehicles have higher mileage than older vehicles. Finally different vehicle groups have different load patterns. The "traffic activity model" therefore expects the following parameters:

- Mileage (km/a and vehicle) differentiated by segment.
- Split of the mileage among road categories (motorways/rural/urban roads)
- Age dependency of the mileage. Figure 15 with Italian/French and Swiss data indicate a comparable tendency indicating that older vehicles tend to have significantly smaller mileage compared to newer vehicles.
- Load patterns. The model allows to describe different load patterns (per segment, as as a function of age and per road category).

Figure 15 with data from different sources indicate that older vehicles tend to have significantly smaller mileage compared to newer vehicles (Data sources: Swedish data: VTI 2005, Belgium data: VITO 2005, Swiss data: Infras 2005, France/Italy: Iveco2003)

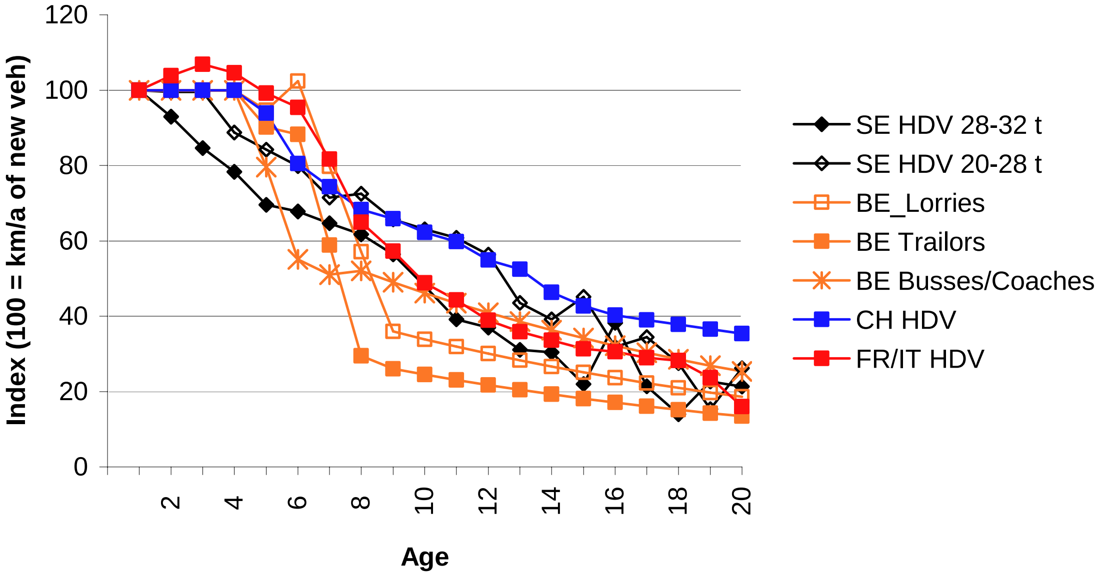


Figure 15: Age dependency of the yearly mileage of HD vehicles as relative index (100% represents the yearly mileage of a new vehicle)

The model also allows to deal with a particularity for HDV: Registration data in general give a description of the truck fleet resp. of tractors for articulated trucks. The relevant traffic activity for emission estimates though refer to "truck + trailers" resp. "articulated trucks". The model allows by means of transformation patterns to convert the truck-related data into more relevant activity descriptions by splitting the total mileage of trucks into "rigid-truck"-km and "truck + trailer"-km.

7.7. THE INTRODUCTION OF EMISSION CONCEPTS

The third element of the fleet model eventually describes the introduction schemes of new emission concepts. These schemes describe how the new registered vehicles were split between the different emission concepts (see Figure 16). In this manner it is taken into account that new concepts have been introduced in the market sometimes well before the dates required by legislation. One can describe alternative (future) introduction schemes for further levels

Introduction scheme of emission concepts

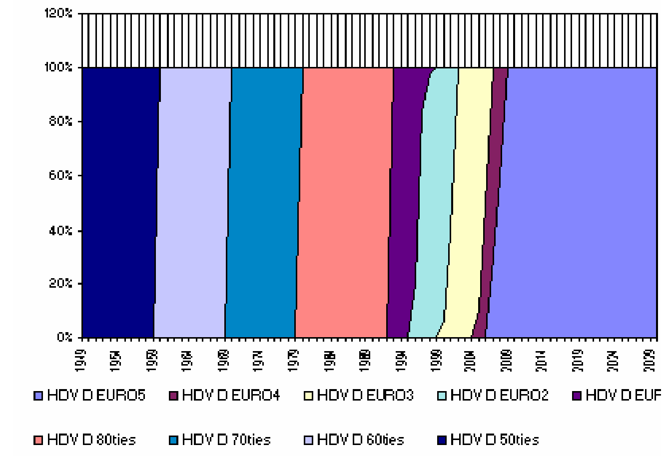


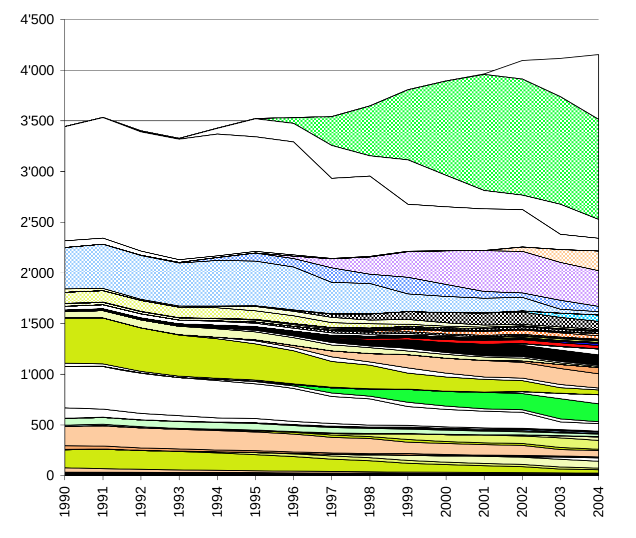
Figure 16: The introduction scheme describe how vehicles complying with new emission standards are introduced into the market.

7.8. Resulting fleet compositions

The ARTEMIS / COST 346 Fleet model eventually produces a description of the traffic activity resp. the fleet in such a way that the data can be linked with the emission factors. As shown in

Traffic activity (HDV-km/a) in Sweden (each slice represents the veh-km of a "subsegment")

In absolute terms (in mio km/a)



HDV Fleet composition (in relative terms, %)

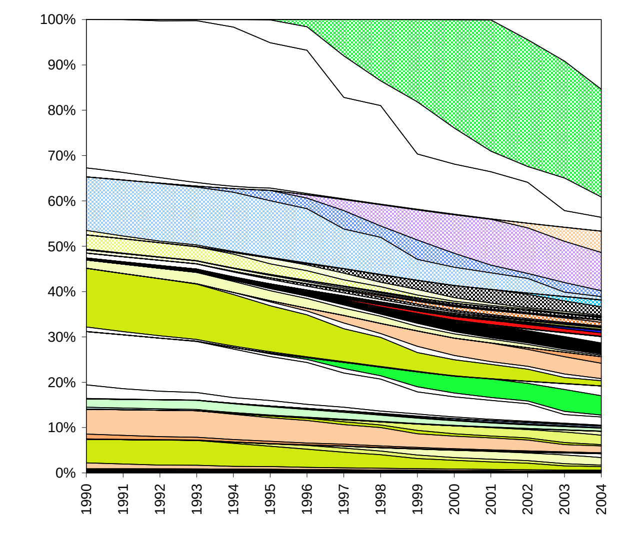


Figure 17 the data are given in absolute as well as in relative terms. The latter describes the relative traffic activity-composition (veh-km) in this example for Austria and may be used for other applications in Austria at regional level where detailed data about the traffic activity-composition might not be available. This shows that the use of the model goes beyond applications at national level. It also serves to harmonize certain assumptions and increases the comparability of emission calculations.

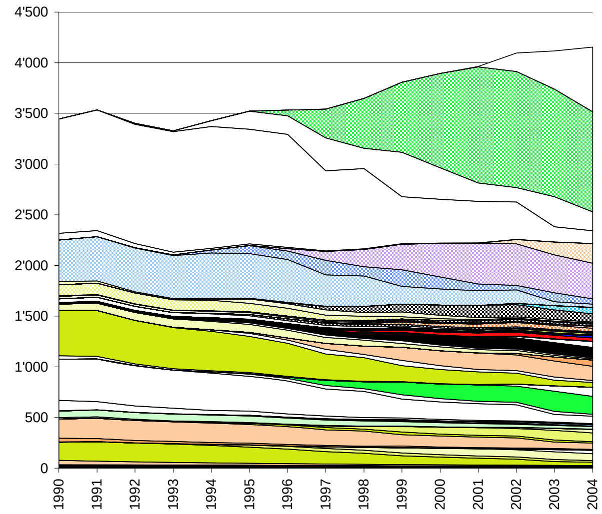
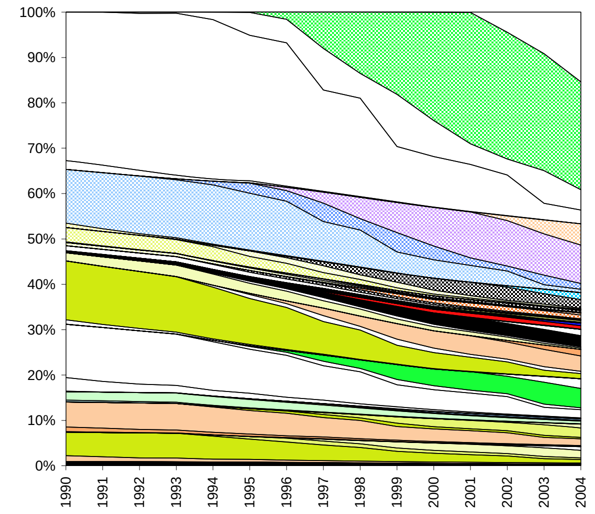
<table>
<tr><td colspan="2">Traffic activity (HDV-km/a) in Sweden (each slice represents the veh-km of a “subsegment”)</td></tr>
<tr><td>In absolute terms (in mio km/a)</td><td>HDV Fleet composition (in relative terms, %)</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Figure 17: Absolute and relative composition of the HDV traffic activity by “sub-segments” in Sweden 1990-2004

7.9. OPERATIONAL CONDITIONS

A part from the fleet composition the model expects also a classification of the traffic activity according to “operational conditions”. The model uses the “traffic situations”-approach, i.e. the operational conditions are defined as a function of the “traffic situations”. Within the frame of COST 346 a classification matrix was developed (see section 0), which takes into account the area (urban/rural areas), the road type (a functional hierarchy), the speed limit and the level of service (in four steps, from “free flow” to “stop and go”).

For each of these situations the emission factors have been calculated by the PHEM model. The underlying driving behaviour (for HDV) has been identified by TueV-Nord on the basis of empirical data. The following figure gives an example of the NO_x emission factors for three different traffic situations, for the segment (TT/AT >34-40t) and different emission concepts (from Euro-1 up to [estimated] Euro-4 and Euro-5). The results show the significant reduction by technological improvements. At the same time it shows that reducing emission standards do not necessarily guarantee the improvement of the actual emission behaviour on the road (e.g. Euro-1 -> Euro-2).

Table 15: Traffic situation scheme (for details see Annex I)

			Speed Limit											
Area	Road type	Levels of Service	30	40	50	60	70	80	90	100	110	120	130	>130
Rural	1 Motorway-National	4 levels						x	x	x	x	x	x	x
	2 TrunkRoad/Primary-National	4 levels				x	x	x	x	x	x			
	3 Distributor/Secondary	4 levels			x	x	x	x	x	x				
	4 Local/Collector	4 levels			x	x	x	x						
	5 Access-residential	4 levels	x	x	x									
Urban	1a Motorway-National	4 levels						x	x	x	x	x	x	
	1b Motorway-City	4 levels				x	x	x	x	x	x			
	2a TrunkRoad/Primary-National	4 levels					x	x	x	x	x			
	2b TrunkRoad/Primary-City	4 levels			x	x	x	x	x					
	3 Distributor/Secondary	4 levels			x	x	x	x						
	4 Local/Collector	4 levels			x	x								
	5 Access-residential	4 levels	x	x	x									

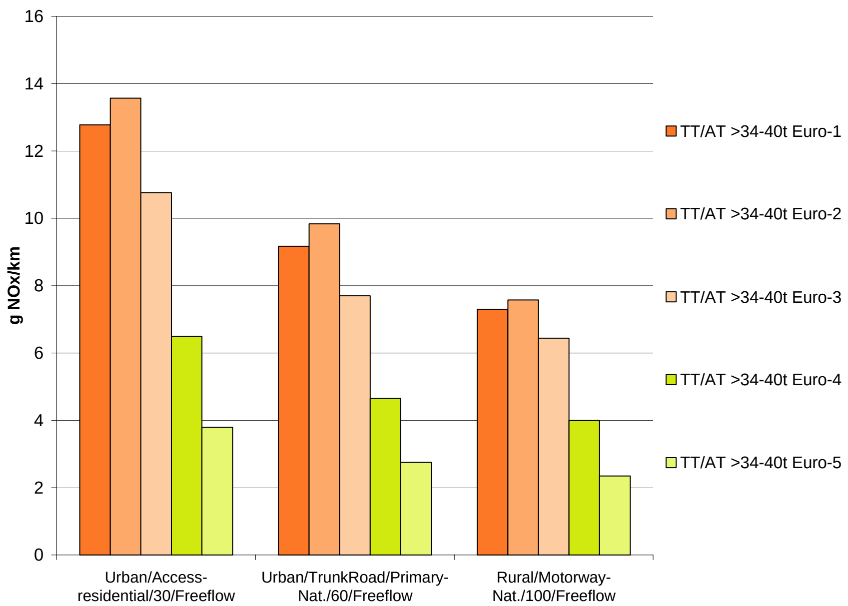


Figure 18: NOx emission factors according the PHEM vehicle emission model for a selected "sub-segment"[>34-40 t HDV (Truck + Trailer/articulated Truck), Euro-3] in different traffic situations

Note that the "fleet model" and hence the fleet composition uses the "traditional distinction" between the three road categories (motorways, rural road, urban roads) while the traffic situation approach uses a different definition: it distinguishes "rural areas" vs. "urban areas" and contains motorways in both area types. Hence, as default, the fleet composition "motorways" is assigned to all motorway traffic situations (in urban as well as in rural areas) while for all remaining "rural" traffic situations the "rural" fleet composition is assigned, and for all remaining "urban" traffic situations the "urban" fleet composition is assigned.

Apart from the "traffic situation approach" the ARTEMIS / COST 346 model provides also emission factors according to the conventional average speed approach in order to allow continuity for users being familiar with that approach. However, the discrete approach takes into account the fact that the average speed is not necessarily a sufficient parameter for describing adequately the operational conditions and hence the emission behaviour. While on an aggregate level this may suffice, for street level applications the "traffic situation" approach gives more flexibility to take into account varying driving behaviour. Figure 19 shows that at the same average speed the spread of the fuel consumption (as well as the NO_x emissions, Figure 18) can vary significantly in particular in the medium speed range (30-50 km/h).

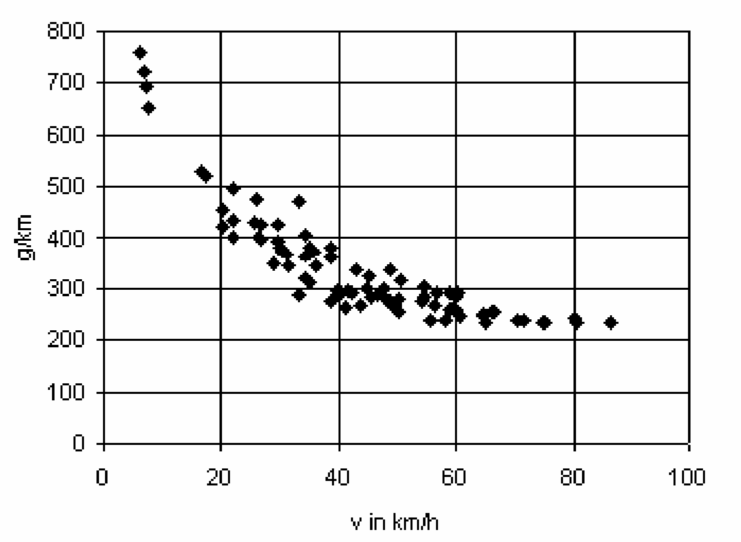


Figure 19: Fuel consumption according the PHEM vehicle emission model for a selected "sub segment"[>34-40 t HDV (Truck + Trailer/articulated Truck), Euro-3] in different traffic situations

7.10. APPLICATIONS

Based on this "traffic situation" approach as well as for an average speed approach, the ARTEMIS / COST 346 model allows the user an aggregate as well as a street level application.

For an aggregate application, the user has to specify how the traffic activity is distributed among different "traffic situations / gradient classes" (or "average speed" classes). For a street level application, the user first has to specify a street network (in terms of links and zones). Then for each "link" resp. "zone" the corresponding "traffic situation" (or average speed) has to be specified. In addition, one may vary the fleet composition on the different links or zones if the necessary data are available. This indicates that an application of the model might indeed be a challenge since the data requirements are considerable. It also shows the limits of the model: even if the emission factors represent the emissions of a particular driving behaviour, it remains an aggregate model, i.e. the underlying emission factors are not designed for instantaneous (e.g. second by second) applications.

7.11. OPERATIONAL ASPECTS

Operationally the model is based on an MS ACCESS database. It will be distributed as runtime version and will be available free of charge. More information about the emission model can be found in the ARTEMIS final report resp. the user guide of the ARTEMIS / COST 346 model.

8. Dissemination (working group C, E. Cornelis, VITO B)

Dissemination during the COST 346 lifetime was mainly based on internet (COST 346 day to day web page), participating in international conferences and holding a dissemination workshop and a final conference.

8.1. COST 346 WEB PAGE

In order to support the internal working of COST 346, an internal web page was set up, which facilitated the communication between the different participants to COST 346, the organisation of meetings and the internal distribution of technical notes and reports.

The structure of the web page is as following:

- What's new

  Contained news from the side of the COST-secretariat, announcements of relevant conferences

- List of actions

  Lists all unclosed actions, with specification of the deadline and the responsible participant

- Planning of the meetings

  Lists the meetings with links to related documents (agenda's, minutes, etc.)

- General documents

  Contains the rules of procedures for implementing COST Actions and a guide for drafting the technical annex describing a COST action

- Management committee documents

  Consists of reports, notes, remarks, data sheets which COST 346 participants wanted to share with each other.

The website was hosted and maintained up-to-date by VITO, Belgium.

8.2. DISSEMINATION CONFERENCE IN ANTWERP, 2004

In 2004 the workgroup COST 346 "Emissions and Fuel Consumption from Heavy Duty Vehicles" planned a conference in order to disseminate the results achieved up so far. This timing was chosen as COST 346 was expected to complete in 2005. As the activities of COST 346 were closely linked to those of two other projects of the 5th Framework Program – namely ARTEMIS and PARTICULATES – it was decided to have a joint conference. These two other research projects are described more into detail here.

ARTEMIS is developing a harmonised emission model for road, rail, air and ship transport to provide consistent emission estimates at the national, international and regional level. The project is structured as 13 interrelated work packages, covering the measurement of emissions of all types of modes as well as traffic characterization and the development of fleet models. ARTEMIS was finalised in the course of 2005.

PARTICULATES aimed at further characterising the automotive particulate emissions. Hence, the relative importance of particulate properties - mass, size, number and composition - to health effects are examined and measurement methodologies as well as particulate reduction technologies are evaluated, especially for the smallest, nucleation mode particles. PARTICULATES was finalised in the course of 2004.

The conference was organised on May 24th, 2004 in the Astrid Park Plaza Hotel, Antwerp, Belgium.

The conference consisted of three main sessions, one for each research project. Closing remarks came from the European Environmental Agency.

The conference was attended by 86 delegates. About half of the attendees work in a research centre; one fourth for a university and a equal number for a national authority. 35 of the attendees were COST Action 346 participants.

8.3. FINAL CONFERENCE IN GRAZ, 2005

The final conference of COST 346 was integrated in the 14th international symposium 'Transport and Air Pollution (TAP 05)', which took place in Graz, Austria on June 1st – 3rd, 2005. One day of this three days event was dedicated to COST 346. A couple of other papers dealing with emissions and driving behaviour were closely linked to COST 346. The 14th symposium 'Transport & Air Pollution' was attended by 156 participants, coming from 27 countries (Europe, Asia and North-America).The papers presented at the TAP 05 conference are published in the conference proceedings (Sturm 2005).

8.4. FUTURE PRESENCE OF COST 346

Dissemination will not be stopped after the lifetime of COST 346. It is foreseen to maintain the COST 346 day to day web page as an open source for further dissemination of the main COST 346 results and for information about following up COST and related research actions.

9. Legislation (working group D, Ivan Pollak, KTI (H), Iddo Riemersma, TNO (NL) and Martin Rexeis, TUG (A))

Over the period that the COST 346/ARTEMIS WP 400 framework has been running (from 1999 up to the end of 2005), the emission performance of heavy duty engines has changed considerably as a result of the European type approval requirements. This has not only had its effect on emissions from engines intended for use in trucks and buses, but also for other applications such as agricultural tractors and non-road machineries.

The new Directive 2005/55/EC of the European Parliament and the Council, published on 20.10.2005, includes new provisions for on board diagnostics (OBD) and durability requirements to facilitate the immediate detection of the deterioration or failure of engine emission control equipment during the useful life of the vehicle. This will enhance diagnostic and repair capability, thereby significantly improving the sustainable emission performance of heavy-duty vehicles in service. It will be introduced in two stages to allow for system development and to prevent the OBD system from giving false indications. The distance covered or the time that has elapsed after a fault has been indicated to the driver is recorded.

In case of exhaust after-treatment systems, the OBD system will monitor any of the following emission control systems for major functional failure:

- a catalyst, where fitted as a separate unit, whether or not it is part of a $deNO_x$ system or a diesel particulate filter;
- a $deNO_x$ system, where fitted;
- a diesel particulate filter, where fitted;
- a combined $deNO_x$-diesel particulate filter system.

In the near future (probably still in 2005) the Commission will include technical measures for emission control systems using consumable reagents to ensure that the reagent quality is assured, and that the reagent tank is not empty. Details on these measures can be found in Document ENTR/2004/1348 which is currently being prepared, and will be added to Directive 2005/55/EC at a later stage.

These latest regulatory developments indicate that policy makers are responding to the scientific results gained in the COST 346.

As already stated in Chapter 5.5 the real world emission levels can differ significantly from the type approval figures, so the need for additional in-use tests based on real world driving is becoming more obvious. The Commission is considering appropriate requirements for in-use compliance checking (IUC) for heavy duty vehicles using portable emission measuring systems (PEMS) which seems to be a cost-effective method in the future. To investigate the technical and practical feasibility of these systems a research project was started by the EC in 2004 with participation of measurement instrument providers, HD vehicle manufacturers and test laboratories, coordinated by the Joint Research Centre (JRC). Main objectives of this project are:

- To assess and validate the application and performance of portable instrumentation relative to each other, and in comparison with alternative options for in-use compliance (IUC) testing;
- To define a test protocol for the use of portable instrumentation within the IUC of Heavy-Duty vehicles;
- To evaluate the US ‘Not To Exceed’ (NTE) approach and possibly develop a simplified method in order to propose IUC pass/fail criteria;

- To address the need of the European industry, authorities and test houses to go through a learning process.

Several test campaigns for evaluation of two PEMS have taken place at different HD vehicle manufacturers, but the results are not publicly available yet. Until now the measurement data have mainly been used to evaluate the NTE approach as applied in the USA. In this procedure an operating window (control area) has been defined in the engine map. If the engine is operated for 30 consecutive seconds or more in the area, the instantaneous emissions are averaged over this period, and compared with an NTE limit which is 1.25 times higher than the type approval limit value. So far the measurement data have learned that the time share in which the engine is operated for 30 seconds or more in the control area is relatively low, especially for vehicles with a high power to mass ratio, e.g. because of a low loading weight.

At this moment the evaluation programme of gaseous emission measurement equipment has been finalised. The next step will be to focus on systems that can measure the particulates. A test protocol has yet to be developed, however there is already a 'Guide for in-field tests' available.

Apart from evaluating the NTE approach, also other alternative on-road IUC testing options are considered. The measurement data that were collected in COST 346/ARTEMIS could be useful for this purpose. The first official report of the results of the heavy duty PEMS project has been presented at the 97th MVEG meeting at 01. 12. 2005.

At this moment each member state has its own methods and models to calculate the overall emissions from traffic for the purpose of national emission inventories, reports for the European Environment Agency and/or UNECE Transport Statistical facts. The COST 346/ARTEMIS emission calculation method and the accompanying fleet model could replace individual methodologies, and allow for a harmonised (and therefore comparable) emission inventory approach amongst all European member states. The Artemis/COST346 partners would recommend the EC to draw attention to this issue.

10. Reports on related activities

The work in the COST 346 Action was always related to the different working groups. However, the working group reports cover the main aspects of the work programme, which were: emission factors and vehicle model, driving behaviour and fleet model. Many other activities were performed and reported during the COST 346 working period. Most of them have been already published at the COST 346 homepage or at different occasions. This section covers some relevant information about work performed in COST 346

10.1. RETROFIT AFTERTREATMENT SYSTEMS FOR DIESEL ENGINES (L. TARTAKOVSKI, Y. ZVIRIN, TECHNION, ISR, S. HAUSBERGER , TU GRAZ, A)

The work concerning retrofit after-treatment systems for diesel engines was presented in detail at the COST 346 final conference in Graz 2005 (Tartakovski et al. 2005).

While new legislation worldwide requires newly manufactured heavy-duty diesel engines to meet tough new emission standards, there have been no major regulatory actions to similarly clean up diesels that are in use today. Because of the long service life of heavy-duty diesels, cleaning up exhaust gases of in-use heavy-duty diesel vehicles would certainly lead to improvements in air quality on the short term.

Retrofit exhaust aftertreatment technologies have emerged in recent years and are increasingly being utilized. Such systems need to be carefully matched to the individual vehicle and may require very low sulphur fuel. When optimized, they are capable of very significant reductions of PM and, to a lesser extent, NOx emissions. The combination of retrofit controls, new engine designs, low-sulphur fuels and advanced lubricants would assist in minimizing urban air pollution by diesel exhaust, while providing the durability and efficiency required from heavy-duty vehicles.

Diesel oxidation catalysts (DOC) were found to provide PM emission reduction of up to 50%. The efficiency increases with higher shares of the soluble fraction on PM and decreases at higher sulfur content of the fuel, together with high exhaust gas temperatures, due to formation of sulfates. Formation of sulfates could even increase the total PM emissions compared to the original muffler. Diesel oxidation catalysts have been one of the most popular control options for both on-road and off-road applications to date because of their low cost, maintenance-free service and negligible impact on vehicle fuel economy.

Diesel particulate filters, or particulate traps, are very efficient in filtering of particulates. VERT-certification carried out by the Swiss Environmental Agency revealed results of trapping by more than 99% of particulates emission. Diesel particulate filters retrofits have rapidly expanded during the last years, mainly due to their very high efficiency of PM reduction and recently achieved high level of durability and reliability in suitable applications. Retrofit of DPF usually leads to fuel economy penalty of between 1% and 3%. A main technical target is to enable sufficient regeneration of the DPF, i.e. a continuous or periodical oxidation of the trapped particles, to prevent overloading of the filter which would result in increased fuel penalties and potential damages. At the moment only an active regeneration with burners or electric heating can guarantee regeneration in all situations. However, applications can work properly also without active regeneration if the vehicle and driving conditions result in sufficient exhaust gas temperatures for the retrofit system selected.

The Catalytic Particulate Oxidizer (CPO or particulate catalyst) technology is characterized by open structures, which can prevent overloading with particles under insufficient thermal operating conditions. This feature is an advantage, especially for retrofit systems where active regeneration most often would need an external heater. However, too low exhaust gas temperatures reduce the efficiency of CPO's and can increase their exhaust gas backpressure. Particulate catalysts can usually achieve particulate emission reductions lower than DPF but higher than DOC.

Most DOCs, as well as CPOs, permit operation with fuels containing up to 350-500 ppm sulfur. For successful operation of DPF, fuel with no more than 50 ppm sulfur is required. The DPF and maybe also some CPOs are sensitive to ashes from additives in the lubrication oil and in the fuel, since these ashes accumulate in the filter and increase the backpressure (e.g. organo-metallic ash). New specifications are being developed recently for engine lubrication oil with reduced ash content that will be compatible with aftertreatment devices.

All DOC's and most of the DPF's and CPO's do have a catalytic coating within the system. The catalytic function reduces HC and CO emissions and reduces the temperature necessary for burning the soot from above 500°C to approximately 300°C. Especially for DPF's and CPO's this effect is very important for regeneration. The lower regeneration temperature is mainly achieved by an increase of NO_2 in the raw exhaust gas which reacts with the soot at lower temperatures than oxygen. The NO_2 is produced on the catalytic coating from the NO, thus total NOx emissions remain rather unchanged by retrofit systems. But the share of NO_2 on the total NO_x can increase from approximately 5% to 10% without retrofit system up to more than 50% with some DPF's and CPO's. The NO_2 topic is matter of discussion for both, retrofit and original equipment DPF systems. Since an increase in NO_2 emissions could be critical, the NO_2 production of a retrofit system should be considered within the selection process.

10.2. EFFECTS OF ENGINE DETERIORATION AND MAINTENANCE ON EMISSIONS (I. RIEMERSMA, TNO, NL))

The work presented in the following section was performed by TNO in the framework of COST 346, ARTEMIS and nationally funded projects. It is described in detail in the COST 346/Artemis working group report.

Emissions of HDVs are influenced by a large number of factors. Apart from the more obvious ones such as use conditions, engine design and technology (to comply with emission legislation), also the age of the engine and the maintenance condition can have a certain influence. In order to determine if this influence should be taken into account for the Artemis emission model, the effect of engine deterioration and maintenance on emissions will be assessed in this section.

10.2.1. Database

For investigating the influence of engine deterioration and maintenance on emissions information sources from The Netherlands and Germany were used. Both sets of data were put together into one (Excel) database, to allow for the assessments. The database was further accommodated by setting restrictions to the mileage and exclusion of some specific outliers. In total, the database consists of 197 vehicles (78 Euro1, 98 Euro 2 and 21 Euro 3).

10.2.2. Deterioration of Euro 1 to Euro 3 vehicles

The most straightforward method to assess the effect on emissions of engine deterioration would be to have the same HDV engine measured multiple times during its useful life. Unfortunately, this kind of data is not available in the database. The next best option is to make a graph of the individual (13-mode) test results against the distance driven by the vehicle (mileage) at the time the tests took place. To prevent maintenance issues from interfering with the deterioration analysis, the emission data *after* applying maintenance (only if necessary) were used.

As an example, Figure 20 shows the emissions of NO_x as a function of mileage for the Euro 2 vehicles in the database.

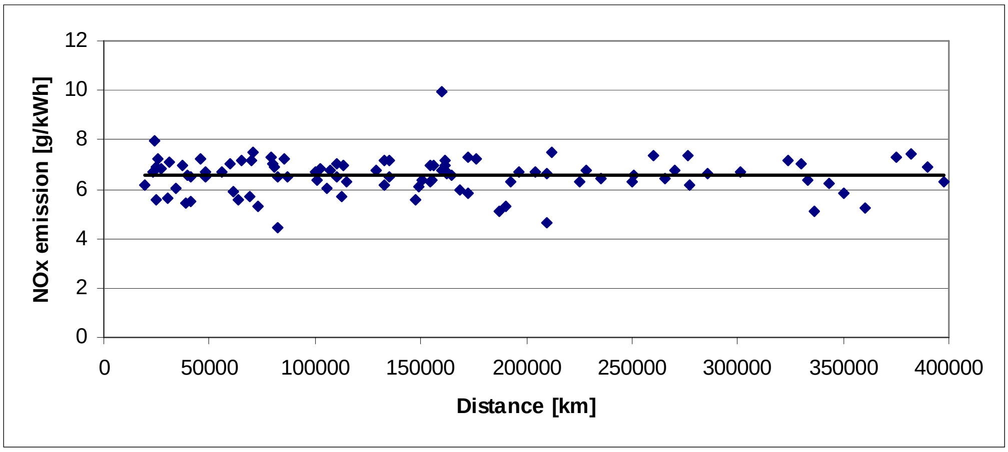


Figure 20. Deterioration lines of emissions (ECE R49 13-mode test) for 98 Euro 2 vehicles (after maintenance)

The results from the deterioration analysis are quite remarkable, especially for Euro 1 and 2 vehicles. Where deterioration with increasing mileage was anticipated, actually an improvement could be noticed for most emission components (or at worst a near flat line). To put this conclusion into perspective, it has to be noted that the variance in measurement points relative to the line is rather high, indicating that the course of the line may be altered if some individual higher or lower test results are added or deleted.

Other potential deterioration analyses focussed on the influence of the vehicle manufacturer, and the influence of the vehicle use. There seems to be a dependence of deterioration characteristics with the vehicle/engine manufacturer, and the type of vehicle application (derived from surveying the rated engine power). However, the value of this conclusion is limited due to the reduced data set it is based on.

The analysis on deterioration leads to the following conclusions:

- Though an increase in emissions with mileage was anticipated, this could not be confirmed for Euro 1 and 2 vehicles by the analysis (for some emissions actually a decrease with mileage was observed). Only a slight deterioration of NO_x-emissions for Euro 1 vehicles was observed (about 3% over 500,000 km), which is not very significant considering the uncertainties within the analysis.
- As there is no logical physical explanation for emissions to decrease with the age of the engine, this emission improvement is considered to be unrealistic.
- The limited amount of Euro 3 vehicles in the database together with a wide range of results prevents a firm conclusion on deterioration of emissions for this vehicle class. It seems safer to assume the same deterioration pattern as found for Euro 2 vehicles.

- The data analysis has proven clearly that the effect of emission deterioration due to engine ageing is (in the worst case situation) only marginal. On the other hand the indicated inaccuracies and assumptions prevent the determination of exact deterioration factors. In fact, the variation of emission results in the database is larger than the effect of deterioration that is tried to observe from it.
- There seems to be a dependence of deterioration characteristics with the vehicle/engine manufacturer, and the type of vehicle application (derived from surveying the rated engine power). However, the value of this conclusion is limited due to the reduced data set it is based on.

The general conclusion is that no deterioration of emission factors needs to be introduced for Euro 1 to Euro 3 vehicles.

NOTE: It is important to realise that these conclusions are based on only steady-state measurements, so nothing can be said with certainty about the deterioration pattern of transient emissions from the assessment made here.

10.2.3. Deterioration of Euro 4 and Euro 5 vehicles

Obviously, there is no database available with measurement results that can be analysed as it was done for the Euro 1 to Euro 3 vehicles, since there are no vehicles tested as yet with a Euro 4 or higher classification. Therefore, the analysis for deterioration of emissions had a rather qualitative nature, focussing on the engine and exhaust gas aftertreatment technology that is expected to be applied on Euro 4 and 5 vehicles. For this purpose, a lot of information could be derived from a study performed in 2001 for the DG Enterprise of the EC (EC 2002)

Once the future engine and aftertreatment technologies were identified and reviewed for their (expected) deterioration pattern, the following conclusions for the emission deterioration of Euro 4 and 5 vehicles could be drawn:

- There is no reason to assume that the deterioration pattern of *engine-out* emissions would differ much from engines of earlier Euro class engines.
- Installed emission control devices (ECDs) can deliver a contribution to deterioration of specific emission components as a result of ageing, malfunctioning or even tampering.
- Some of the anticipated deterioration aspects (mainly malfunctioning and tampering, but possibly also deterioration) can be prevented by installation of an OBD system, which will be mandatory from the moment ECDs will be used on HD engines (Euro 4 and beyond).
- ECDs containing catalysts will show some emission deterioration over the useful life of the vehicle due to ageing processes. At this moment it is hardly possible to give exact percentages since the technology is very premature, and only little data is available.

Finally, it should be noted that engines equipped with ECDs will potentially show higher emission levels in real-life driving situations compared to stationary (and possibly even) transient test cycles, due to the increased possibilities for cycle optimisation.

10.2.4. Effects of maintenance

The database of the Dutch In-Use Compliance program makes a perfect source for analysing the relation between maintenance and emissions, as the emissions before and after maintenance are both available on the same vehicle It contains 39 Euro 1 and 29

Euro 2 vehicles that required maintenance (52% of tested Euro 1 vehicles and 33% of tested Euro 2 vehicles). None of the 24 tested Euro 3 vehicles that were monitored had emission problems related to maintenance issues. Unfortunately, the data from the German IUC project lacks this detail of information, and is therefore left out of the database.

In the analysis the focus is laid first on NO_x and PM, being the most critical emission components of HD diesel engines. Figure 21 shows these emissions for Euro 1 and 2 vehicles in the database that needed one or more maintenance corrections. The little markers give the results for the individual vehicles before (diamond) and after (square) carrying out maintenance, while the big two markers present the average of all vehicles before and after.

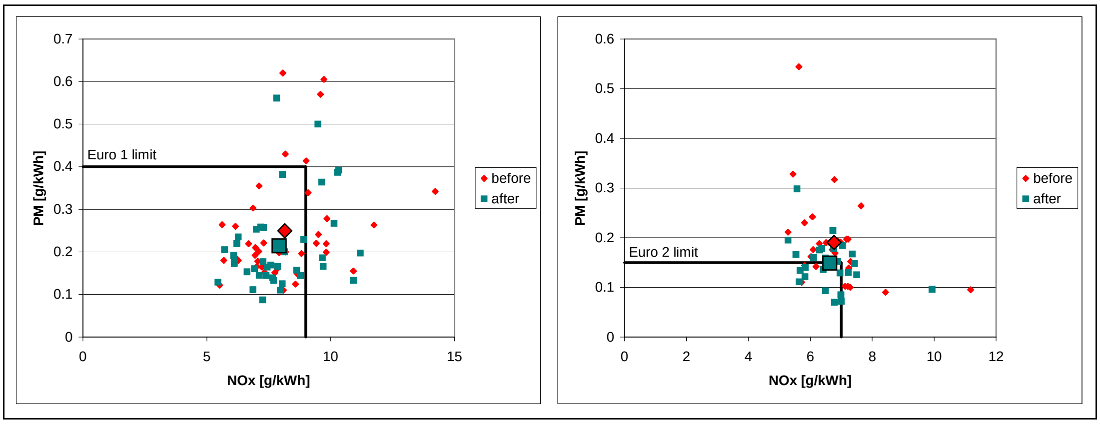


Figure 21: NOx and PM emissions (13-mode test) of Euro 1 and 2 vehicles before and after maintenance (all defects)

The reduction in emissions by applying maintenance is on average for both Euro 1 and 2 hardly noticeable for NO_x (3 or 2% respectively) and reasonable for PM (15% and 23%).

The analysis of maintenance corrections has also been performed for the other two legislated emission components (HC and CO). The overall results, including those of Figure 21, are summarised in Table 16. The (expected) overall effect has been calculated by multiplying the percentage of vehicles needing maintenance by the average reduction in emissions, imposed by applying the necessary corrective maintenance actions. The reductions have been compensated for potential differences in fuel consumption as a result of the maintenance correction, since this will have a secondary influence on the emission level of the tests.

Table 16: Average emission effects as a result of maintenance activities, and the expected overall effect on average Euro 1 and 2 fleet (compensated for fuel consumption differences)

	Euro 1	**Euro 2**
percentage of vehicles needing maintenance	52%	33%
Average effect on PM	-15%	-23%
Average effect on NO_x	-3%	-2%
Average effect on CO	-17%	-4%
Average effect on HC	2%	-11%
overall effect on PM	-8%	-7%

	Euro 1	Euro 2
overall effect on NO_x	-1%	-1%
overall effect on CO	-9%	-1%
overall effect on HC	1%	-4%

The analysis on maintenance leads to the following conclusions:

- As a result of deficiencies in the maintenance condition of HD engines, emissions may increase, especially PM. About 52% of the tested Euro 1 vehicles needed maintenance; for Euro 2 this concerned 33% of the vehicles. None of the 24 tested Euro 3 vehicles had emission problems related to the maintenance condition.
- The introduction of electronic fuel pumps and engine management systems has a positive effect on this situation, as problems with timing or fuel pump delivery become less viable to occur. For Euro 3 this will be commonly applied technology, and so far the experiences in the Dutch In-Use Compliance testing project support this expectation.
- The most important maintenance issue at this moment and in the future concerns the condition of the fuel injectors. Wear of the nozzles or an incorrect opening pressure may result in serious increases of PM emissions (up to 23% on average). For the future this problem could show more often, due to higher injection pressures. However, for the first (relatively new) 24 Euro 3 vehicles no injector problems have appeared.
- Though the fuel injectors were expected to deteriorate with increasing mileage of the vehicle, no correlation of such kind could be established.
- For individual cases the rise in emissions (especially PM) can be quite spectacular, but on an overall fleet basis, the effect of maintenance corrections on emissions stays at a relatively low level (a few percentages, up to 9% at maximum).

A pragmatic approach for adding a ‘maintenance module’ to the emission model is to assume for the entire Euro 1 and 2 vehicle classes an increase in emissions (as a result of the actual maintenance condition) according to the expected overall effect shown in Table 16. For Euro 3 technology (electronic fuel pumps and engine management system) the condition of the fuel injectors can be expected to be the main issue. Based on the Euro 2 data, the according increase in PM emissions would be 3-4% at the fleet level. For the other emission components of Euro 3 vehicles the rise (in absolute emissions) is expected to be insignificant.

Evidently, at this point nothing can be said with certainty about maintenance effects on Euro 4 and 5 vehicles. Some kind of insurance for proper functioning may be expected from the introduction of an On-Board Diagnostics system (OBD), at the same time as Euro 4 takes effect. This system aims at preventing issues that can be resolved through corrective maintenance, by checking for irregularities in the engine and its subsystems.

It is important to realise that these conclusions on maintenance are based on only steady-state measurements, so it is not a certainty that transient emissions show the same response to maintenance issues. Furthermore, it has to be noted that this analysis was based on vehicles that were voluntarily supplied by their owners to the measurement programme.

For obvious reasons it is not unlikely that very poor maintained vehicles did not participate in this programme.

10.3. ON-ROAD EMISSION MEASURENETS (P. SOLTIC, EMPA CH)

On road emission measurements are very often used in order to monitor real world emission behaviour of single vehicles. As one of many applications the following study concerning “On-Road Emission Measurements and Emission Modelling Results for a Tractor-Semitrailer in Trans-Alpine Operation” is presented as an example to show the capabilities and limitations of on-board emission measurements.

This study was presented at the COST346 dissemination conference in Antwerp (24.5.2005) and at the 13th international scientific symposium "Transport and Air Pollution" in Boulder, details can be found in Soltic et al.(2004).

Concentrations of several gaseous emissions, mass flows, pressures, temperatures and engine speed and torque of a tractor-semitrailer were measured during trans-alpine driving across Switzerland (Figure 22) within a Swiss Project, financed by the Swiss Agency for the Environment, Forests and Landscape (SAEFL) and performed by EMPA.

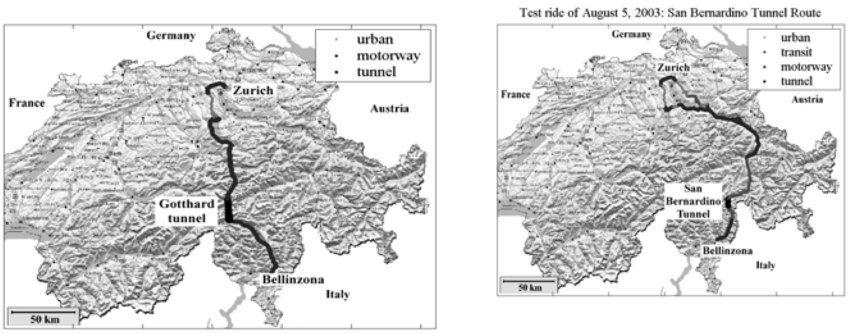


Figure 22: Gotthard tunnel route (left) and San Bernardino tunnel route (right)

The vehicle, equipped with an engine certified according to the Euro-3 emission level, was fully loaded to a total mass of 40 tons and equipped with a mobile emission measurement device. A logger was installed which collected data from own sensors and also signals broadcasted form the vehicle and engine electronics (such as engine speed, engine torque, actual gear). Figure 23 depicts the setup, Figure 24 and Table 17 show the main results.

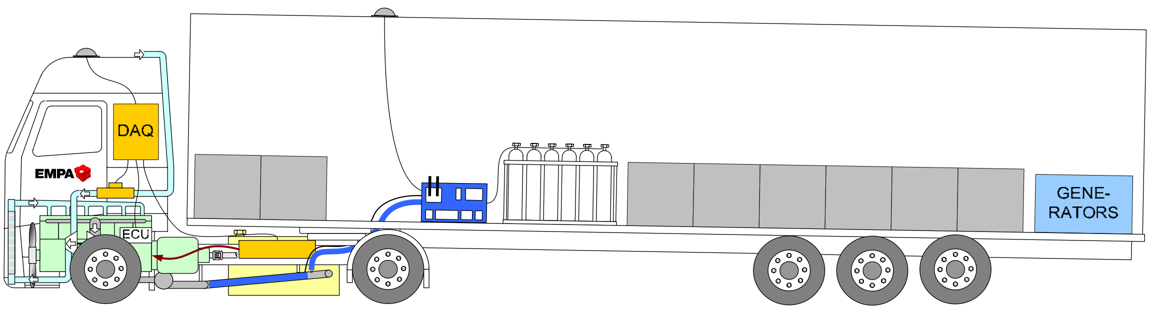


Figure 23: Setup of the tractor-semitrailer

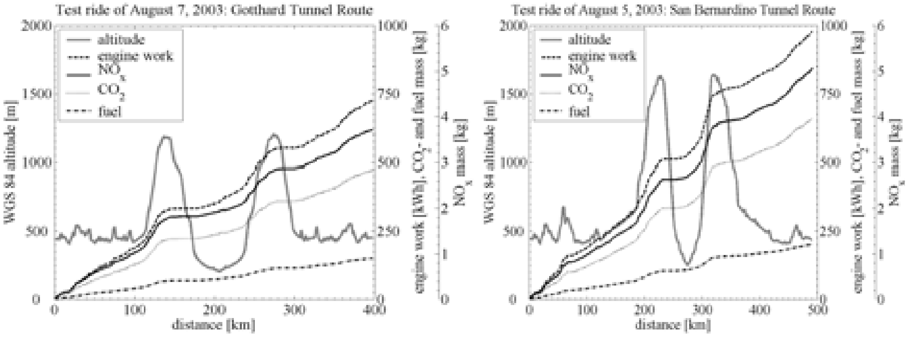
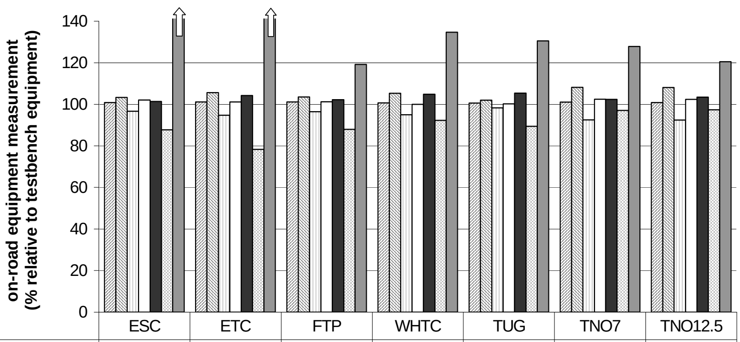


Figure 24: On-road measured altitude profile and cumulative fuel, CO2, NOx masses

Table 17: Key figures for two measurements (fuel density: 0.827 kg/l at 15°C)

		Gotthard	Bernardino
Av. Speed (*total trip-length*)	[km/h] (*[km]*)	65 (*397*)	63 (*490*)
Av. engine power (energy)	[kW] (*[kWh/km]*)	120 (*1.827*)	126 (*1.995*)
Av. fuel consumption	[g/km] ([l/100 km])	380 (46.0)	412 (49.8)
Av. brake-specific fuel consumption	[g/kWh]	208	207
Av. CO_2 emissions	[g/km]	1,188	1,343
Av. NO_x emissions	[g/km] (*[g/kWh]*)	9.36 (*5.1*)	10.34 (*5.2*)

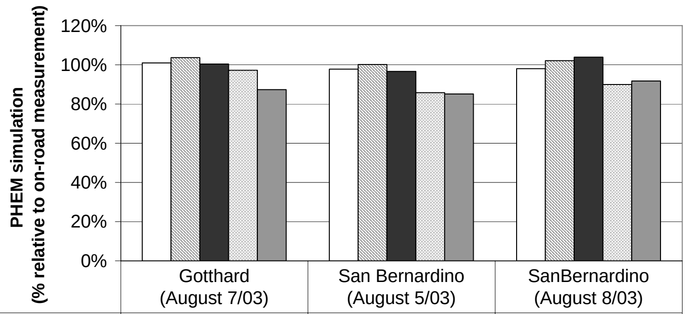
After the on-road measurements, the engine was dismantled and measured on an engine dynamometer in several official and real-world cycles where the laboratory and on-road measurement equipment were operated in parallel. Besides of the carbon monoxide (CO) measurement, the on-road measurement equipment showed a very good correlation.



	ESC	ETC	FTP	WHTC	TUG	TNO7	TNO12.5
air+fuel mass	100.9	101.2	101.2	100.7	100.5	101.0	100.8
engine work	103.3	105.6	103.5	105.3	102.0	108.1	108.1
bsfc	96.7	94.7	96.4	95.0	98.3	92.5	92.4
CO2 mass	102.0	101.1	101.2	99.9	100.2	102.5	102.4
NOx mass	101.3	104.2	102.2	104.9	105.4	102.4	103.4
THC mass	87.7	78.3	87.9	92.3	89.4	97.1	97.4
CO mass	237.7	144.3	119.2	134.7	130.5	127.8	120.5

Figure 25: Comparison of results from on-road and laboratory instrumentation

In order to cross-check the on-road measurement- and emission modelling methodology, the dynamometer emission data and the speed and slope data of three driven routes were used by the TU Graz as input data for the PHEM emission model described in section 4.2.1. Figure 26 shows the comparison between the on-road measured and simulated emissions.



	Gotthard (August 7/03)	San Bernardino (August 5/03)	SanBernardino (August 8/03)
fuel mass	101%	98%	98%
engine work	104%	100%	102%
NOx mass	100%	97%	104%
THC mass	97%	86%	90%
CO mass	87%	85%	92%

Figure 26: Comparison of simulation according to the COST436 methodology and direct on-road measurement

A very good match of the on-road measured and simulated emissions could be observed: fuel consumption (and with it CO2 emissions) agree within ± 2%, and NOx emissions agree within ± 4%.

The attempt to measure emissions of a heavy-duty vehicle on the road, remove its engine and measure the emissions on a dynamometer according to laboratory standards and simulate the driven vehicle rides using only the dynamometer data gave important indications on the quality of those different approaches. The on-road measurement of a vehicle yielded valuable and high-quality data on its emission behaviour for the rides driven. Nevertheless, it would be prohibitively time-consuming and expensive to systematically collect comprehensive emission data for different heavy-duty vehicle classes with different total masses, different bodyworks and in different driving situations on the road. Even if on-road measurements will increase in importance in the future, an emissions model will still be needed to extrapolate emissions from measured to unmeasured situations. The emissions model PHEM from the TU Graz (section 4.2.1), which is based on engine dynamometer emission data, showed good emission prediction quality for the diesel engine equipped vehicle without exhaust gas treatment. However, the attractive possibility of collecting data for the emission model database on the road instead of in the laboratory must be investigated in the future.

This article focuses on gaseous emissions, although on-road particle emission data would also be of significant interest. The question of reasonable and comparable particle emission measurement techniques, other than the regulated filter weighting method using full-flow dilution of the exhaust gases, remains unsolved as long as no common opinion is established in the scientific community regarding alternative laboratory techniques.

10.4. RESEARCH OF HEAVY DUTY VEHICLE EMISSIONS AND FUEL CONSUMPTION IN SWEDEN (U. HAMMARSTRÖM, VTI, S)

In Sweden vehicle models based on quasi stationary engine maps have been in use for many years

- for road planning: fuel consumption; tire wear; brake wear and exhaust emissions
- for estimates of heavy duty vehicle emission factors to be used for national inventories of road traffic exhaust emissions
- for evaluation of different measures in the road transport system.

This type of model demand large amounts of input data for: vehicle, road and driver. Lack of data is mainly for the vehicle: engine; transmission; tyres; vehicle body and load. All vehicle data are of the same importance. The focus in COST 346 has been on the engine. The Swedish efforts in COST 346 are:

- Compilation of engine maps from earlier measurements
- New engine map measurements
- Need for transient corrections
- Method for transient corrections
- Auxiliaries

The following engine maps from earlier measurements have been supplied to the engine map data bank:

- SCANIA DSC9 07 Euro 1 (185 kW)
- VOLVO D7B260 Euro 2 (191 kW)

The new engine map measurements performed at AVL MTC AB include:

- 3 Euro 3 engines:
- SCANIA DC 12 01(309 kW)
- VOLVO D12C 420 (309 kW)
- SCANIA DT 12 02 470 (345 kW)
- All engines have been measured for two fuel qualities: EC1 Swedish fuel(low sulphur and aromatic content); TUG reference fuel
- Both stationary and transient measurements
- Enlargement of stationary points both for negative torque and for torque=0 Nm. The last alternative both with and without engine brake

In order to simulate engine power needed under different conditions auxiliary equipment power demand has to be described, see Hedbom (2002). Auxiliaries include (maximum case for HDV:s with gross vehicle weight>15 t): compressor for brakes ; compressor for suspension; pump for power steering; compressor for air-conditioning system (30 kW busses); alternator (15 kW busses) and cooling fan (15 kW).

Estimates of emissions based on quasi stationary simulation models need corrections, especially of CO, HC and PM, see Egnell(2005a,b). CO and PM are underestimated and HC overestimated, see figure 1.

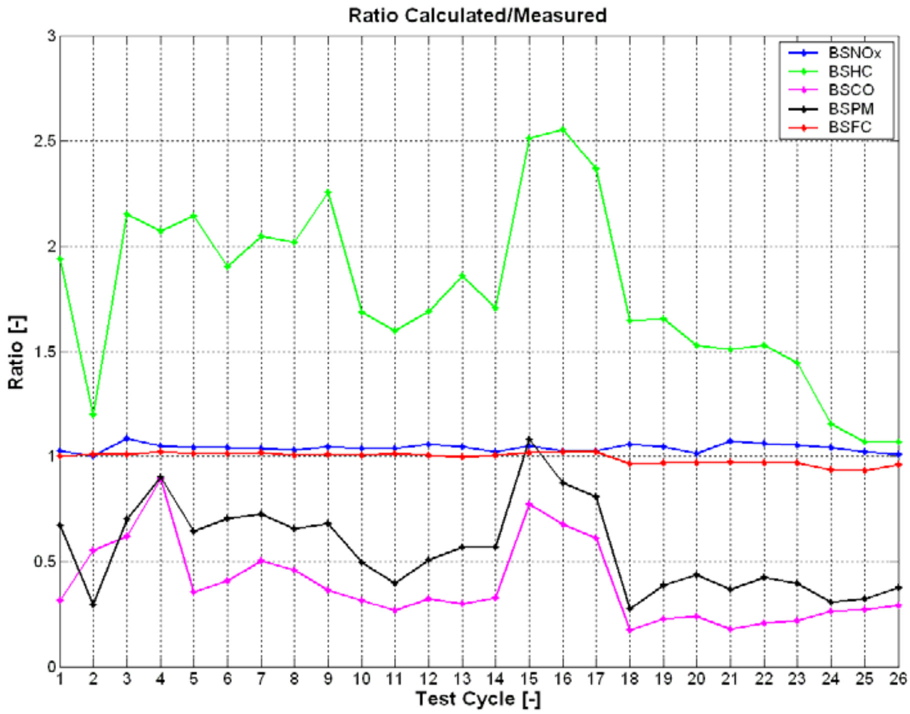


Figure 27: Ratio of calculated and measured fuel consumption and emissions for 26 test cycles (Egnell,2005a)

Figure 27 illustrate there is no need for correction of fuel and NO_x. By comparing the lambda values from static and dynamic load conditions, support is found for the idea that the dynamics of the turbocharger and air supply is one of the major reasons for changes of the combustion boundary conditions during fast speed and load changes. A method was developed in order to describe such a process. Because of problems with limited input data and extrapolation performance of the software used this first attempt resulted in an error of +/-20 %. In addition alternative stepwise and case wise black box approaches were tested. These approaches resulted in an error of the same magnitude as the mechanistic approach.

The ideas from Egnell (2005a,b) have to some extent been the base for “Transient emission predictions with quasi stationary models”, Ericsson et al (2005). A transient correction model was developed based on the delay introduced by the turbo charger. Quasi stationary based emissions are compensated dynamically time step by time step as a function of time delay and a corresponding transient air-fuel equivalence ratio.

General viewpoints on HDV diesel engine simulation are compiled in Egnell(2005b): warming up phase; classification of engines in order to estimate average engines and transient corrections.

10.5. DEMONSTRATION AND EVALUATION PROJECTS ON RETROFIT TECHNOLOGIES FOR BUSES IN FLANDERS, BELGIUM (M. VAN POPPEL, VITO, B)

The Flemish Transport Company ‘De Lijn’ has set-up different demonstration project to test clean technologies and fuels for buses. During the last 5 years, the main focus was on aftertreatment technologies for diesel buses. An accompanying test program was set-up to evaluate the real life performance of these technologies. The measurements were funded by the Environmental Department of the Flemish Region. The real life performance evaluation was done by on-board emission measurements using Vito’s On-the-road Emission and Energy Measurement system (for Low emitting vehicles) (VOEM (Low)).

10.5.1. CRT retrofitting

In a first demonstration project, the Flemish Transport Company 'De Lijn' equipped 18 Van Hool A308 city buses (with Euro 2 MAN D0824 4.58L 114 kW engine) with a Eminox/Johnson Matthey CRT (Continuous Regenerating technology). On one of these buses, a real life evaluation of the performance was executed.

The CRT is found to reduce PM emissions to over 90% thereby also reducing CO and THC to over 85%. No significant NO_x change was detected. The raise in fuel consumption is <2-3%. Follow-up measurements after one year showed no deterioration of the CRT. A slight increase in PM emissions was observed after two years, however still resulting in a filter efficiency of 85 to 90%.
The report (in Dutch!) can be downloaded at the site of the environment department of the Flemish region http://lucht.milieuinfo.be/

10.5.2. SCR + CRT retrofitting

In a new demonstration project, The Flemish Transport Company 'De Lijn' equipped Jonckheere Transit 2000 buses with a combined system for PM and NOx reduction. The Environmental Department of the Flemish Region funded a measurement campaign of two different systems including measurements after retrofit and after one year. The first CRT – SCR system shows a high reduction efficiency for all regulated emissions as well over test cycles as in real traffic. The CRT-SCR system is found to reduce PM emissions by over 90% and NOx emissions by 83 – 86%. Moreover, CO emissions are reduced by 89 – 93% and THC emissions by 83 – 86%. Average ammonia emissions are 5 to 10 ppm over the test cycles and 12 ppm in real traffic. The ammonia emissions are measured using a novel Tuneable Diode laser. The reason for the slightly higher ammonia emissions in real traffic is a somewhat too aggressive urea injection strategy in relation to the size of the SCR catalyst. Further system improvements are underway in order to reduce ammonia slip at same or better NOx reduction efficiencies. Follow-up measurements are planned. A second system equipped on the same type of bus is also evaluated in this project

Intermediate results of this on-going project were presented at the COST 346 final conference in Graz 2005 (Van Poppel et al. 2005).

The reports can be downloaded at the site of the environment department of the Flemish region http://lucht.milieuinfo.be/

10.6. Heavy duty vehicle operational characteristics, emission measurements, derivation of average speed functions and the application of the PHEM model (McCrae I, Boulter P, Barlow T and Latham S, TRL Limited)

This section provides a summary of projects, undertaken by TRL, which were associated with COST Action 346. In addition, it provides a brief summary of an attempt to use the PHEM model to evaluate on-road emissions.

10.6.1. The development of driving cycles, characteristic of traffic management schemes

Traffic management can result in a spatial and temporal redistribution of traffic in terms of flow, composition and vehicle operation. The overall impact of any traffic management schemes on local air quality will be related to the combined effects of such changes, and the air quality modelling exercises conducted by local authorities will need to take this into account. For emission measurement and modelling purposes, vehicle operation may be defined in terms of a number of parameters, although it usually relates to engine speed, engine load, gear selection and, most commonly, vehicle speed. It is this vehicle operation aspect of traffic management which was the focus of this TRL study.

For light-duty vehicles (LDVs), real-world operational profiles in relation to traffic management have been recorded in various studies, often for use as the input to emission models. In a small number of studies, LDV operational profiles have been referenced to specific traffic management measures, and subsequently used to develop representative driving cycles for measuring emissions in the laboratory. However, for heavy-duty vehicles (HDVs) very few driving cycles have been developed to specifically represent traffic management schemes, and the emissions performance of such vehicles in relation to traffic management is therefore not well documented.

TRL Limited was commissioned by the Department for Transport (DfT) to undertake a project (UG214) to address the gaps in the understanding of operational profiles and emissions for HDVs. The specific objectives of the project were:

1. To identify a range of traffic management schemes for which driving cycles could be developed.
2. To measure operational profiles for a range of vehicles in relation to the schemes identified.
3. To produce generic driving cycles for use in emissions testing.

Driving cycles were developed for seven generic categories of traffic management measure:

- Bus lanes
- Cycle lanes
- Traffic calming: road humps
- Traffic calming: other
- Mini roundabouts
- One-way systems
- Urban traffic control (UTC)

In addition to the above, three control cycles were developed to represent stretches of road with no traffic management.

Examples of each type of traffic management were identified in more than one town or city in the UK to minimise, as far as possible, any site-specific influences on driving patterns. Six sites were chosen in total, each having a substantial number of traffic management measures. These were:

- West London (Kingston/Richmond area)
- Southampton
- Havant
- Oxford
- Gloucester
- Reading

At each site a car, a light goods vehicle, a heavy goods vehicle and bus were equipped with a PC-based data logger and a Global Positioning System (GPS), both of which collected continuous vehicle speed data as the vehicles were driven around a set route. In total, forty driving cycles were developed from these measurements. Ten were developed for each vehicle type and within each vehicle type one cycle was developed for each of the seven traffic management measure categories and the three control categories. Details of the resulting bus and HGV cycles are shown in Table 18 and Table 19.

Table 18: A statistical summary of the HGV cycles and sub cycles

Bus Cycles	Distance (km)	Duration (s)	Average Speed (km/h)		Max. Speed (km/h)	Average positive Accel (m/s^2)		Max. Accel(m/s^2)
			Derived Cycles	All Data		Derived Cycle	All Data	
Road Hump	5.75	1010	20.49	21.18	34.2	0.29	0.39	0.86
Traffic Calming	6.70	885	27.26	27.32	38.31	0.30	0.40	1.26
Cycle Lane (CL)	6.83	985	24.93	25.08	57.04	0.34	0.30	1.14
CL: Non-congested	*5.21*	*513*	*36.53*	*36.93*	*57.04*	*0.30*	*0.29*	*1.12*
CL: Congested	*1.62*	*472*	*12.29*	*13.23*	*35.33*	*0.38*	*0.30*	*1.14*
Bus Lane (BL)	6.56	930	25.37	24.21	52.19	0.33	0.33	1.68
BL: Non-congested	*4.80*	*472*	*36.64*	*35.79*	*52.19*	*0.29*	*0.29*	*0.96*
BL: Congested	*1.76*	*458*	*13.77*	*12.62*	*43.21*	*0.37*	*0.36*	*1.68*
One Way (OW)	4.02	947	15.26	15.21	43.71	0.37	0.46	1.11
OW: Non-congested	*3.07*	*535*	*20.64*	*21.17*	*43.71*	*0.35*	*0.42*	*1.11*
OW: Congested	*0.95*	*412*	*12.67*	*9.26*	*34.52*	*0.40*	*0.43*	*1.04*
Mini-roundabouts	5.80	927	22.51	23.87	48.39	0.34	0.44	1.05
Urban Traffic	5.07	954	19.11	20.52	45.47	0.40	0.42	1.22
Control, Congested	2.51	835	10.84	12.09	48.52	0.37	0.42	1.33
Control, Non-	8.81	875	36.22	34.85	66.69	0.34	0.34	1.28
Control, Suburban	5.12	790	23.31	24.44	51.10	0.36	0.43	0.96

Table 19: A statistical summary of the bus cycles and sub cycles

Bus Cycles	Distance (km)	Duration (s)	Average Speed (km/h)		Max. Speed (km/h)	Average positive Accel (m/s^2)		Max. Accel (m/s^2)
			Derived Cycles	All Data		Derived Cycle	All Data	
Road Hump	5.31	944	20.25	21.34	43.26	0.43	0.37	1.28
Traffic Calming	5.94	855	24.97	26.35	45.25	0.37	0.29	1.45
Cycle Lane (CL)	5.65	1080	18.82	20.05	45.02	0.47	0.44	3.08
CL: Non-congested	*4.12*	*542*	*27.31*	*28.46*	*45.02*	*0.52*	*0.46*	*3.08*
CL: Congested	*1.53*	*538*	*10.26*	*11.65*	*31.20*	*0.41*	*0.42*	*1.19*
Bus Lane (BL)	8.34	1192	25.17	23.48	39.94	0.46	0.55	1.73
BL: Off Peak	*4.12*	*611*	*25.00*	*23.86*	*39.94*	*0.48*	*0.56*	*1.73*
BL: Peak	*3.93*	*581*	*24.31*	*23.09*	*38.77*	*0.44*	*0.53*	*1.53*
One Way (OW)	4.36	941	16.65	17.01	41.42	0.52	0.56	1.99
OW: Non-congested	*2.80*	*471*	*21.35*	*21.17*	*41.42*	*0.51*	*0.57*	*1.55*
OW: Congested	*1.56*	*470*	*11.92*	*12.84*	*39.45*	*0.53*	*0.56*	*1.99*

Mini-roundabouts	7.88	1076	26.33	25.09	46.45	0.38	0.41	1.28
Urban Traffic Control	5.41	894	21.76	22.09	49.56	0.50	0.44	1.79
Control, Congested	3.08	1051	10.53	11.51	38.20	0.39	0.49	1.19
Control, Non-	7.61	983	27.82	28.89	47.68	0.49	0.55	1.80
Control, Suburban	6.39	886	25.95	27.42	48.00	0.40	0.50	1.43

These HGV and bus driving cycles were subsequently made available to COST 346 partners.

10.6.2. Pilot application of the PHEM model

The M42 motorway, to the south of Birmingham carries in excess of 150,000 vehicles a day and is thus associated with significant peak hour congestion and its associated emissions and air pollution impacts. A pilot project of active traffic management (ATM) is being introduced to target congestion. This section provides a summary of the assessment of vehicle exhaust emissions of the ATM, through the use of instrumented vehicles to characterise before and after driving characteristics, and the use of the PHEM model to characterise changes in emissions.

The Highways Agency has introduced Active Traffic Management (ATM) on the M42 motorway between Junctions 3A and 7, in the form of mandatory 3 lane Variable Speed Limits. It will be introducing hard shoulder running as part of this pilot scheme by winter 2007. Both 3 lane Variable Speed Limits and hard shoulder running are known as Operational Regimes.

The pilot scheme includes the following features:

- Lightweight gantries with lane-specific signals (Advanced Motorway Indicators) and signs (Advanced Motorway Signs). These can be used to open and close lanes, control speeds to prevent flow breakdown, and to provide enhanced driver information;
- Cameras to monitor traffic conditions and automatic queue detection (MIDAS - Motorway Incident Detection Automatic Signalling) to detect queuing traffic and set warning signals;
- Digital speed enforcement equipment;
- Controlled use of the hard shoulder as an additional running lane for incident management and during periods of heavy congestion.

The ATM scheme aims to bring together a number of technologies to demonstrate how they can be used in parallel to make better use of the existing road space, thereby providing additional capacity and potentially reducing the need for the widening of roads.

Earlier studies of the M25 variable speed limit pilot scheme, estimated associated improvements of up to 10% in carbon monoxide (CO), oxides of nitrogen (NO_X) and carbon dioxide (CO_2) emissions. This early assessment employed relatively simple modelling tools, which have now been supplemented by more sophisticated tools arising from ARTEMIS project and COST Action 346.

The way in which vehicles are operated has significant impacts on the fuel consumption and associated exhaust emissions. To assess the impact of ATM on this relationship, vehicle operational characteristics were recorded through the use of instrumented vehicles. The approach requires the measurement and comparison of these operational characteristics, before and after the introduction of each of the proposed ATM operational regimes. The recorded driving characteristics are subsequently developed into representative driving cycles. These are in turn used as input to emission models to allow emission estimates of CO, NO_X, VOC, PM, SO_2 and CO_2.

Light duty and heavy goods vehicle driving characteristics were measured using instrumented ‘floating’ vehicles over various predefined routes along the M42, during two, two-week periods. For the light duty vehicle assessment, a modern medium-sized car, typical of the UK fleet (a 2000cc Ford Mondeo), was selected. The vehicle was fitted with two measurement systems, both of which were logged onto a portable PC. Firstly, vehicle road speed, engine speed and clock time were recorded from the vehicle’s on board diagnostic (OBD) system at a frequency of approximately 2Hz. Secondly, a GPS system was installed in the vehicle to record vehicle location (at approximately 1Hz). Similarly heavy-duty driving characteristics were measured using an instrumented tractor unit and articulated trailer combination (A DAF model CF85 tractor unit, incorporating an engine power output of 430hp, transferred through two driven wheels. It was linked to a Schmitz 13.6m Euroliner trailer, 3-axle unit with air suspension. The nominal weights of the tractor unit and trailer were 7 and 5 tonnes, respectively. The vehicle had a maximum laden weight of 31 tonnes.) A curtain-sided trailer was laden with 9 tonnes of concrete blocks to simulate an approximate load of 60% of the permissible maximum laden weight, characteristic of the vehicles in use on the trunk road network. Vehicle speed, engine speed, load and time were directly recorded from the CAN bus, and logged onto a PC. Again a GPS system was installed on the roof of the tractor unit, which provided location data at a frequency of 1Hz. Both vehicle measurement systems were supported by a driver’s log which was designed to confirm the start and end times of each of the driven test routes, and to record the time and location of specific incidents such as congestion, accidents, and maintenance or traffic management activities.

Two baseline campaigns were undertaken (24 June 2003 to 7 July 2003 and 12 – 26 November, 2003), encompassing 10,000 miles of light-duty driving and 7,587 miles of HGV operation. An example of typical data collection for one test route is shown in Figure 28.

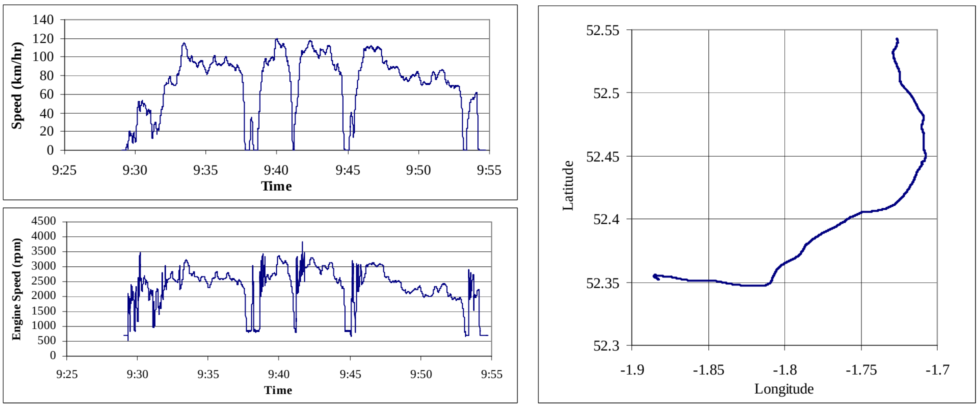


Figure 28: An example of the logged data recorded on the M42

For the heavy duty vehicle assessment, the resulting driving characteristics were used with the PHEM model to provide estimates of HGV emissions for the various test routes over various times and under various traffic conditions. The PHEM model was configured to estimate the emissions associated with 6 Euro emission classes, operating at 50% load, and zero gradient. Typical results are shown in Figure 29.

Further driving characteristic measurements will be recorded after the scheme become live. At that time, this study will be extended to provide a comparison of the before and after impacts on emissions and air quality.

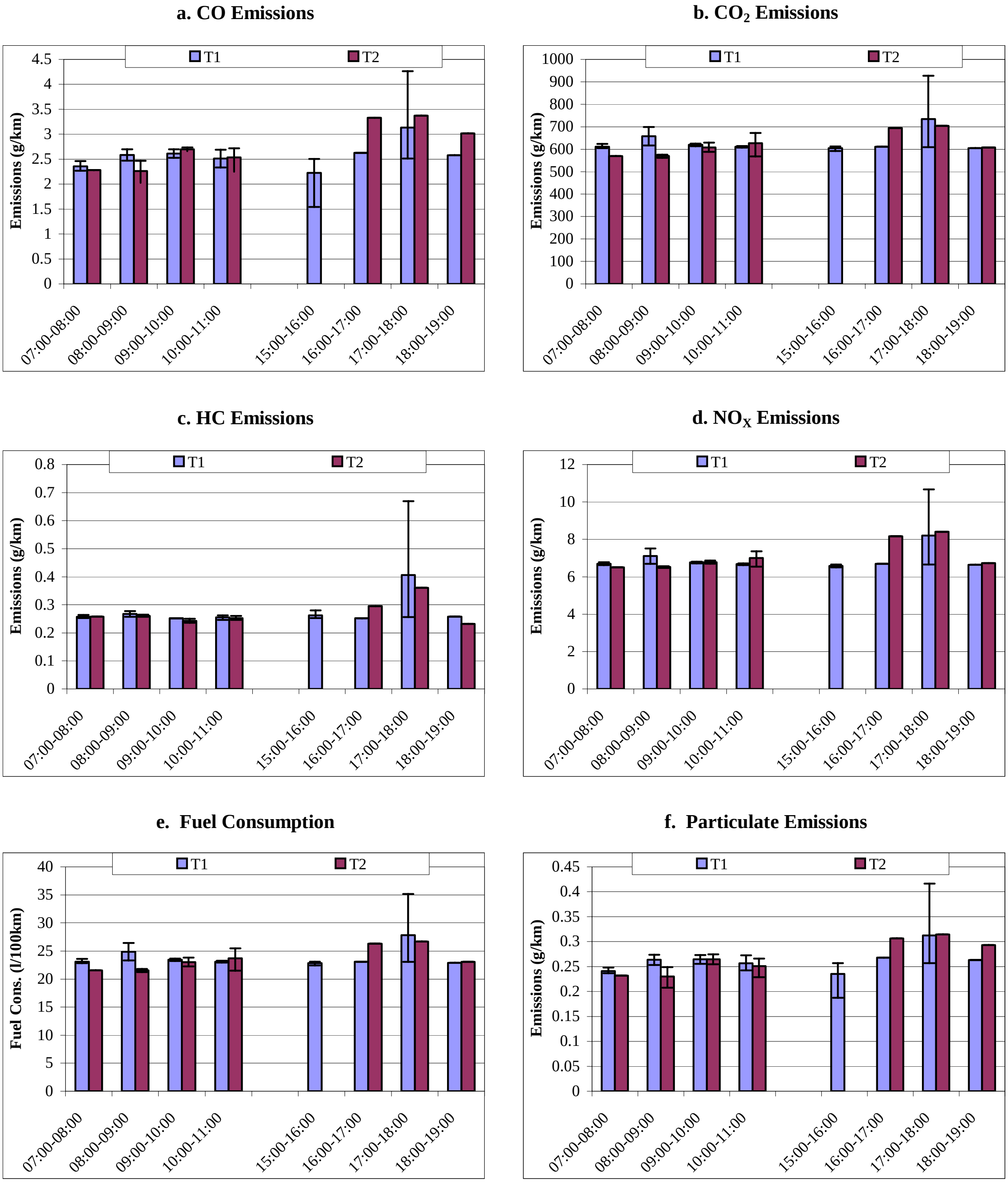


Figure 29: ***Comparison of the average hourly emissions HGV: Route 2 - M42 Southbound***

10.7. CHARACTERISATION OF THE BUS DRIVING IN URBAN AREA, DERIVED DRIVING CYCLES AND EMISSIONS (BY M. ANDRÉ, INRETS, B. GARROT, RATP; F)

The estimation of the emissions at a local scale implies a good knowledge of the driving conditions and the possibility to measure or model the emissions at this scale. With these aims in view an approach in 3 steps was developed for the case of the urban buses: 1- to describe and characterize in detail the urban context in which buses are driven, 2- to instrument buses and monitor their driving conditions in this context, 3- to derive representative driving cycles enabling a detailed measurement and analysis of the emissions as a function of local specificities.

10.7.1. Characterisation of urban context and of the bus lines

Considering that vehicle operating conditions are first of all dependent on the "urban context", we analyse this one through data on population, employment, housing, road network, traffic, and the areas served (schools, stations, retail outlets, etc.) and crossed (André *et al*., 2003, 2004). This data is calculated for the Ile-de-France region divided into units of 100 x 100 metres and stored in a GIS (Geographical Information System). This is completed by bus route characteristics and operating statistics.

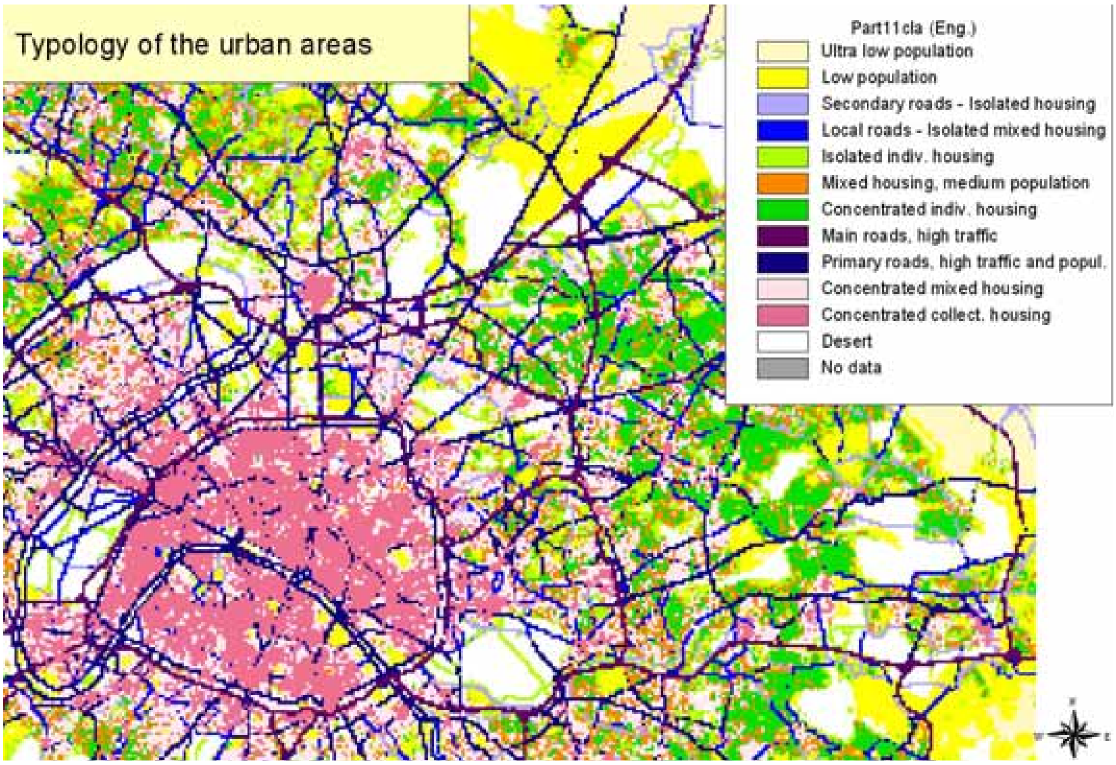


Figure 30: Description of the Paris area in typical urban areas

Through factorial analyses we establish a typology of the areas. The conurbation is then “zoned” into: low population level, houses, remoteness from facilities, intermediary areas of isolated houses, mixed and dense housing, areas near major roads that associate very dense housing, and dense Parisian and suburban town centres (Figure 30). Bus routes are analysed according to their itineraries through these areas. We define then 4 main categories of lines: 1- lines that use the main road network with high-levels of traffic and serve dense town centres (high service level and irregularity rates[2]), 2- lines connecting mixed or isolated housing areas in the more remote suburbs, 3- lines serving dense mixed and individual housing areas in the remote suburb, 4- lines mainly serving Paris and high density housing areas (with the highest rates of service irregularity and accidents).

[2] The irregularity rate is defined from timetable variations of passage at different points on the bus line.

10.7.2. Instrumentation of buses to monitor the driving conditions

Four representative lines were selected to cover the previously defined lines categories and areas. Two buses (Renault R312 and Agora) were then instrumented and regularly monitored under normal commercial operating conditions for a duration of 1 month, with usual driver turnaround. More than 25,000 km were recorded. The average travel speed was much lower on the Parisian bus line 47 (11 km h-1) than on more remote suburban lines. Time durations relative to bus stops are over 40% of trip duration for lines 47 and 163 (Table 20) and about 23% for the other lines.

Speed, engine and auxiliaries operating parameters and passenger load were continuously measured. The localisation of data (essential to associate driving conditions with local specificities) was achieved by the use of GPS data when measured (although strong inaccuracies) and by an automatic recognizing of the profiles of commercial bus stops. This second approach was very efficient. This enables us to analyse the local average driving conditions and to highlight the strong contrasts between the areas (Table 21).

Table 20: Average driving characteristics as regards the 4 categories of bus lines

Geographical area	Distance covered in %	Average speed km/h	Running speed km/h	Stop rate per km [%]	Stop duration %
Unidentified areas and connections	5,0	17	26	2,2	33,6
Low population, very remote	0,6	31	36	0,6	14,6
Remote houses, secondary road-network	3,7	26	29	1,3	11,0
Mixed remote housing, second. and tertiary road-network	7,3	16	23	2,9	29,4
Remote detached housing, gradient	2,5	18	24	2,0	27,0
Dense mixed housing, proximity	4,8	21	25	1,7	15,5
High-density individual housing	2,8	25	27	0,9	8,4
Main routes, high level of traffic	6,3	19	24	2,1	18,5
High population near primary axes	30,2	14	22	4,4	34,9
Dense mixed housing, high population	13,6	17	23	2,6	26,7
Dense council housing, high pop. and employment	22,5	11	20	5,2	43,3
Uninhabited areas	0,8	19	22	1,6	13,3

Table 21: Average driving characteristics according to the geographical areas.

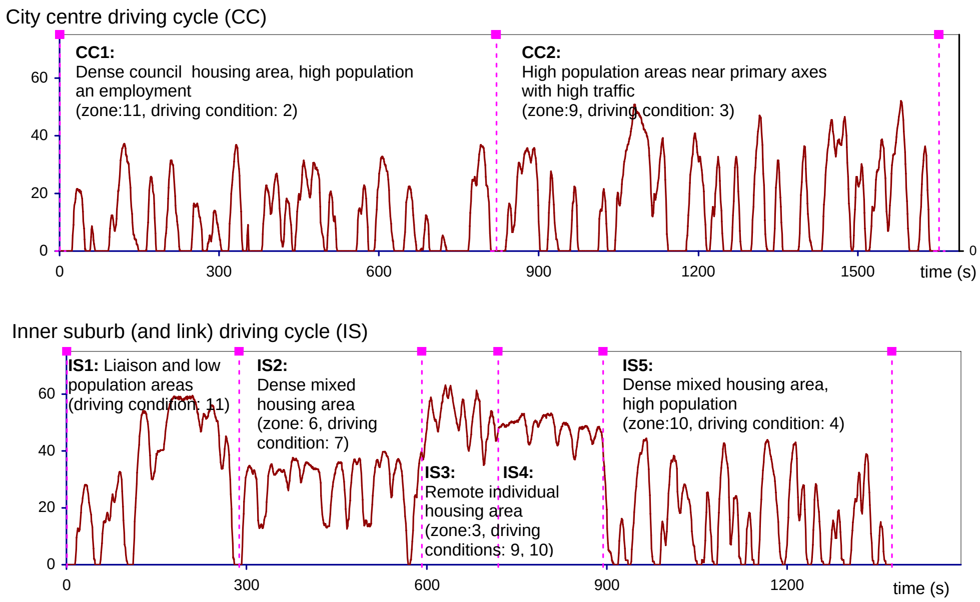
Geographical area	Distance covered in %	Average speed km/h	Running speed km/h	Stop rate per km [%]	Stop duration %
Unidentified areas and connections	5,(	17	26	2,2	33,6

Low population, very remote	0,(	31	36	0,6	14,6
Remote houses, secondary road-network	3,'	26	29	1,3	11,0
Mixed remote housing, second. and tertiary road-network	7,:	16	23	2,9	29,4
Remote detached housing, gradient	2,!	18	24	2,0	27,0
Dense mixed housing, proximity	4,8	21	25	1,7	15,5
High-density individual housing	2,8	25	27	0,9	8,4
Main routes, high level of traffic	6,:	19	24	2,1	18,5
High population near primary axes	30,2	14	22	4,4	34,9
Dense mixed housing, high population	13,6	17	23	2,6	26,7
Dense council housing, high pop. and employment	22,5	11	20	5,2	43,3
Uninhabited areas	0,8	19	22	1,6	13,3

10.7.3. Driving cycles and emissions as regards the urban context

The segments driven in each of the geographical areas were analysed as regards the two-dimensional distribution of instantaneous speeds and accelerations (André et al, 2005). This enables the identification of a typology of driving conditions and the building-up of 3 representative bus cycles (Figure 31) structured in 11 sub-cycles representing the driving patterns and areas. Quite marked contrast is observed in these cycles, from phases at 5 km h-1 and 73% of stops to phases at 50 km h-1. The city centre includes 2 phases at 10 and 16 km h-1 respectively and a stop rate that doubles from 4 to 8 stops per km.

The pollutants emissions of 3 buses measured using these cycles (Garrot et al. 2004) highlights the high variability of the emissions as a function of the driving patterns (Figure 32). CO2 and NOx emissions vary by a factor 2 to 4 between the different areas.



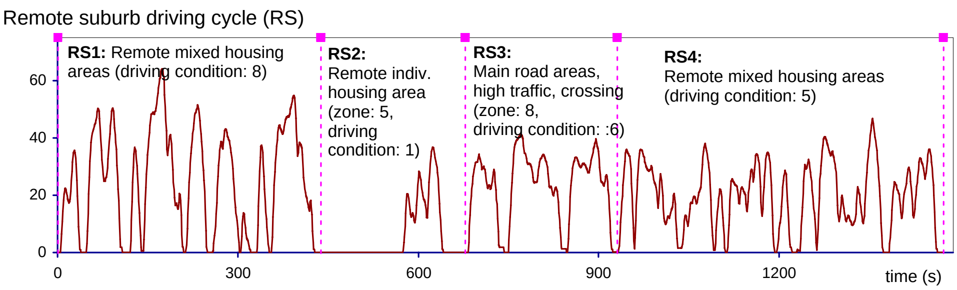


Figure 31: Three bus driving cycles, representative of the driving conditions observed in the city centre, in the suburbs and during the liaison to the bus depot

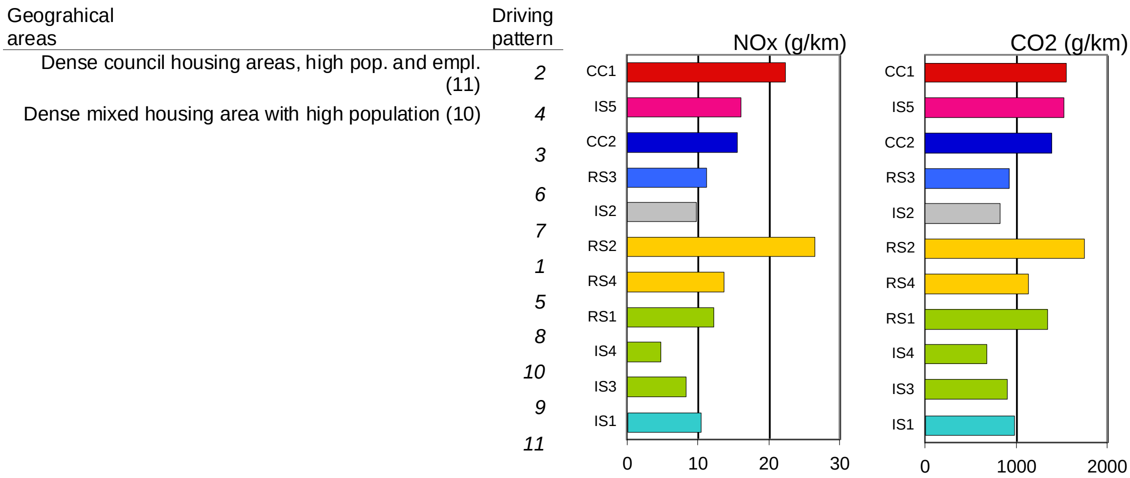


Figure 32: Pollutant emissions and their variability across the different geographical areas as a function of the encountered driving patterns (urban bus EURO3)

10.7.4. Conclusion

By analysing the urban context, we have build representative driving cycles that characterize both geographical areas and the driving conditions. This enables analysing emissions as regards the urban context and assessing their local impacts. The application to other bus networks should enable a validation of these results. To ensure coherency for the emission calculation tools (inventory), such approach should also be contemplated for other vehicle categories.

10.8. Complementary information regarding Traffic Characteristics (M. André, N. Adra, INRETS, F)

In the framework of the ARTEMIS (WP 1000) an analyses of the state-of-the-art has been conducted as regards different traffic related parameters for the road vehicles. The analysis, based on existing statistics and reports (surveys, projects, etc), aimed to identify the main variation factors and should help future users to build-up their input data taking into account these existing sources and statistics. These analyses concern: 1- load factor and empty running rate, 2- annual mileage and 3- Trip lengths, 4- Fuel characteristics. We recapitulate here the main conclusions. A complementary report dealing with the survival rates (for the fleet estimation) can also be mentioned (Adra et al. 2004a).

10.8.1. Load factor and empty running rate

Load factor and the empty running rate were analysed as well as their trends. The synthesis and the analysis of statistics from Europe, France, Great Britain, Switzerland, etc, and data from international institutions highlighted various aspects and difficulties (Adra, et al. 2004e). In order to better consider load factor and empty running rate when estimating pollutant emissions it is recommended to consider them according the vehicles types and sizes, and possibly to consider correction function (or evolution) with the time. For goods transport, the following conclusions were drawn:

> Load factor:

- The difference between load factor for loaded trips (excluding empty running) and load factor for all trips (including empty running) is not always clear. More work is needed at the EU level to provide harmonized and reliable data for load factors through clear definitions.
- An adoption of the following definitions is strongly recommended: - the empty running corresponds to the mileage driven without load – the average load factor is the average ratio between the actual load in weight during the non-empty running, versus the load capacity of the vehicle.
- The load factor in the EU ranges from 35% to 80% and it tends to gradually decrease. This decrease can be due to the increase of the loading capacity per vehicle and to reductions in the weight transported per trip (lower densities of modern high-quality goods).
- Load factor depends on the vehicle type and weight: It can vary from 58% for the articulated vehicles to 52% for the rigid vehicles. Rigid vehicles with a gross weight 3.5 to 7.5 tonnes has an average load factor of 42%, while a vehicle over 25 tonnes is loaded at 65%.
- Load factor decreases with the time: corrections functions as regards time have been established for rigid and articulated vehicles, that enable to determine the load factor at a given year n as a function of the load factor at n_0, with the form: $LF^i(n)=P*(n-n_0)+LF^i(n_0)$ Where $LF(n_0)$ is the load factor at a year n_0. This function was adapted to the vehicle types used in COST346

> For the empty running rate:

- The empty running rate is decreasing with time. Relations to estimate the rate at a given year have also been derived from the available data.
- The empty running rate depends also on the age of the vehicle. This parameter could have an impact if the age distribution is spread.
- The use of an empty running rate of 25% as sometimes adopted is close to the average empty rates in Great Britain (26.5% in 2002) and in France (25.2% in 2001).
- When data is available, the significant distinction between the two modes of working: “hire or reward” should be done (respectively 22% and 35% in France in 2001).
- The distinction between “rigid vehicles” and “articulated vehicles” should also be done. Indeed, The important differences exist, depending on the payload of vehicles.

10.8.2. Annual mileage

The review of the available statistics enabled to highlight the tendency of the annual mileage and the numerous factors affecting this parameter (Adra et al, 2004d). 'Usage factors' representing these influences have been developed. In order to better take into account the annual mileage when estimating pollutant emissions, it is recommended to apply corrections as regards time and usage factors for the different vehicle weights:

- The French and British statistics show significant variations between lorries and articulated vehicles: usage factors are 0.6 to 1.4 in France and 0.7 to 1.8 in UK.
- The distinction between "rigid vehicles" and "articulated vehicles" should also be done and could be of a ratio 1.4-1.8.
- Important variations are observed according to the vehicle weight.
- A significant variation is observed as a function of the mode of working (public haulage or own account): public haulage leads generally to a more intensive usage of the vehicle (usage factors are respectively 1.4 for public haulage and 0.5-0.7 for own account). If data are available, the distinction should be done.
- The annual mileage varies with time. We have defined correction functions that can be used when data at year n0 are available for a country.
- If data are available, the distinction between payload categories of vehicle should be done.

10.8.3. Fuel characteristics

The analysis of the data on fuel characteristics and volumes from different countries and institutions highlighted that the EU Commission does the collection of information on Fuel quality officially since 2001. The information is summarised in annual reports.

The EU fuel quality monitoring report provides a reliable data source. Mean values can be used by country for the emissions calculation. Important discrepancies can however be observed between the countries. Where data is available, regional and seasonal specificities must be considered (Adra et al, 2004c).

10.8.4. Trip length

The collection and analysis of data and statistics on trip length from different sources e.g. European projects, national surveys, etc., highlight the trends of the trip length values and the influence of various factors (Adra et al. 2004b). On the European level, although some countries collect information on the trip characteristics and trip length, it seems that:

- No EU-wide data is yet available for passenger and even less for goods transport.
- There is no standard data sets for all countries
- There is no common definition for 'Trip'.

It was suggested to adopt the following definition: a TRIP is a one-way movement of a vehicle between the engine starting and the engine stopping. The TRIP LENGTH is then the distance between the two points.

Passenger cars

On the European level, there is a lack of standard data sets for trip description. The EU-average trip length is 13 km and tends to increase. We note that the average value from vehicle instrumentation is 7 km. Detailed information on trips related to passenger transport and mobility may be available from national surveys. The impact of various factors is sometimes derived from these surveys:

- Factors related to the driver (e.g. age, sex, professional and marital status, income)
- Factors related to the trip (e.g. trip purpose, trip type, type of use), to the vehicle (e.g. vehicle type)
- Factors related to the local context (e.g. residential area, city size, origin and destination, etc), and to the time (e.g. season, day of the week, time period).

The taking into account of such correction factors should improve the emission estimation.

Goods transport

For goods transport, there is few available data concerning the description of trip length. The existing information concerns the length of haul, the goods transported and their flow (tons x kilometres). The factors that can influence the length of haul are:

- Time: in Sweden the length of haul increased by 20% from 1993 to 2001,
- Vehicle type: articulated vehicles carry goods 3 times further than rigid vehicles,
- Vehicle size: the variation with vehicle size is more important for rigid vehicles, and is particularly significant for the vehicles 17 t to 25 (Figure 33).

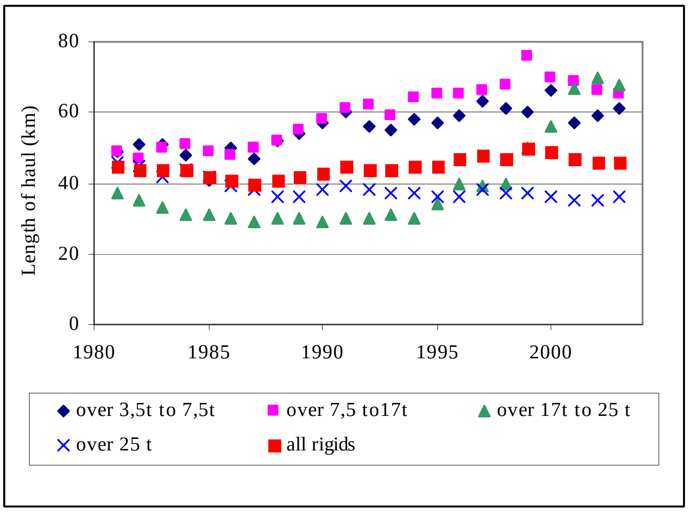


Figure 33: Variation of the length of haul with vehicle size in UK

- Goods category: The Swedish survey and the GB data show that the haulage distance varies greatly depending on the category of goods.
- For local and regional approaches, it is necessary to give specific distributions for trip lengths as these seem highly depending on the local characteristics. It should be useful, when possible to consider detailed trip description.

10.9. USE OF COST 346 RESULTS: EMISSION LOADS OF TRAFFIC, AND ESPECIALLY OF HEAVY DUTY VEHICLES ON SOME MAIN ROADS IN FINLAND (KOSKINEN, FIN)

The work concerning the utilisation of emission maps for emission estimation for heavy duty vehicles on specific roads in Finland was presented in detail at the COST 346 final conference in Graz 2005 (Koskinen et al. 2005).

On rural highways in Northern Europe the vertical alignment or the topography causes in most cases more speed variations for heavy duty vehicles than the traffic congestion itself. In traffic flows vehicles move freely in general, and this is especially typical for the heaviest vehicles. The upward slopes determine the instantaneous speed, and a vehicle of this kind is very sensitive to fall into a transient state on upgrades, but on the other hand downgrades also make the vehicle accelerate very fast. As well known, the Nordic road trains differ from the other EU goods vehicles by their technical characteristics, that also causes different dynamic behaviour. For example, if a truck + trailer combination having the gross mass of 60 tons and the rated engine power of 300 kW (minimum requirement is 5 kW/t) climbs up a longitudinal gradient of one percent, a constant speed of 80 km/h cannot be maintained any more.

The technical road characteristics as emphasized with the vertical alignment are of a greater importance rather than the traffic flow and its congestion, because the heaviest vehicles move mostly independently. Therefore special attention has to be paid to roads as well as to the different vehicle categories and their shares in the traffic flows.

11. Conclusions and outlook

The work performed under the framework of the COST 346 action has definitely improved the knowledge on emissions and fuel consumption of heavy duty vehicles under real world conditions. COST 346 led to a strong improvement in the data base on measured engines. Due to the commonly used test protocol and the co-operation with Artemis WP 400, most of the HGV related emission work within the participating countries could be utilised. In addition a methodology for an emission factor database has been developed which can be adapted to each individual country on basis of their own fleet distribution. A lack of data still exists in the description of the transmission losses and all other forces acting on the vehicle as well as in the description of the influence of auxiliaries.

However, the work is not finished yet and topics for further activities have been identified. The measurements covered engines up to EURO 3 technology with some exceptions of EURO 4/5 prototypes. As EURO 4 enters at the end of 2005 the market and EURO 5 may come earlier than originally expected the measurement programme has to be prolonged. EURO 4 and EURO 5 will have to utilise high end technology in order to achieve the required low emission levels. After treatment systems, controlled EGR combined with improve combustion processes will be required. The high technical standard will open the gap between type approval tests and real world emission behaviour. This fact calls for an extensive monitoring of the real world emission behaviour, which itself require improved field test possibilities.

The available fleet emission model provides the framework for an emission calculation. As the emission factors describe the emissions of the present vehicles in Europe, the basic data is generally usable for all vehicle categories from pre-EURO to EURO 3 emission standards. However, this is not the case for the fleet distribution and activity data. The data describing the fleet characteristics is available only for a few countries and serve as an example. In order to use the model on a nationally bases the local fleet characteristic has to be inputted into the model scheme.

There will be a big need for further work in estimating and checking emissions of road vehicles in general and heavy duty vehicles in special. The highly sophisticated engine and exhaust gas after treatment technique which is required to fulfil the EURO 4 and EURO 5 standards has to prove its effectiveness not only during the type approval, much more important it has to show the emission reduction capacity in real world. This calls for improved test procedures for on-road testing and effective short test in I/M procedures.

In addition it turned out, that in future engine measurements based on taking the engine out of the vehicle might not be a realistic solution based both on representative and economical reasons. Economical reasons of course also influence representativness since there is a risk that the number of engines will be to small. This problem of course is most relevant both for future legislation and for emission factors to emission models.

Simultaneously it will be necessary improve the knowledge in to rolling resistance data on different road pavements and during different weather conditions, air resistance data of different HDV configurations, technical road data (unevenness data) and driving pattern data. The currently available description of the driving behaviour is definitely an improvement compared to the situation before the start of COST 346. However, driving situations e.g. like for free flowing traffic in rural areas are not well investigated and of high concern in countries with a lower traffic density.

Furthermore, several incoherencies with the other vehicle categories for a given traffic situation, the lack of data for certain cases and its quite low representativity demonstrate the need of collecting driving behaviour data at a large European scale.

The further development work of models and input data could be carried out most effectively in the framework of a European co-operation activity.

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Annex I. Road type and traffic situation matrix

Area	Roadtype	level of service	Speed limit in km/h											
			30	40	50	60	70	80	90	100	110	120	130	>130
Rural	Motorway	Freeflow						x	x	x	x	x	x	x
Rural	Motorway	Heavy						x	x	x	x	x	x	x
Rural	Motorway	Saturated						x	x	x	x	x	x	x
Rural	Motorway	Stop+go						x	x	x	x	x	x	x
Rural	Semi-Motorway	Freeflow							x		x			
Rural	Semi-Motorway	Heavy							x		x			
Rural	Semi-Motorway	Saturated							x		x			
Rural	Semi-Motorway	Stop+go							x		x			
Rural	TrunkRoad	Freeflow				x	x	x	x	x	x			
Rural	TrunkRoad	Heavy				x	x	x	x	x	x			
Rural	TrunkRoad	Saturated				x	x	x	x	x	x			
Rural	TrunkRoad	Stop+go				x	x	x	x	x	x			
Rural	Distributor	Freeflow			x	x	x	x	x	x				
Rural	Distributor	Heavy			x	x	x	x	x	x				
Rural	Distributor	Saturated			x	x	x	x	x	x				
Rural	Distributor	Stop+go			x	x	x	x	x	x				
Rural	Distributor-sinuous	Freeflow			x	x	x	x	x	x				
Rural	Distributor-sinuous	Heavy			x	x	x	x	x	x				
Rural	Distributor-sinuous	Saturated			x	x	x	x	x	x				
Rural	Distributor-sinuous	Stop+go			x	x	x	x	x	x				
Rural	Local	Freeflow			x	x	x	x						
Rural	Local	Heavy			x	x	x	x						
Rural	Local	Saturated			x	x	x	x						
Rural	Local	Stop+go			x	x	x	x						
Rural	Local-sinuous	Freeflow			x	x	x	x						
Rural	Local-sinuous	Heavy			x	x	x	x						
Rural	Local-sinuous	Saturated			x	x	x	x						
Rural	Local-sinuous	Stop+go			x	x	x	x						
Rural	Access	Freeflow	x	x	x									
Rural	Access	Heavy	x	x	x									
Rural	Access	Saturated	x	x	x									
Rural	Access	Stop+go	x	x	x									
Urban	Motorwa-Nat.	Freeflow						x	x	x	x	x	x	
Urban	Motorwa-Nat.	Heavy						x	x	x	x	x	x	
Urban	Motorwa-Nat.	Saturated						x	x	x	x	x	x	
Urban	Motorwa-Nat.	Stop+go						x	x	x	x	x	x	
Urban	Motorway-City	Freeflow				x	x	x	x	x	x			
Urban	Motorway-City	Heavy				x	x	x	x	x	x			
Urban	Motorway-City	Saturated				x	x	x	x	x	x			
Urban	Motorway-City	Stop+go				x	x	x	x	x	x			
Urban	TrunkRoad-Nat.	Freeflow					x	x	x	x	x			
Urban	TrunkRoad-Nat.	Heavy					x	x	x	x	x			
Urban	TrunkRoad-Nat.	Saturated					x	x	x	x	x			
Urban	TrunkRoad-Nat.	Stop+go					x	x	x	x	x			
Urban	TrunkRoad-City	Freeflow			x	x	x	x	x					
Urban	TrunkRoad-City	Heavy			x	x	x	x	x					
Urban	TrunkRoad-City	Saturated			x	x	x	x	x					
Urban	TrunkRoad-City	Stop+go			x	x	x	x	x					
Urban	Distributor	Freeflow			x	x	x	x						
Urban	Distributor	Heavy			x	x	x	x						
Urban	Distributor	Saturated			x	x	x	x						
Urban	Distributor	Stop+go			x	x	x	x						
Urban	Local	Freeflow			x	x								
Urban	Local	Heavy			x	x								
Urban	Local	Saturated			x	x								
Urban	Local	Stop+go			x	x								
Urban	Access	Freeflow	x	x	x									
Urban	Access	Heavy	x	x	x									
Urban	Access	Saturated	x	x	x									
Urban	Access	Stop+go	x	x	x									

Annex II. Comparison of engine maps for in-use driving and type approval tests

The following text is an extract from Steven (2005).

Annex II.1: Measurement procedures and limit values for type approval

Heavy duty vehicles (HDV) are commercial vehicles with gross vehicle mass (GVM) above 3500 kg. HDV covers vehicles of categories N2, N3, M2 (> 3500 kg GVM) and M3 as specified in the ECE consolidated resolution on the construction of vehicles (RE 3). In contrast to cars HDV are not produced in large scale manufacturing but with a broad variety of chassis dimensions and transmissions. For that reason the engine (or even more exact a parent engine of an engine family) is certified with respect to its exhaust emissions during type approval. The measurement procedures and limit values are specified in ECE regulation 49 and the corresponding EU directives. The emission stages EURO 1 and EURO 2 are specified in Revision 2 of this regulation, the stages EURO 3, 4 and 5 in revision 3. The limit values and enforcement dates are shown inTable 22.

Table 22: Emission stages for HDV Diesel engines in the EU (EEV" means Enhanced Environmentally Friendly Vehicle)

Emission Stage	Enforcement Date	Test Cycle	CO g/kWh	HC g/kWh	NOx g/kWh	Particulates g/kWh	Smoke m^{-1}
EURO 1	1992/93	ECE R 49	4.5	1.10	8.0	0.36	
EURO 2	1995/96	ECE R 49	4.0	1.10	7.0	0.15	
EURO 3	2000	ESC/ELR	2.1	0.66	5.0	0.1 (0.13) *)	0.8
EURO 4	2005	ESC/ELR	1.5	0.46	3.5	0.02	0.5
EURO 5	2008	ESC/ELR	1.5	0.46	2.0	0.02	0.5
EEV		ESC/ELR	1.5	0.25	2.0	0.02	0.15

*) values in brackets for engines having a swept volume of less than 0.75 dm^3 per cylinder and a rated power speed of more than 3000 min^{-1}

Emission Stage	Enforcement Date	Test Cycle	CO g/kWh	NMHC g/kWh	CH_4 *) g/kWh	NOx g/kWh	Particulates g/kWh
EURO 3	2000	ETC	5.45	0.78	1.6	5.0	0.16 (0.21) **), ***)
EURO 4	2005	ETC	4.0	0.55	1.1	3.5	0.03 ***)
EURO 5	2008	ETC	4.0	0.55	1.1	2.0	0.03 ***)
EEV		ETC	3.0	0.40	0.65	2.0	0.02

*) for natural gas engines only

**) values in brackets for engines having a swept volume of less than 0.75 dm^3 per cylinder and a rated power speed of more than 3000 min^{-1}

***) not applicable for gas fuelled engines

Annex II.2: Test cycles

The different emission stages are related to different test cycles. For EURO 1 and 2 a steady state 13-mode cycle was used, which is called ECE R 49 in this report. The measurement modes and their weighting factors for the calculation of the final result are shown in Table 23.

"Rated speed" means the maximum full load speed allowed by the governor as specified by the manufacturer in his sales and service literature, or, if such a governor is not present, the speed at which the maximum power is obtained from the engine, as specified by the manufacturer in his sales and service literature. "Intermediate speed" means the speed corresponding to the maximum torque value if such speed is within the range of 60 to 75 per cent of rated speed; in other cases it means a speed equal to 60 per cent of rated speed.

For EURO 3 the test cycle was changed to the European steady state cycle ESC and a load response test (ELR) was added. The ESC is also a steady state 13-mode test but measurements have to be made at 3 different engine speeds, called A, B and C, (plus idling speed) and the engine speeds are shifted to a lower range compared to the ECE R 49 cycle. The engine speeds A, B and C depend on two reference speeds n_{lo} and n_{hi} that are related to the full load power curve of the engine.

Table 23: ECE R 49 13-mode steady state cycle

Mode no.	Engine test speed	Per cent load	Weighting factor
1	idle	-	8.33%
2	intermediate	10	8.00%
3	intermediate	25	8.00%
4	intermediate	50	8.00%
5	intermediate	75	8.00%
6	intermediate	100	25.00%
7	idle	-	8.33%
8	rated	100	10.00%
9	rated	75	2.00%
10	rated	50	2.00%
11	rated	25	2.00%
12	rated	10	2.00%
13	idle	-	8.33%

n_{lo} means the lowest engine speed where 50 per cent of the declared maximum power occurs. n_{hi} means the highest engine speed where 70 per cent of the declared maximum power occurs. The test speeds A, B and C are derived from these reference speeds using the following equations (see also Figure 34):

$$A = n_{lo} + 0.25*(n_{hi} - n_{lo}),$$

$$B = n_{lo} + 0.5*(n_{hi} - n_{lo}),$$

$$C = n_{lo} + 0.75*(n_{hi} - n_{lo}),$$

The rank order of the 13 modes, the engine load values and the weighting factors for the calculation of the final result are shown in Table 24. Additionally, NOx must be measured at three test points within the control area selected at random by the Technical Service doing the tests. The measured values of NOx emissions at these three points must correspond closely to values calculated from the standard test points closest to the selected test points. This control check is intended to ensure the effectiveness of the emission control of the engine within the typical engine operating range. The three additional test points are selected using approved statistical methods of randomisation. (If there is a discrepancy between the tested and calculated values the engine fails type approval testing).

The ELR test consists of a sequence of load steps at constant engine speeds as shown in Figure 35. For more information see ECE Regulation 49, revision 3

The ETC test consists of 1800 second-by-second transient modes. The time pattern of normalised engine speed and load are shown in Figure 36.

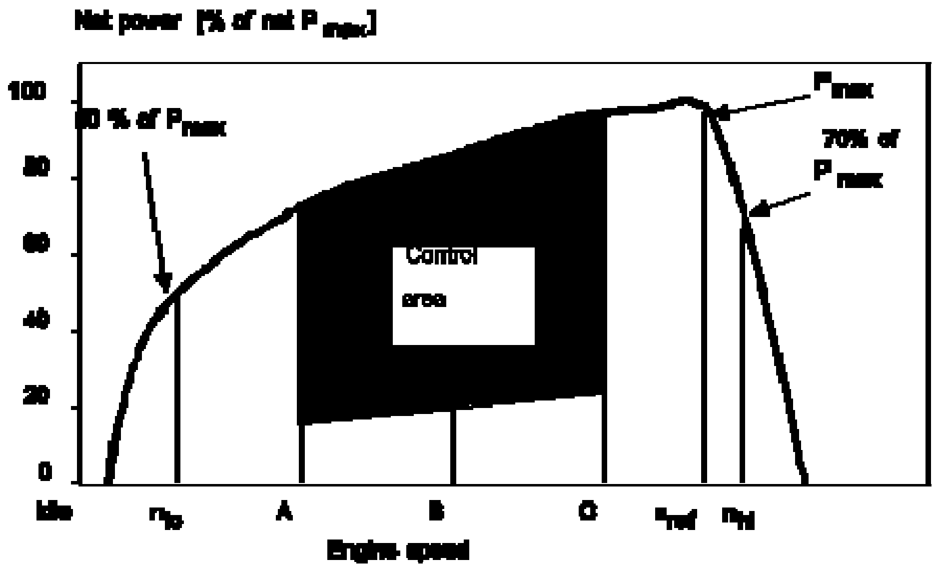

Figure 34: Reference speeds and test speeds fort he ESC (from ECE R 49, rev 3)

Table 24: ESC 13-mode steady state cycle

Mode Number	Engine Speed	Percent Load	Weighting Factor	Mode Length
1	idle	-	15%	4 minutes
2	A	100	8%	2 minutes
3	B	50	10%	2 minutes
4	B	75	10%	2 minutes
5	A	50	5%	2 minutes
6	A	75	5%	2 minutes
7	A	25	5%	2 minutes
8	B	100	9%	2 minutes
9	B	25	10%	2 minutes
10	C	100	8%	2 minutes
11	C	25	5%	2 minutes
12	C	75	5%	2 minutes
13	C	50	5%	2 minutes

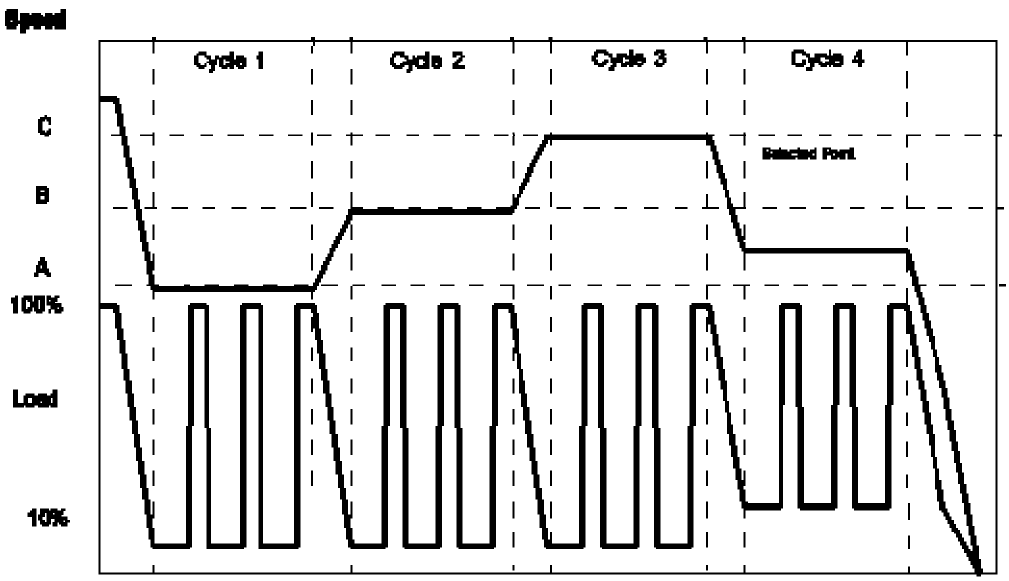

Figure 35: Sequence of ELR test (from ECE R 49, rev 3)

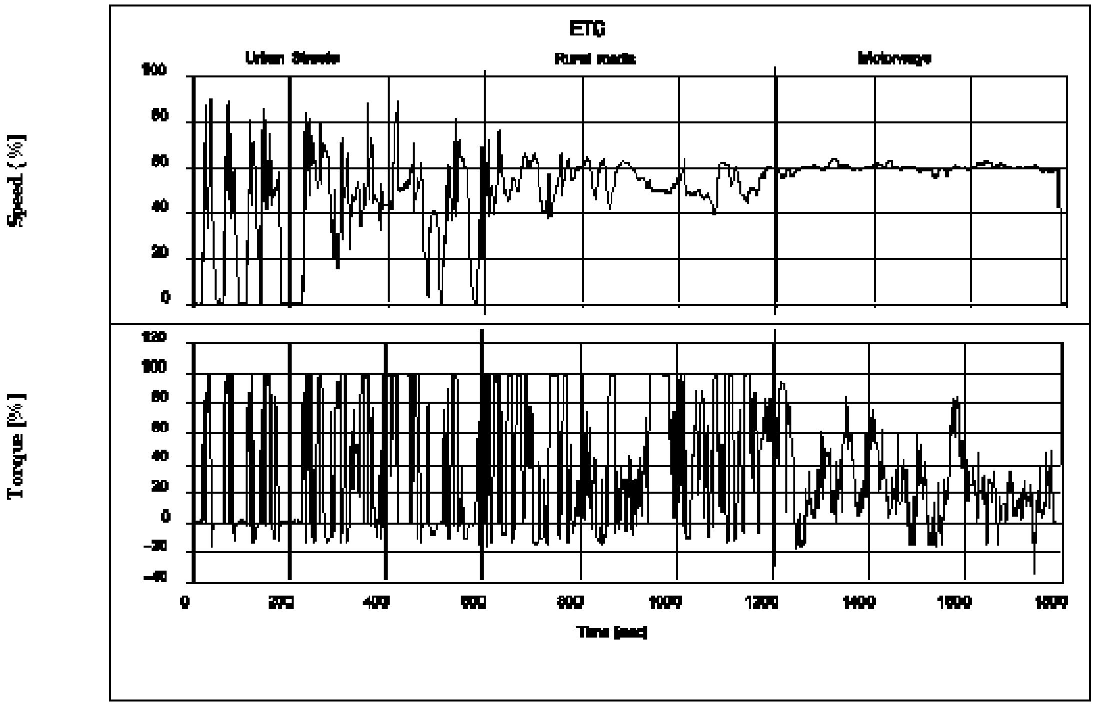

Figure 36: ETC dynamometer schedule (from ECE R 49, rev 3)

To run the ETC on a test bench for a particular engine the normalised speed pattern have to be transformed into engine speeds by using the following equations:

$n = n\_norm\_ETC * (n_{ref} – n_{idle}) + n_{idle}$

with n – actual engine speed,

n_norm_ETC = %-value of the dynamometer schedule of Figure 36,

$n_{ref} = n_{lo} + 0.95*(n_{hi} - n_{lo})$, n_{lo} and n_{hi} as defined above,

n_{idle} – idling speed.

For EURO 4 and 5 the ETC is mandatory in addition to the ESC and ELR.

The intended reduction of the pollutant emissions for EURO 3 compared to EURO 2 can be summarised as an overall 30% reduction that was achieved by internal measures, mainly by the introduction of electronic engine management. EURO 4 means a further 30% reduction in CO, HC and NOx and 80% reduction in particulates for the test cycles compared to EURO 3.

Annex II.3: Comparison of Operating Conditions of the Test Cycles and Operating Conditions in real Traffic

The difference in operating conditions between real world driving and type approval tests for heavy duty vehicles shall be demonstrated for the following examples:

- Delivery truck with 7500 kg gross vehicle mass (GVM),
- Delivery truck with 17000 kg GVM,
- Trailer truck with 30000 kg GVM,
- Long haulage trailer truck with 40000 kg GVM.

The in-use data used for the comparison is from the database shown in Table 7.

Figure 37 shows this comparison for the delivery truck with 7500 kg GVM and the ECE R 49 test cycle, which was used for type approval up to EURO 2. This figure and also the following figures do only contain conditions with positive or zero power output, motoring sections, where the vehicle is decelerating and the engine is running at speeds above idling but with negative torque, are not shown.

Since this vehicle is mainly used in urban areas its engine conditions are not focussed on specific engine speed and load areas but are widely spread between idling speed and 75% of rated speed and zero to 100% engine load. Idling is about 38% of the driving time, the vehicle operates in real traffic nearly 30% of the time with engine speeds below 55% of rated speed. Rated speed is never reached. The discrepancy between the type approval test conditions and the real world operation conditions is obvious. This is also the case for the ESC (see Figure 38) and even the ETC (Figure 39) covers only the upper end of the engine speed range used in real world driving.

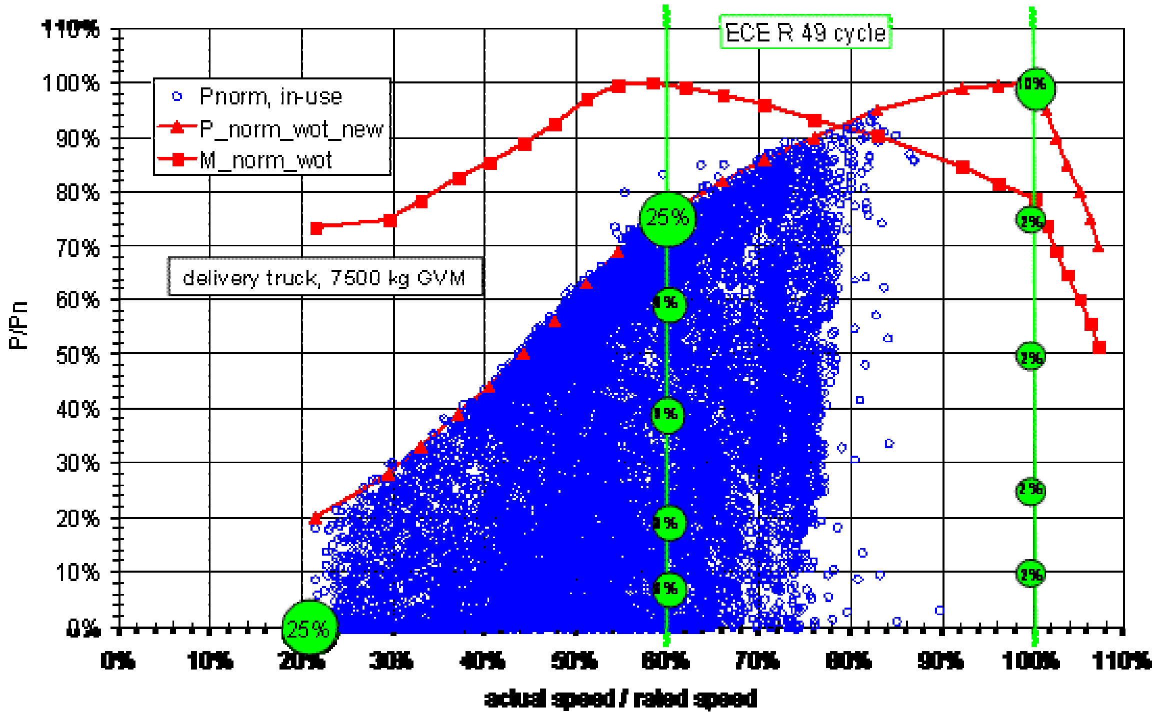

Figure 37: In-use engine speed and load points compared to corresponding points for the ECE R49 cycle, delivery truck with 7500 kg GVM

The corresponding comparisons for the delivery truck with 17000 kg GVM are shown in Figure 40 to Figure 42. The test conditions of the ESC and the ETC are better matched with in-use operating conditions but the 22% of operating time with engine speeds below speed A of the ESC is not covered by the test cycles. On the other hand, the test speed B of the ESC as well as the most frequently used engine speed of the ETC are very close to the most frequently used engine speed range for in-use operation. For in-use operation idling is 10% of the total driving time with zero or positive power output.

The comparisons for the trailer truck with 30000 kg GVM are shown in Figure 43 to Figure 45. The ECE R 49 cycle is not in line with in-use operation. The ESC fits better but the most frequently used engine speeds for real world operation are focussed between speeds A and B. For this example the ETC is very much in line with in-use operation. For real world operation idling time is 13% and the engine speed range between 67% and 77% of rated speed covers 50% of the driving time. The focus on a preferred speed is typical for cases where rural and motorway operation dominates. For urban conditions the engine speed distribution gets broader.

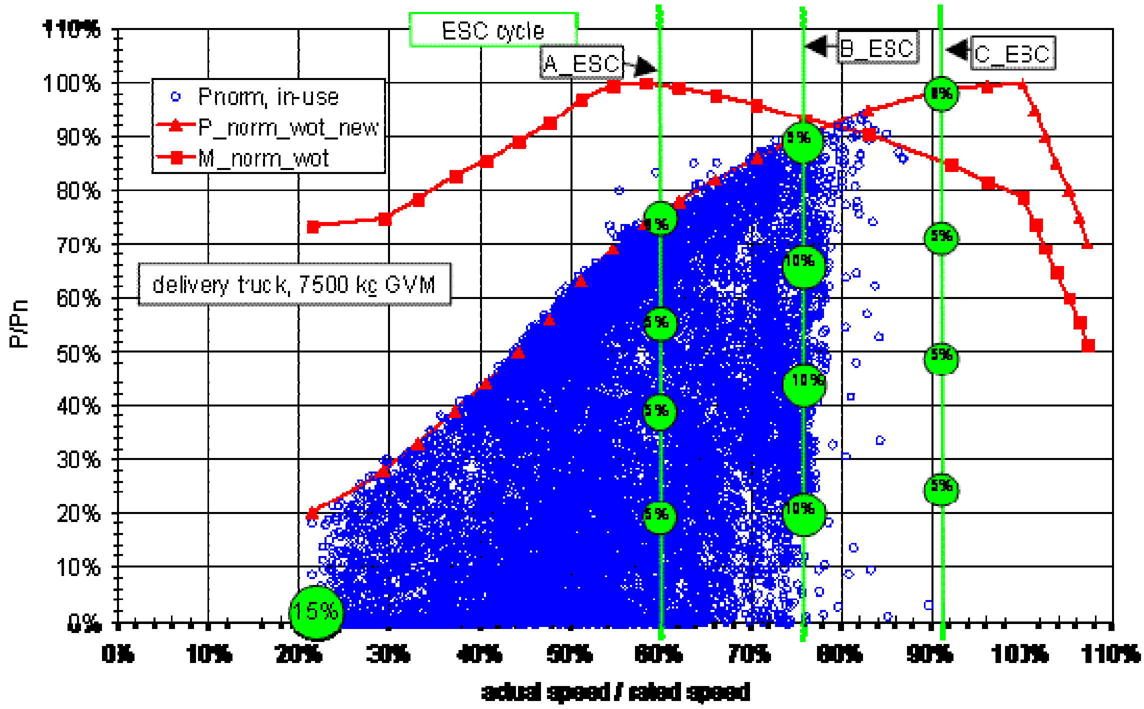

Figure 38: In-use engine speed and load points compared to corresponding points for the ESC cycle, delivery truck with 7500 kg GVM

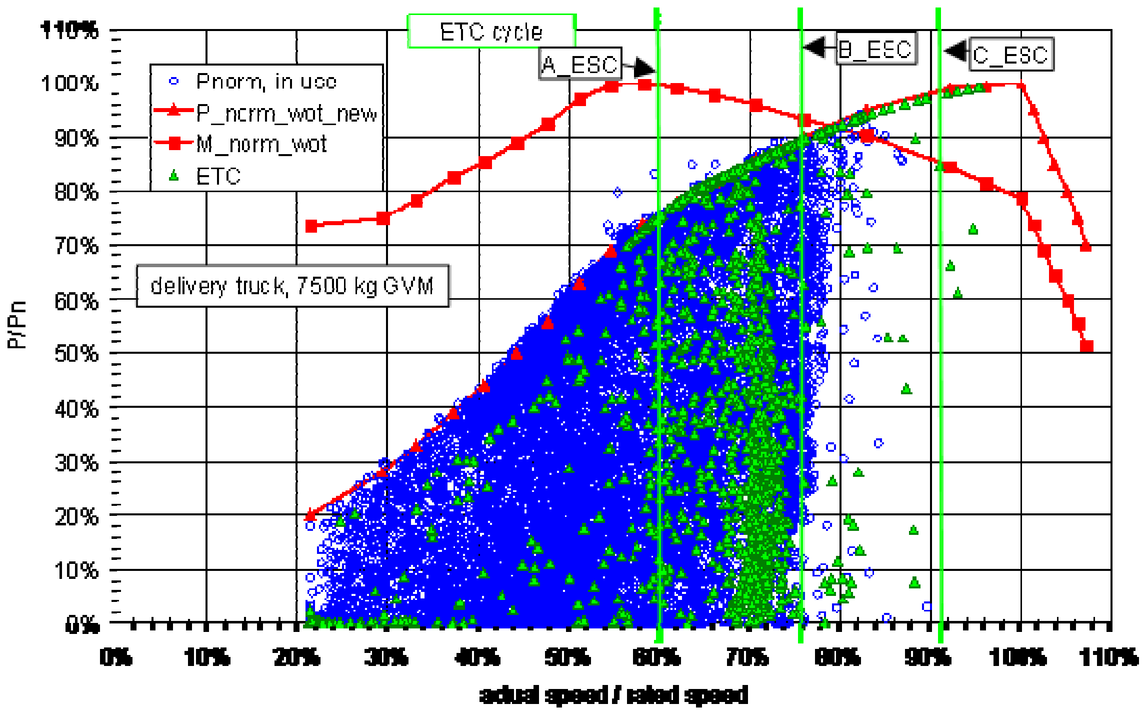

Figure 39: In-use engine speed and load points compared to corresponding points for the ETC cycle, delivery truck with 7500 kg GVM

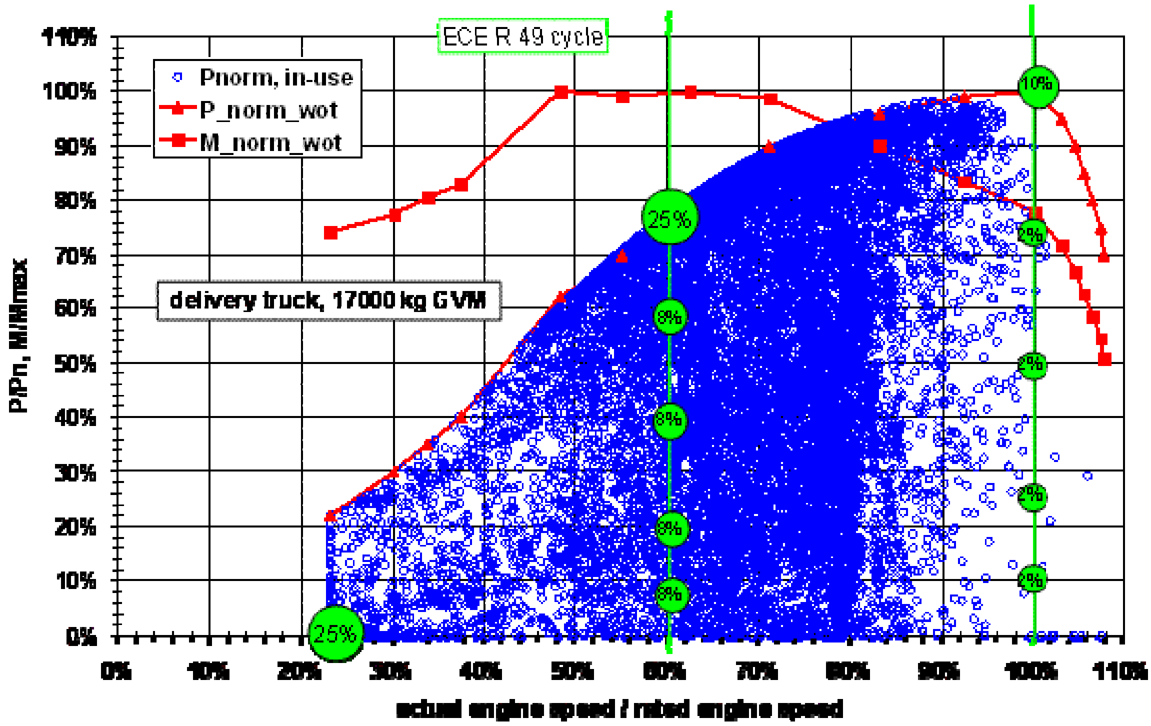

Figure 40: In-use engine speed and load points compared to corresponding points for the ECE R49 cycle, delivery truck with 17000 kg GVM

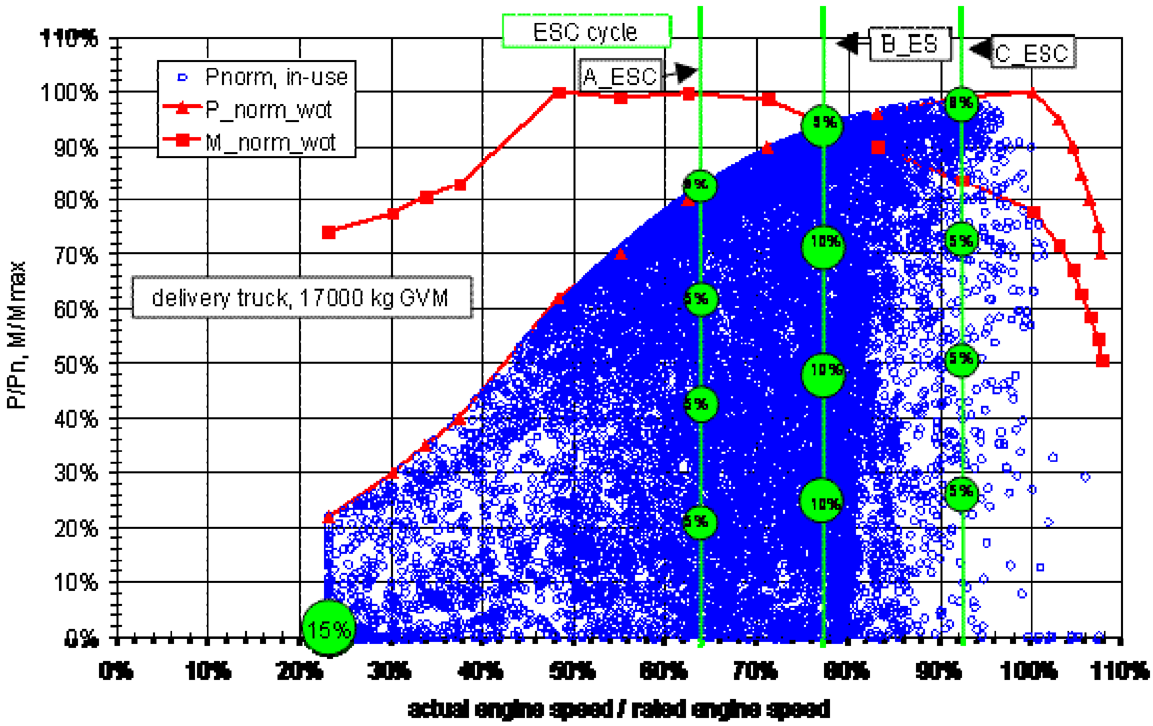

Figure 41: In-use engine speed and load points compared to corresponding points for the ESC cycle, delivery truck with 17000 kg GVM

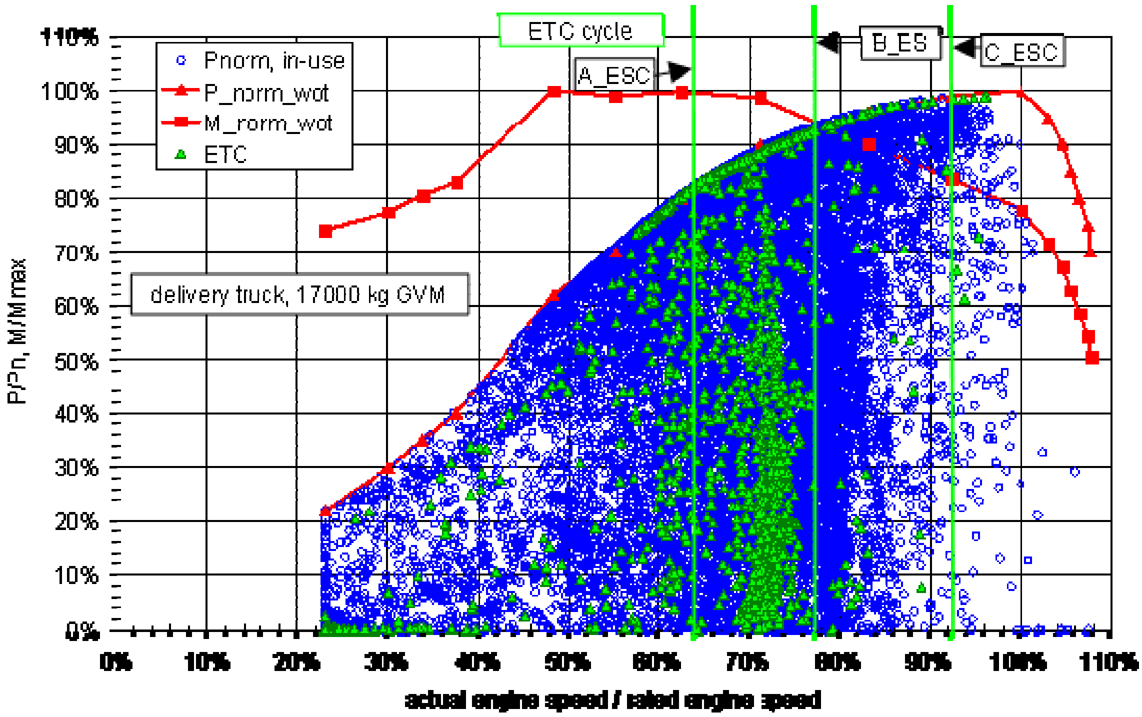

Figure 42: In-use engine speed and load points compared to corresponding points for the ETC cycle, delivery truck with 17000 kg GVM

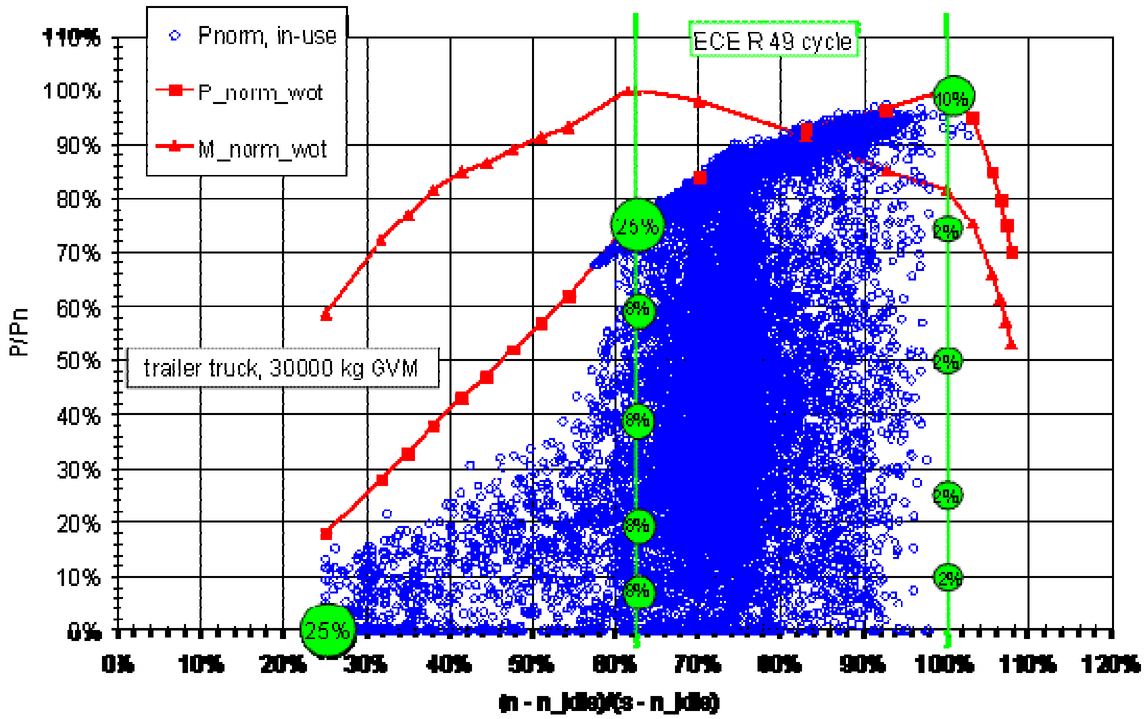

Figure 43: In-use engine speed and load points compared to corresponding points for the ECE R49 cycle, trailer truck with 30000 kg GVM

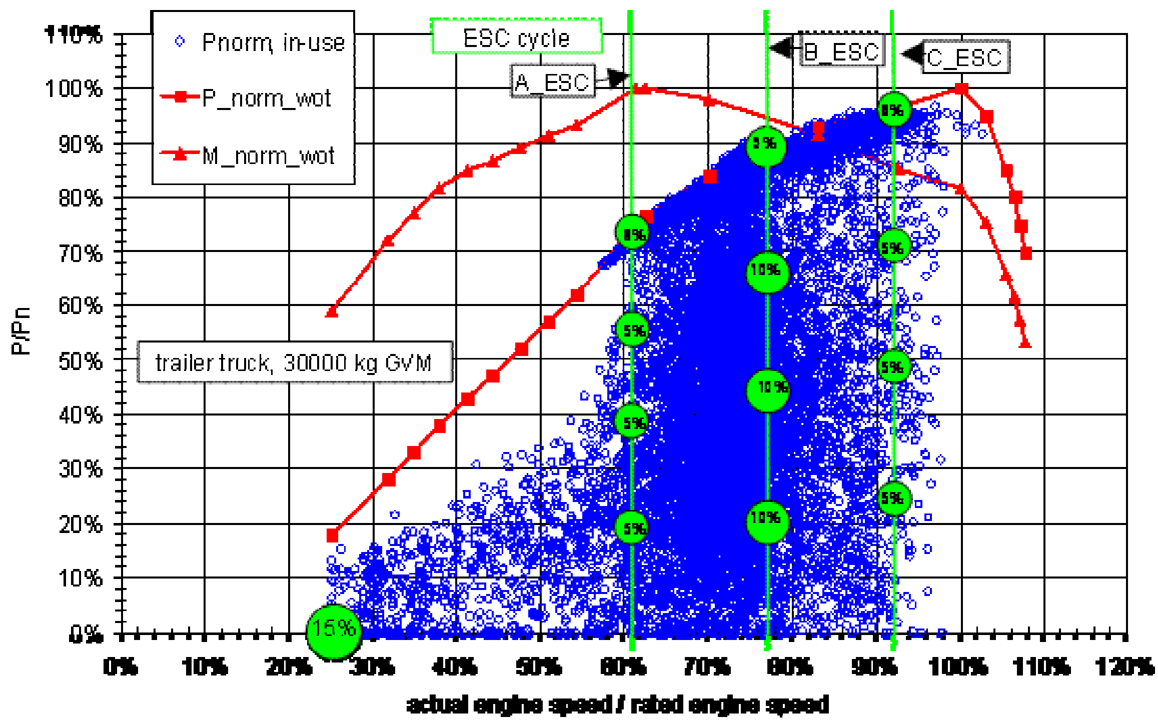

Figure 44: In-use engine speed and load points compared to corresponding points for the ESC cycle, trailer truck with 30000 kg GVM

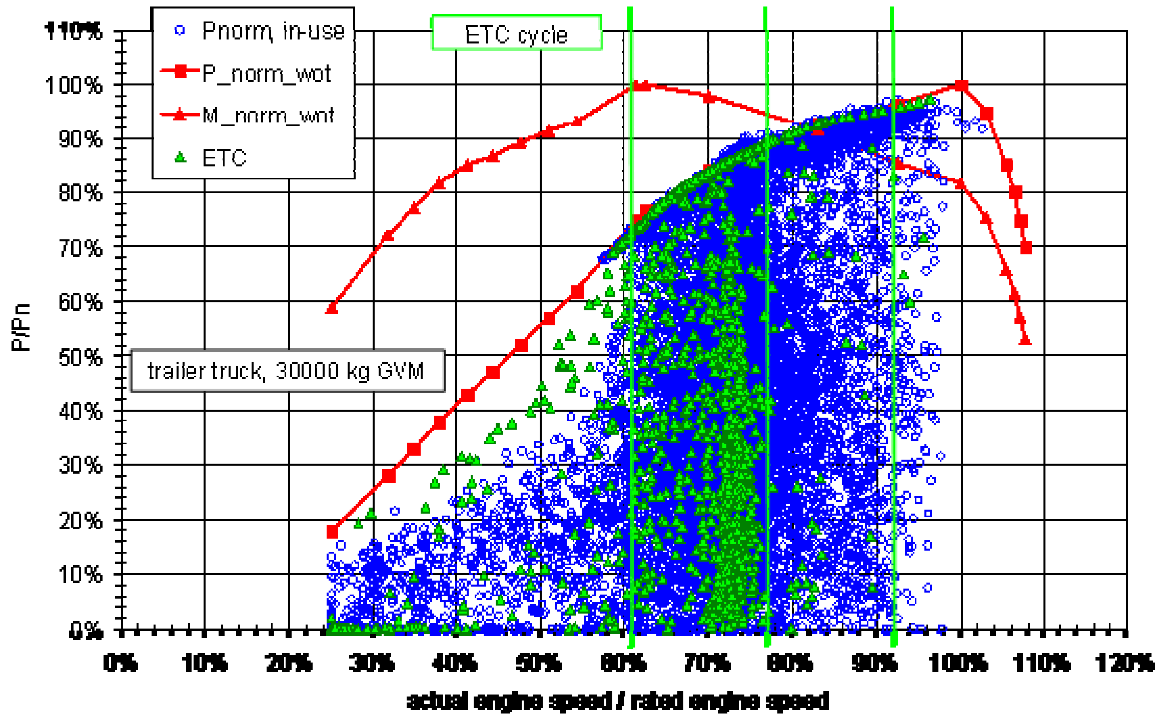

Figure 45: In-use engine speed and load points compared to corresponding points for the ETC cycle, trailer truck with 30000 kg GVM

The comparisons for the trailer truck with 40000 kg GVM are shown in Figure 46 to Figure 50. The ECE R 49 cycle is shown in Figure 46. The intermediate speed is quite close to the most frequently used speed for in-use operation, but as for the examples before, rated speed is rarely used in real world operation. In order to demonstrate one gap of the ESC/ETC procedure both cycles are shown for two different engine designs with respect to n_{hi}. In one case n_{hi} is 107% of rated speed, in the other case n_{hi} is increased to 129% of rated speed. The full load curve up to rated speed remains unchanged, so that there is no influence on the ECE R 49 cycle.

The comparisons with in-use operation for the ESC are shown in Figure 47 and Figure 48. In both cases speeds B and C are far above the most frequently used engine speeds for real world operation. With n_{hi} = 107% of rated speed. A is at the lower end of the most frequently used engine speeds for real world operation, with n_{hi} = 129% speed A moves to the higher end of the in-use speed range and speed C moves to 110% of rated speed. The ETC is in both cases not in line with in-use operation but the mismatch is highest for n_{hi} = 129%. This enables the manufacturer to optimise the test cycle operation for low NOx emissions and the in-use operation, which is below the control area of the ESC/ETC procedure for fuel consumption and would certainly lead to higher NOx emissions than one would expect from the test results.

A state of the art engine with an electronically controlled management system typically has a rated speed value around 1800 revs per minute. A maximum speed of 2300 2400 $rev.min^{-1}$ is technically no problem. It may be even advantageous for downhill operation, because it provides high engine brake forces. The layout of the power curve above rated speed is then just a matter of the design of the management system.

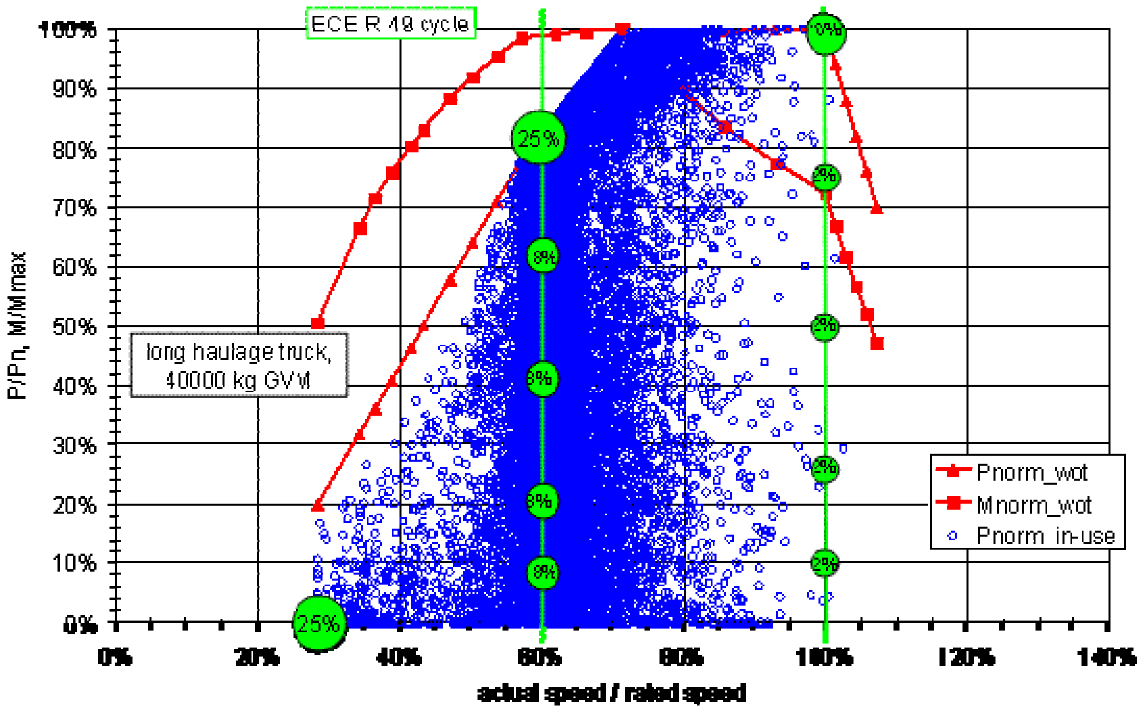

Figure 46: In-use engine speed and load points compared to corresponding points for the ECE R49 cycle, trailer truck with 40000 kg GVM

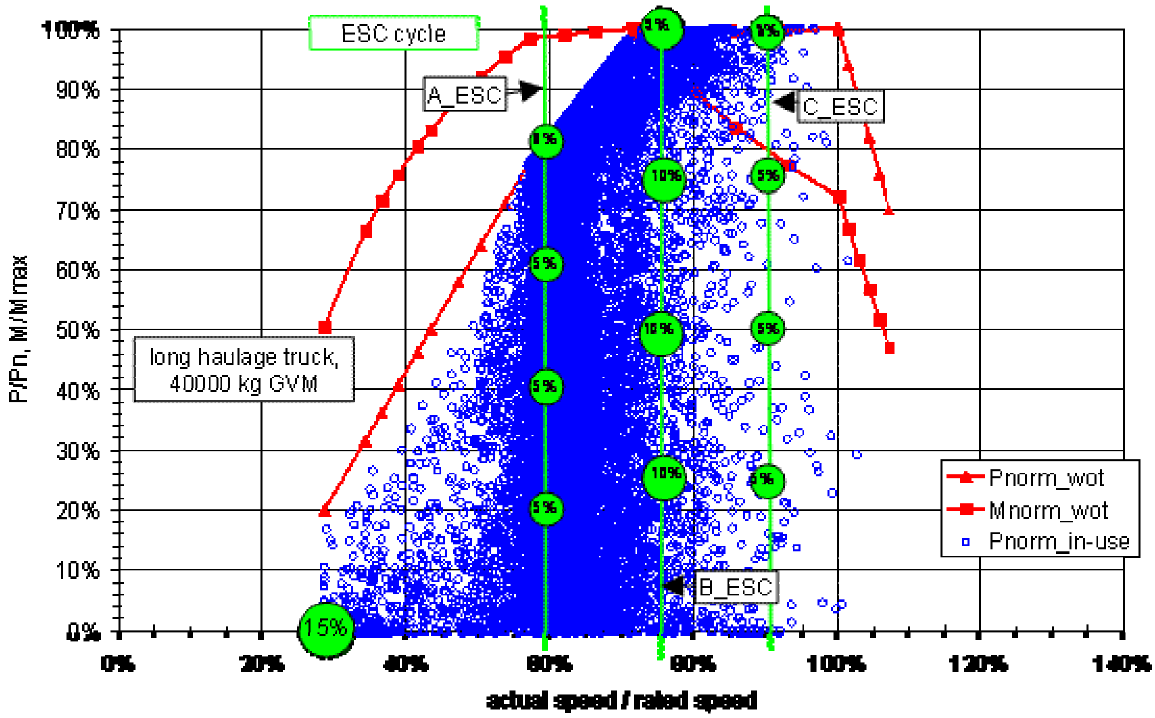

Figure 47: In-use engine speed and load points compared to corresponding points for the ESC cycle, trailer truck with 40000 kg GVM

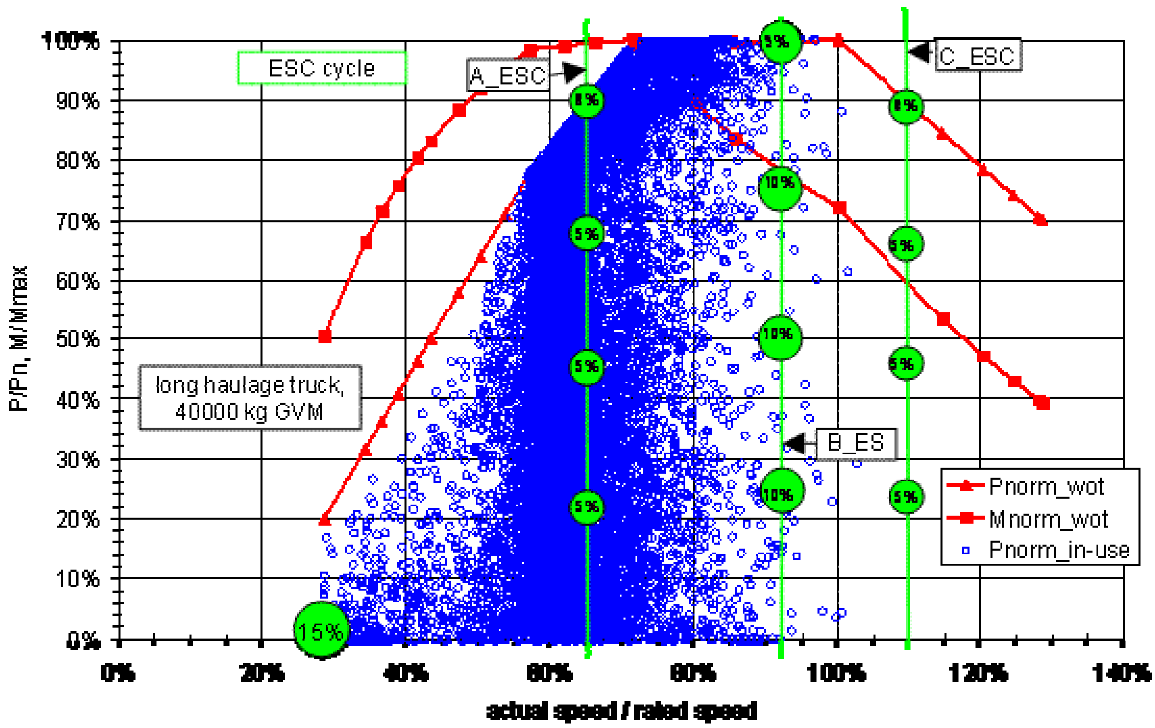

Figure 48: In-use engine speed and load points compared to corresponding points for the ESC cycle, trailer truck with 40000 kg GVM and modified n_{hi}

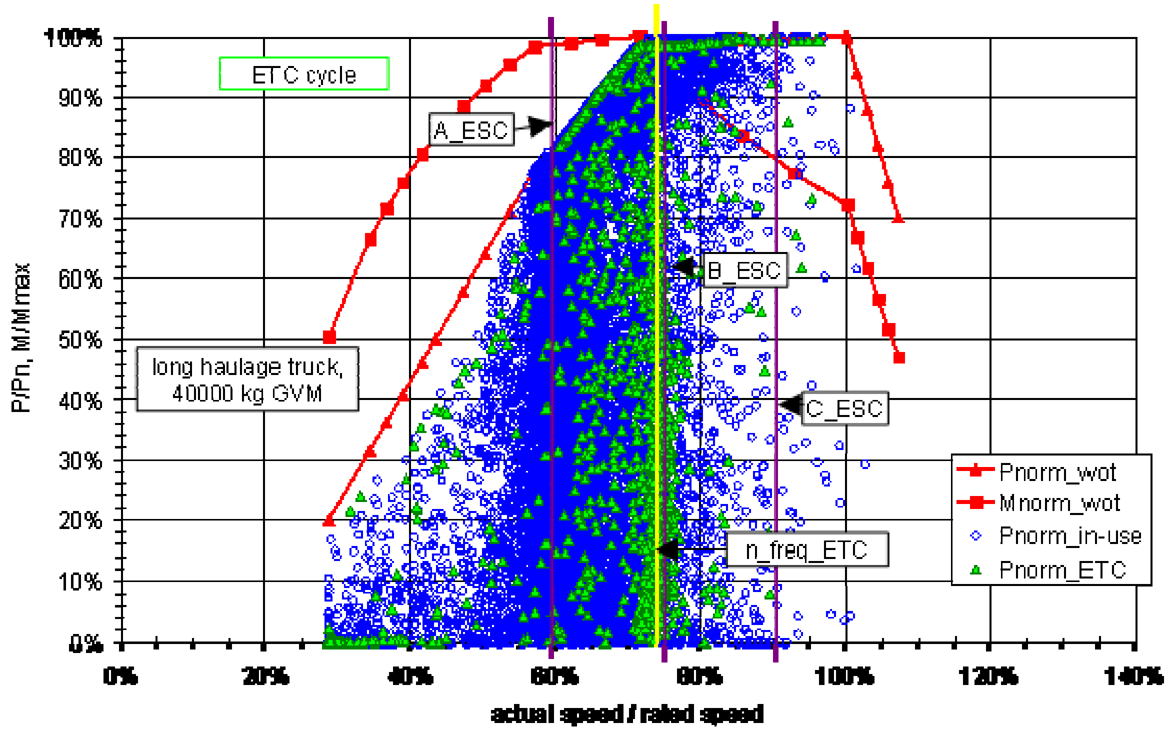

Figure 49: In-use engine speed and load points compared to corresponding points for the ETC cycle, trailer truck with 40000 kg GVM

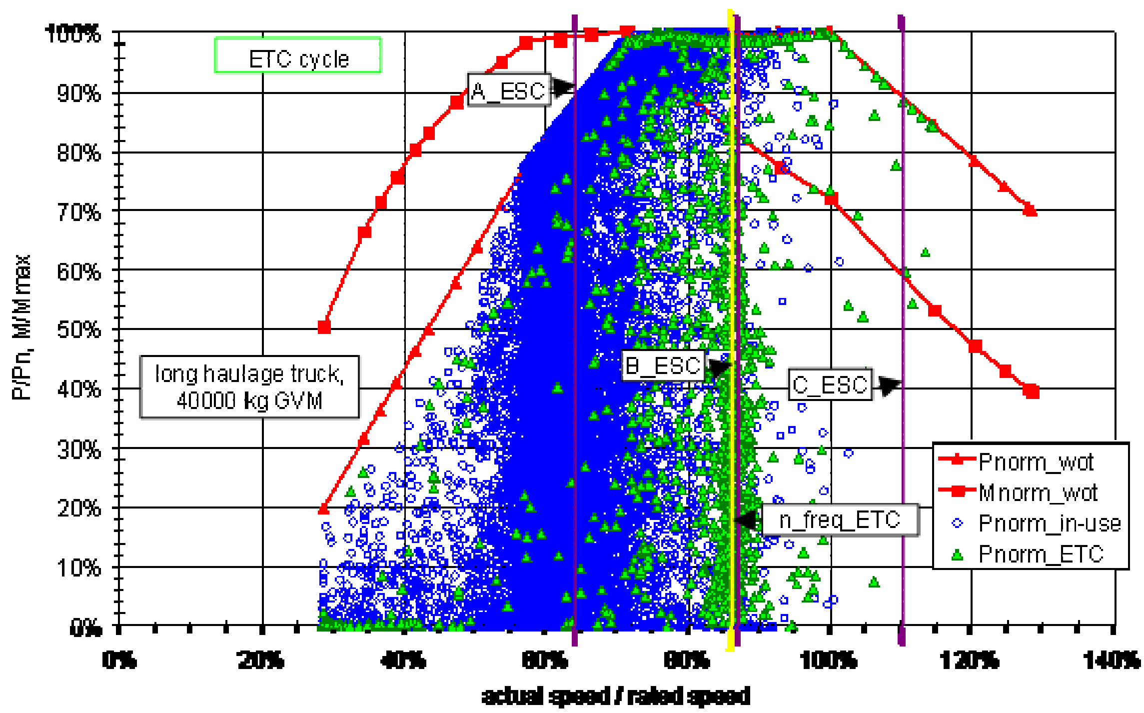

Figure 50: In-use engine speed and load points compared to corresponding points for the ETC cycle, trailer truck with 40000 kg GVM and modified n_{hi}

Annex II.4: Recommendations

For heavy duty vehicles the main gap with respect to cycle bypass measures is the already mentioned possibility to design the power-train of a vehicle in such a way that the most frequently used engine speed range for in-use operation falls between the ESC test speeds A and B or even below A (seeabove). For EURO 3 this gave the manufacturer the possibility to optimise NOx emission for the test cycle and fuel consumption for the in-use conditions. Furthermore it is well known that the particulate emissions at low engine speeds and high engine load might exceed the limit values significantly. If the in-use operation focuses on the speed range below A, no limitation will be effective at all.

In addition to that the results presented in above clearly show the need to extend the control area down to n_{lo}.

The weakness of the ESC and ETC test cycles with respect to speed range shifting can be repaired by replacing these cycles by the WHSC (**w**orldwide **h**eavy duty diesel engine **s**tationary test **c**ycle) and WHTC cycles (**w**orldwide **h**eavy duty diesel engine **t**ransient test **c**ycle) that were developed under the umbrella of the GRPE (Group of Experts on Pollution and Energy of the United Nations Economic Commission for Europe) subgroup WHDC (**w**orldwide **h**eavy duty **d**iesel engine **c**ertification procedure, see Steven (2001)). The principle is similar as for the ESC/ETC but the denormalisation procedure is much more robust against speed range shifting.

The WHTC and WHSC engine speed schedules use normalised engine speed values. The denormalisation procedure is based on three characteristic engine speed values; all of them are related to the full load power curve of the engine. The procedure is much more robust against cycle bypass measures than the ETC.

The denormalisation of the WHTC engine speed schedule (nnorm_ref) is done using the following equation:

n = nnorm_ref*(0,45*n_low + 0,45*n_pref + 0,1*n_high - n_idle)*2.0327 + n_idle

with n_low - lowest engine speed where the engine supplies 55% of its rated power at full load,

n_high - highest engine speed where the engine supplies 70% of its rated power at full load,

n_pref - engine speed where the integral of the torque curve from idling speed to n_pref is 51% of the whole integral from idling speed to the highest speed where the engine develops 95% of its rated power.

The corresponding stationary test cycle WHSC contains 12 modes distributed over 6 engine speed values (including idling) and up to 4 different load points between 25% and 100% (see Table 25). In order to bring the cycle work of the WHSC close to the cycle work of the WHTC (which is not the case for ESC and ETC) a weighting factor for motoring is added with 0 emissions.

The de-normalisation of nnorm_ref for the WHSC uses the same equation as for the WHTC.

Table 25: Engine speed/load combinations of the WHSC

		Engine load					
nnorm_ref	**motoring**	**0%**	**25%**	**50%**	**70%**	**100%**
motoring	**24%**					
0%		**17%**				
25%			**8%**			
35%			**10%**	**8%**		**2%**
45%			**6%**		**3%**	
55%			**10%**	**5%**	**3%**	**2%**
75%						**2%**

The differences between the ETC and WHTC cycles are shown for the long haulage vehicle in Figure 51 to Figure 54. The robustness of the WHTC is obvious.

With respect to after-treatment systems cycle bypass measures are conceivable for SCR systems. The manufacturer could optimise the SCR system for the test cycle but would allow high off-cycle NOx emissions in order to save AdBlue. This gap will be closed, if the NOx monitoring and the OBD will work properly and will cover engine speeds between n_{lo} and n_{hi} and engine loads between 10% and 100% as a not-to-exceed area. This is not yet ensured with the current proposals for the directive amendment.

In addition the NOx threshold values for OBD should be reduced significantly.

With respect to particulate filters it should be ensured that the efficiency in the whole not-to-exceed area is the same as for the type approval test.

Cycle bypass measures for EGR are rarely to be expected because there is nearly no benefit if the EGR is switched off or shortcut. The situation for cars could be different.

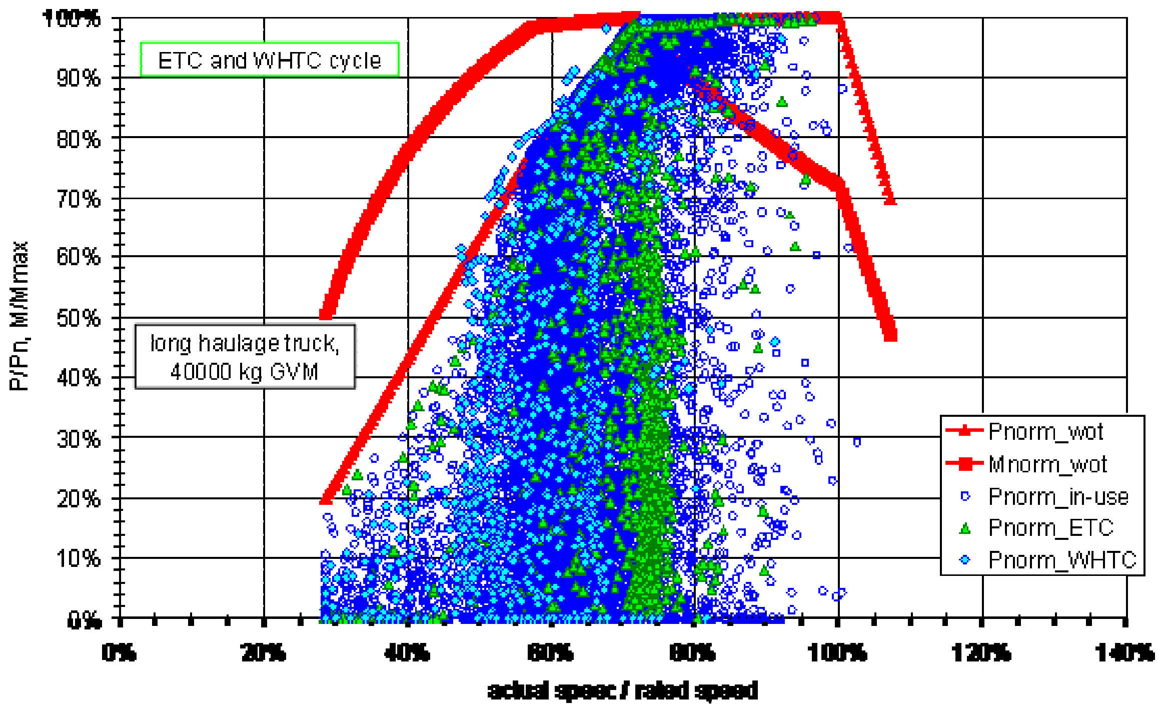

Figure 51: In-use engine speed and load points compared to corresponding points for the ETC and WHTC cycles, trailer truck with 40000 kg GVM and low n_{hi}

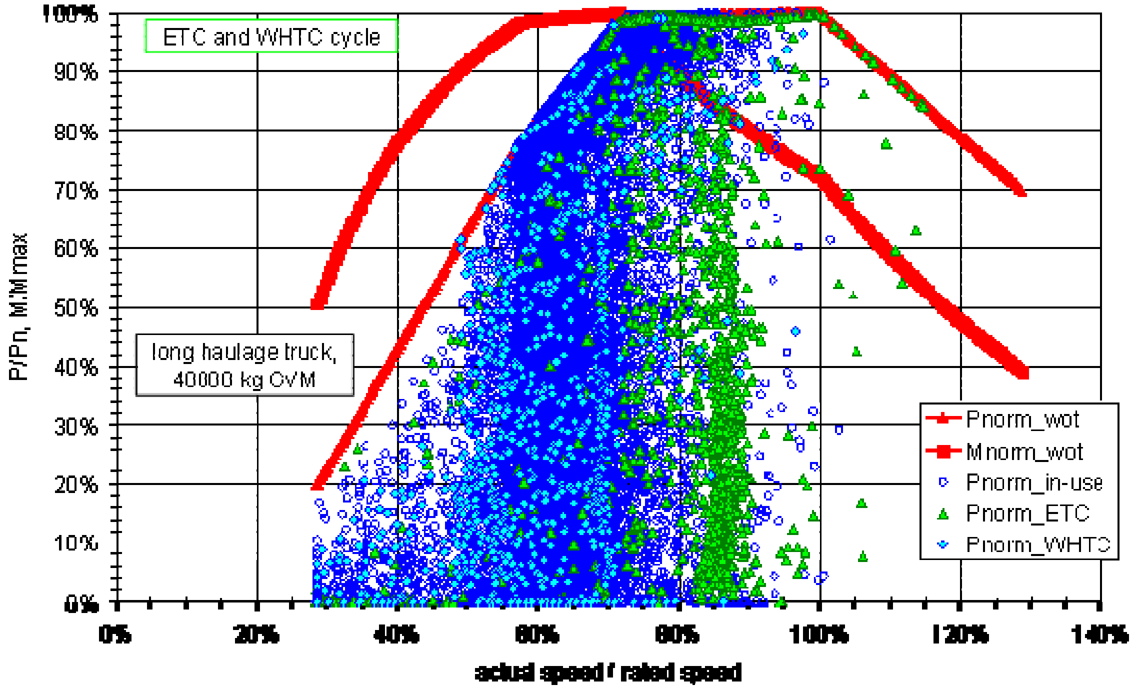

Figure 52: In-use engine speed and load points compared to corresponding points for the ETC and WHTC cycles, trailer truck with 40000 kg GVM and high n_{hi}

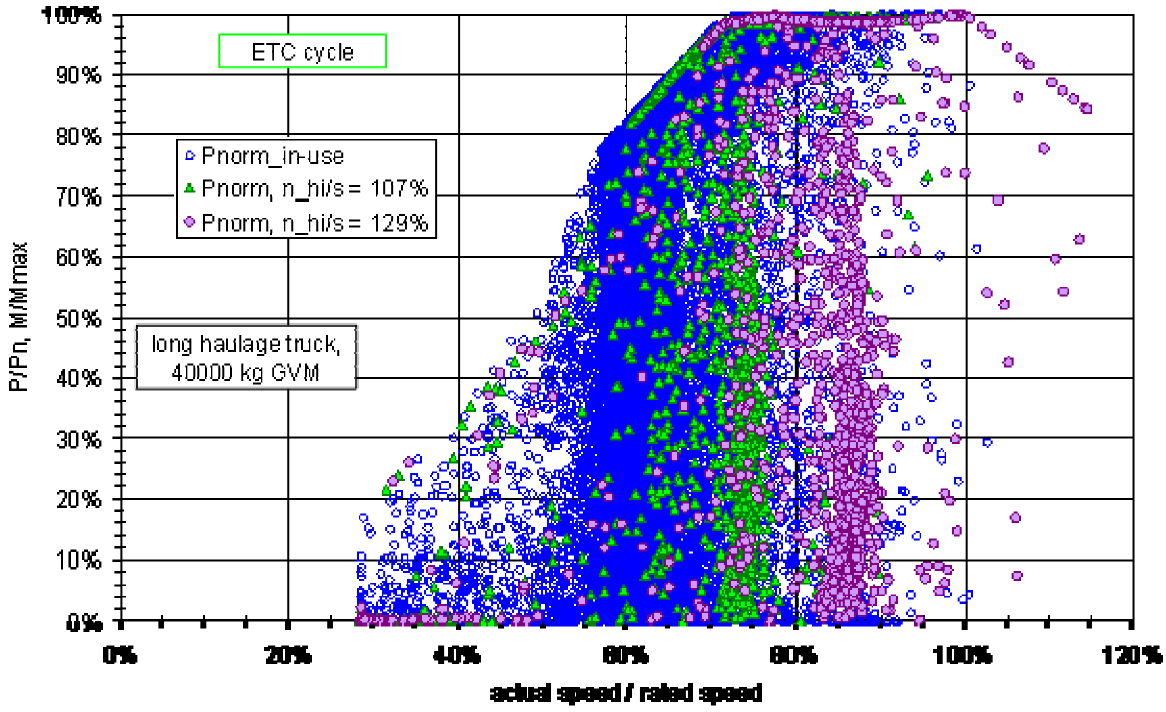

Figure 53: In-use engine speed and load points compared to corresponding points for the ETC cycle, trailer truck with 40000 kg GVM, low and high n_{hi}

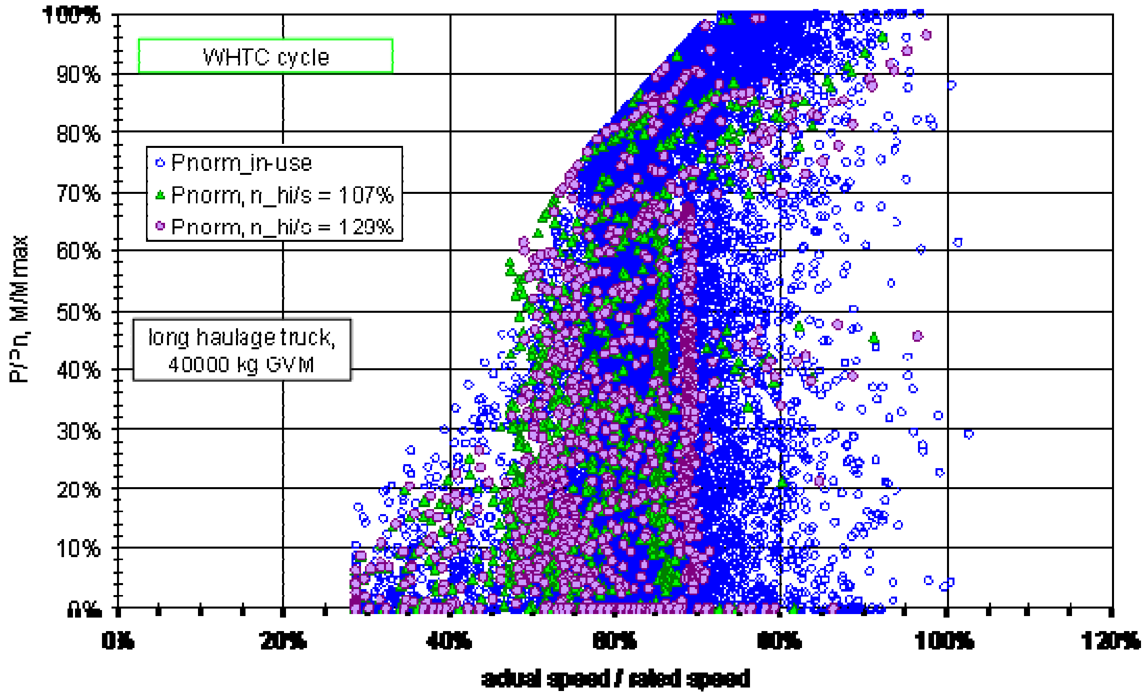

Figure 54: In-use engine speed and load points compared to corresponding points for the WHTC cycle, trailer truck with 40000 kg GVM, low and high n_{hi}

Annex III. The effects of traffic management schemes on emissions from heavy-duty vehicles (Ian McCrae, TRL)

In 2000 TRL was commissioned by the Department for Transport to measure the effects of various types of traffic management measure on exhaust emissions from heavy-duty vehicles, and to develop an appropriate predictive emission model for the evaluation of planned and existing schemes. Prior to the development of the PHEM model, there was relatively little information on the in-service emission levels of HDVs, and models have generally been based upon a small numbers of tests.

A sample of 50 vehicles were selected and subjected to emission tests using a Variable Temperature Emissions Chamber, equipped with a heavy-duty chassis dynamometer. A variety of vehicles were tested, including HGVs ranging from 7.5 tonne trucks up to 44 tonne articulated vehicles, midi-buses, single-decker buses and double-decker buses. In addition to the different vehicle types, vehicles compliant with different emissions legislation were tested – ranging from pre-Euro 1 to Euro 4. Each vehicle was tested in the ‘as received’ condition.

Each vehicle was tested over a pre-defined set of transient traffic management driving cycles that had been developed in a previous TRAMAQ (TRAffic Management and Air Quality) project – UG214 Vehicle operating profiles (see section 10.6.1). In addition, a number of standard driving cycles and steady-speed cycles (including ECE-R49 (13-mode) simulation, ESC (OICA), ARTEMIS, ETC (FIGE) and the Millbrook London Transport bus cycle.

The first four vehicles in the test programme were subjected to a comprehensive series of emission tests, including repeat measurements under identical conditions. These vehicles (three HGVs and one bus) were selected to provide an indication of the range and variability of the emission results likely to be encountered in the main programme. The driving cycles developed to represent HDV operation through traffic management measures were found to be driveable and repeatable on a chassis dynamometer. The worst repeatability of engine speed was observed for the Euro 1 bus, which was equipped with an automatic gearbox. A list of the vehicle types tested during this project is given inTable 26.

The effects of the traffic management measures were considered for HGVs and buses separately. Various methods were attempted to reduce the variability in results such as adjusting for weight and legislation. However the most successful criteria found was to consider the emissions rates (g/km) per tonne of vehicle weight – g/tonne.km. In the emission tests, each vehicle was tested at an inertia weight typical of the normal running of that type of vehicle. Thus, the resulting emissions rates (g/km) were divided by the inertia weight (tonnes) used for the tests to derive standardised emission values which could be compared directly. Separate weighted emission values were calculated and analysed for each pollutant and for HGVs and buses separately.

In addition to regulated emissions, a range of unregulated pollutants were recorded during the test programme. Gaseous pollutants were recorded using a FTIR instrument and number-weighted particle size distributions were recorded using an ELPI. An analysis of the FTIR results showed reliable results for nitrogen dioxide, nitric oxide, nitrous oxide, ethylene, propene, 1,3-butadiene and formaldehyde. These data were further analysed to provide typical emission rates for these pollutants from rigid HGVs, articulated HGVs and buses of various emission certification levels.

Table 26: ***Summary of vehicle categories used in the test programme by type and emission legislation (dashes indicate type and emission control combinations which were not tested)***

Type of vehicle, number of axles & gross vehicle weight	Number of test vehicles of each type by certification level					
	Pre-Euro 1 ('Euro 0') 88/77/EEC	Euro 1 91/542/EEC	Euro 2 91/542/EEC	Euro 3 1999/96/EC	Euro 4[3] 1999/96/EC	TOTAL
Rigid HGV (2 axle, 3.5 to 7.5 tonnes)	-	1	2	3	-	6
Rigid HGV (2 axle, 7.5 to 17 tonnes)	1	1	3	3	-	8
Rigid HGV (3/4 axle, 17 to 26 tonnes)	-	-	1	2	-	3
Rigid HGV (4 axle, 26 to 32 tonnes)	-	-	1	4	-	5
Articulated HGV (4 axle, up to 33 tonnes)	-	1	-	1	1	3
Articulated HGV (5/6 axle, over 33 tonnes)	-	1	4	2	1	8
Bus (Midi, 17 to 35 seats)	-	1	1	1	-	3
Bus (Single-decker, >35 seats)	1	1	3	2	1	8
Bus (Double-decker)	1	1	2	2	-	6
TOTAL	3	7	17	20	3	50

One of the main objectives of the project was to develop a relatively undemanding stand-alone model which could be used to predict how different traffic management schemes affect HDV emissions, particularly in site-specific situations. The SCHEME (System for Conducting Heavy vehicle EMission Estimates) model was developed as such a predictive tool.

The first stage in the development of the SCHEME model was a survey of end user requirements, the results of which were used to refine the scope and level of detail of the model. A questionnaire was sent to 25 air quality professionals from a range of

[3] The Euro 4 category, which included vehicles not certified as Euro 4 but compliant with the Euro 4 emission standards, was included to illustrate their potential benefits of including such vehicles. Two of these vehicles used alternative fuels (LPG and LNG).

organisations in order to ascertain the current and likely future needs of emission model users. Apparent from this survey, there was a general lack of understanding of what the current emission factors relate to and how to use them. For example, respondents did not seem to understand that the average-speed modelling approach includes idling and periods of acceleration, deceleration and cruising. There is also quite a range of sources of emission factors in use, and this must surely lead to inconsistencies in emission estimates both within and between studies. To counter this, any model would have to be issued with a clear explanation of how the data that populate the model had been collected, and how the data were then processed into the output of the model. There must also be guidance on the valid use of the model, including details on uncertainty and accuracy.

The issues raised were taken into account in the development of the SCHEME model. Firstly, a power-based modelling approach was developed. Secondly, instead of using the rather impractical approach of asking the user to state vehicle operation in detail, a more subjective approach was chosen whereby a proposed scheme could be defined using a series of photographs of similar road layouts. The photographs are selected from a database within the model. The use of this approach meant that non-technical users with limited information would be more likely to be able to use this type of input rather than any of the alternatives such as average speed or a driving cycle. These photographs are linked to associated emission factors for different vehicle categories, and emissions from traffic through the scheme are determined by weighting the emission factors by traffic flow and composition information provided by the user.

Whilst some limited inter-comparison was undertaken between the SCHEME model and the standard UK average speed emission factors, an inter-comparison with the PHEM model remains outstanding. The overall idea of using photographs or video clips to characterise traffic situation, is a main recommendation of this study.

References:

Latham S, Boulter B and Barlow T (2004). The effects of traffic management schemes on emissions from heavy-duty vehicles. TRL report PR/SE/960/04. TRL Limited, Wokingham.

Annex IV. Derivation of revised average speed HGV emission functions (Ian McCrae, TRL)

This Section describes the derivation of average-speed fuel consumption and emission functions for conventional heavy-duty road vehicles in the COST Action 346/COST 346/ARTEMIS project. The functions are based on a database of fuel consumption values and emission factors compiled using a model called PHEM (Passenger car and Heavy-duty vehicle Emission Model). The exhaust pollutants covered are carbon monoxide (CO), total hydrocarbons (THC), oxides of nitrogen (NOx) and particulate matter (PM).

The three main heavy-duty vehicle categories defined in the model are ‘coaches’, ‘urban buses’ and ‘heavy goods vehicles’. These are then further divided into sub-groups according to type and mass (Figure 55). At the most detailed level in the COST 346/COST 346/ARTEMIS model the sub-groups are divided into emission classes, which are termed ‘sub-segments’. A total of 114 distinct sub-segments are defined.

In order to generate the emission factor database a large number of pre-defined driving cycles were entered into the PHEM model. These pre-defined cycles, which are listed in Table 4 and 5 were specific to given vehicle categories. However, the PHEM model adjusts the driving cycle, and reduces the cycle speed profile if it can not be followed with the given engine power performance. Consequently, the actual driving cycles used were individually distinctive, and varied according to the vehicle category, the gradient and the vehicle load.

Three levels of vehicle load are taken into consideration: 0%, 50% and 100%, and seven gradient classes are included: -6%, -4%, -2%, 0%, +2+, +4% and +6%.

For each combination of sub-segment, gradient, vehicle load and pollutant, a regression curve was fitted to the emission data, describing the emission factor (and fuel consumption) (g/km) as a function of average trip speed. This process led to the derivation of 11,970 average speed functions. In addition to the basic hot exhaust emission functions, a number of other factors were taken into account. These included the effects of fuel quality, engine deterioration with time, maintenance, particle traps and alternative engine concepts.

These new average speed emission functions were subsequently compared with those provided in one of the most widely-used emission models in Europe, COPERT III (Ntziachristos and Samaras, 2000).

It is important to note that that there are more vehicle categories in the COST346/COST 346/ARTEMIS database than in COPERT III, and hence there are few opportunities to provide direct comparisons. More precisely, a wider range of weight classes are presented in COST346/COST 346/ARTEMIS. Any COST346/COST 346/ARTEMIS category which overlapped with a COPERT III category was therefore included in the comparison for a given combination of vehicle category and pollutant. In addition, COPERT III specifies ‘Pre-Euro I’ (Euro 0), whereas COST346/COST 346/ARTEMIS specifies ‘1980s’ vehicles. It was assumed that these categories were equivalent.

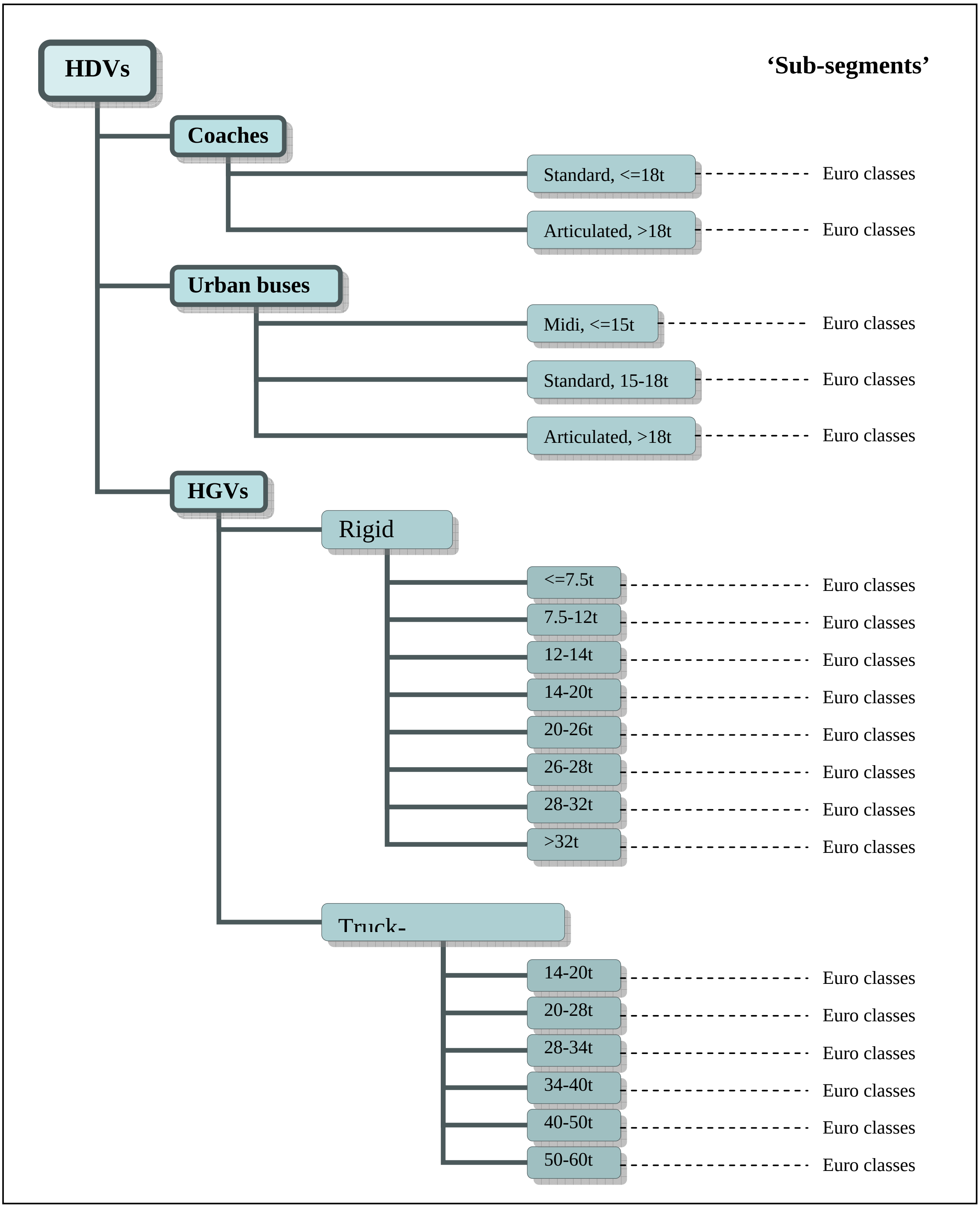

Figure 55: ***HDV classification hierarchy in the COST 346/ARTEMIS model.***

Table 27 ***Rural driving cycles.***

Code	Description[1]	Code	Description
11011	Rural/Motorway-Nat./60/Freeflow	13023	Rural/Distributor/Secondary/70/Saturated
11012	Rural/Motorway-Nat./60/Heavy	13031	Rural/Distributor/Secondary/80/Freeflow
11013	Rural/Motorway-Nat./60/Saturated	13032	Rural/Distributor/Secondary/80/Heavy
11014	Rural/Motorway-Nat./60/Stop+go	13033	Rural/Distributor/Secondary/80/Saturated
11021	Rural/Motorway-Nat./70/Freeflow	13041	Rural/Distributor/Secondary/90/Freeflow
11022	Rural/Motorway-Nat./70/Heavy	13042	Rural/Distributor/Secondary/90/Heavy
11023	Rural/Motorway-Nat./70/Saturated	13043	Rural/Distributor/Secondary/90/Saturated
11024	Rural/Motorway-Nat./70/Stop+go	13051	Rural/Distributor/Secondary/100/Freeflow
11031	Rural/Motorway-Nat./80/Freeflow	13052	Rural/Distributor/Secondary/100/Heavy
11032	Rural/Motorway-Nat./80/Heavy	13053	Rural/Distributor/Secondary/100/Saturated
11033	Rural/Motorway-Nat./80/Saturated	13101	Rural/Distributor/Secondary(sinuous)/50/Freeflow
11041	Rural/Motorway-Nat./90/Freeflow	13102	Rural/Distributor/Secondary(sinuous)/50/Heavy
11042	Rural/Motorway-Nat./90/Heavy	13103	Rural/Distributor/Secondary(sinuous)/50/Saturated
11043	Rural/Motorway-Nat./90/Saturated	13111	Rural/Distributor/Secondary(sinuous)/60/Freeflow
11051	Rural/Motorway-Nat./100/Freeflow	13112	Rural/Distributor/Secondary(sinuous)/60/Heavy
11052	Rural/Motorway-Nat./100/Heavy	13113	Rural/Distributor/Secondary(sinuous)/60/Saturated
11053	Rural/Motorway-Nat./100/Saturated	13121	Rural/Distributor/Secondary(sinuous)/70/Freeflow
11061	Rural/Motorway-Nat./110/Freeflow	13122	Rural/Distributor/Secondary(sinuous)/70/Heavy
11062	Rural/Motorway-Nat./110/Heavy	13123	Rural/Distributor/Secondary(sinuous)/70/Saturated
11063	Rural/Motorway-Nat./110/Saturated	13131	Rural/Distributor/Secondary(sinuous)/80/Freeflow
11071	Rural/Motorway-Nat./120/Freeflow	13132	Rural/Distributor/Secondary(sinuous)/80/Heavy
11072	Rural/Motorway-Nat./120/Heavy	13133	Rural/Distributor/Secondary(sinuous)/80/Saturated
11073	Rural/Motorway-Nat./120/Saturated	13141	Rural/Distributor/Secondary(sinuous)/90/Freeflow
11081	Rural/Motorway-Nat./130/Freeflow	13142	Rural/Distributor/Secondary(sinuous)/90/Heavy
11082	Rural/Motorway-Nat./130/Heavy	13143	Rural/Distributor/Secondary(sinuous)/90/Saturated
11083	Rural/Motorway-Nat./130/Saturated	13151	Rural/Distributor/Secondary(sinuous)/100/Freeflow
12011	Rural/TrunkRoad/Primary-Nat./60/Freeflow	13152	Rural/Distributor/Secondary(sinuous)/100/Heavy
12012	Rural/TrunkRoad/Primary-Nat./60/Heavy	13153	Rural/Distributor/Secondary(sinuous)/100/Saturated
12013	Rural/TrunkRoad/Primary-Nat./60/Saturated	14051	Rural/Local/Collector/50/Freeflow
12021	Rural/TrunkRoad/Primary-Nat./70/Freeflow	14052	Rural/Local/Collector/50/Heavy
12022	Rural/TrunkRoad/Primary-Nat./70/Heavy	14053	Rural/Local/Collector/50/Saturated
12023	Rural/TrunkRoad/Primary-Nat./70/Saturated	14061	Rural/Local/Collector/60/Freeflow
12031	Rural/TrunkRoad/Primary-Nat./80/Freeflow	14062	Rural/Local/Collector/60/Heavy
12032	Rural/TrunkRoad/Primary-Nat./80/Heavy	14063	Rural/Local/Collector/60/Saturated
12033	Rural/TrunkRoad/Primary-Nat./80/Saturated	14071	Rural/Local/Collector/70/Freeflow
12041	Rural/TrunkRoad/Primary-Nat./90/Freeflow	14072	Rural/Local/Collector/70/Heavy
12042	Rural/TrunkRoad/Primary-Nat./90/Heavy	14073	Rural/Local/Collector/70/Saturated

Code	Description[1]	Code	Description
12043	Rural/TrunkRoad/Primary-Nat./90/Saturated	14081	Rural/Local/Collector/80/Freeflow
12051	Rural/TrunkRoad/Primary-Nat./100/Freeflow	14082	Rural/Local/Collector/80/Heavy
12052	Rural/TrunkRoad/Primary-Nat./100/Heavy	14083	Rural/Local/Collector/80/Saturated
12053	Rural/TrunkRoad/Primary-Nat./100/Saturated	14151	Rural/Local/Collector(sinuous)/50/Freeflow
12061	Rural/TrunkRoad/Primary-Nat./110/Freeflow	14152	Rural/Local/Collector(sinuous)/50/Heavy
12062	Rural/TrunkRoad/Primary-Nat./110/Heavy	14153	Rural/Local/Collector(sinuous)/50/Saturated
12063	Rural/TrunkRoad/Primary-Nat./110/Saturated	14161	Rural/Local/Collector(sinuous)/60/Freeflow
13001	Rural/Distributor/Secondary/50/Freeflow	14162	Rural/Local/Collector(sinuous)/60/Heavy
13002	Rural/Distributor/Secondary/50/Heavy	14163	Rural/Local/Collector(sinuous)/60/Saturated
13003	Rural/Distributor/Secondary/50/Saturated	14171	Rural/Local/Collector(sinuous)/70/Freeflow
13011	Rural/Distributor/Secondary/60/Freeflow	14172	Rural/Local/Collector(sinuous)/70/Heavy
13012	Rural/Distributor/Secondary/60/Heavy	14173	Rural/Local/Collector(sinuous)/70/Saturated
13013	Rural/Distributor/Secondary/60/Saturated	14181	Rural/Local/Collector(sinuous)/80/Freeflow
13021	Rural/Distributor/Secondary/70/Freeflow	14182	Rural/Local/Collector(sinuous)/80/Heavy
13022	Rural/Distributor/Secondary/70/Heavy	14183	Rural/Local/Collector(sinuous)/80/Saturated

1 Area type/road type 1/road type 2/speed limit/traffic level

Table 28: ***Urban driving cycles.***

Code	Description	Code	Description
21011	Urban/Motorway-Nat./60/Freeflow	22052	Urban/TrunkRoad/Primary-Nat./100/Heavy
21012	Urban/Motorway-Nat./60/Heavy	22053	Urban/TrunkRoad/Primary-Nat./100/Saturated
21013	Urban/Motorway-Nat./60/Saturated	22061	Urban/TrunkRoad/Primary-Nat./110/Freeflow
21021	Urban/Motorway-Nat./70/Freeflow	22062	Urban/TrunkRoad/Primary-Nat./110/Heavy
21022	Urban/Motorway-Nat./70/Heavy	22063	Urban/TrunkRoad/Primary-Nat./110/Saturated
21023	Urban/Motorway-Nat./70/Saturated	22064	Urban/TrunkRoad/Primary-Nat./110/Stop+go
21031	Urban/Motorway-Nat./80/Freeflow	23001	Urban/Distributor/Secondary/50/Freeflow
21032	Urban/Motorway-Nat./80/Heavy	23002	Urban/Distributor/Secondary/50/Heavy
21033	Urban/Motorway-Nat./80/Saturated	23003	Urban/Distributor/Secondary/50/Saturated
21041	Urban/Motorway-Nat./90/Freeflow	23004	Urban/Distributor/Secondary/50/Stop+go
21042	Urban/Motorway-Nat./90/Heavy	23011	Urban/Distributor/Secondary/60/Freeflow
21043	Urban/Motorway-Nat./90/Saturated	23012	Urban/Distributor/Secondary/60/Heavy
21051	Urban/Motorway-Nat./100/Freeflow	23013	Urban/Distributor/Secondary/60/Saturated

Code	Description	Code	Description
21052	Urban/Motorway-Nat./100/Heavy	23014	Urban/Distributor/Secondary/60/Stop+go
21053	Urban/Motorway-Nat./100/Saturated	23021	Urban/Distributor/Secondary/70/Freeflow
21061	Urban/Motorway-Nat./110/Freeflow	23022	Urban/Distributor/Secondary/70/Heavy
21062	Urban/Motorway-Nat./110/Heavy	23023	Urban/Distributor/Secondary/70/Saturated
21063	Urban/Motorway-Nat./110/Saturated	23024	Urban/Distributor/Secondary/70/Stop+go
21071	Urban/Motorway-Nat./120/Freeflow	23031	Urban/Distributor/Secondary/80/Freeflow
21072	Urban/Motorway-Nat./120/Heavy	23032	Urban/Distributor/Secondary/80/Heavy
21073	Urban/Motorway-Nat./120/Saturated	23033	Urban/Distributor/Secondary/80/Saturated
21081	Urban/Motorway-Nat./130/Freeflow	24051	Urban/Local/Collector/50/Freeflow
21082	Urban/Motorway-Nat./130/Heavy	24052	Urban/Local/Collector/50/Heavy
21083	Urban/Motorway-Nat./130/Saturated	24053	Urban/Local/Collector/50/Saturated
22001	Urban/TrunkRoad/Primary-Nat./50/Freeflow	24054	Urban/Local/Collector/50/Stop+go
22002	Urban/TrunkRoad/Primary-Nat./50/Heavy	25031	Urban/Access-residential/30/Freeflow
22003	Urban/TrunkRoad/Primary-Nat./50/Saturated	25032	Urban/Access-residential/30/Heavy
22004	Urban/TrunkRoad/Primary-Nat./50/Stop+go	25051	Urban/Access-residential/50/Freeflow
22011	Urban/TrunkRoad/Primary-Nat./60/Freeflow	25052	Urban/Access-residential/50/Heavy
22012	Urban/TrunkRoad/Primary-Nat./60/Heavy	30001	Stop+Go
22013	Urban/TrunkRoad/Primary-Nat./60/Saturated	30070	Coach (HBEFA 7030)
22021	Urban/TrunkRoad/Primary-Nat./70/Freeflow	30080	Coach (HBEFA 8030)
22022	Urban/TrunkRoad/Primary-Nat./70/Heavy	30090	UrbanBus (HBEFA 9040)
22023	Urban/TrunkRoad/Primary-Nat./70/Saturated	30100	UrbanBus (HBEFA 10040)
22031	Urban/TrunkRoad/Primary-Nat./80/Freeflow	30110	UrbanBus (HBEFA 11040)
22032	Urban/TrunkRoad/Primary-Nat./80/Heavy	30112	UrbanBus (HBEFA 11240_6s)
22033	Urban/TrunkRoad/Primary-Nat./80/Saturated	30114	UrbanBus (HBEFA 11440_6g)
22041	Urban/TrunkRoad/Primary-Nat./90/Freeflow	30163	UrbanBus (Inrets 47-163)
22042	Urban/TrunkRoad/Primary-Nat./90/Heavy	30206	UrbanBus (Inrets 206)
22043	Urban/TrunkRoad/Primary-Nat./90/Saturated	30319	UrbanBus (Inrets 319)
22051	Urban/TrunkRoad/Primary-Nat./100/Freeflow		

Furthermore, in COPERT III emission functions are only provided for Euro 0 vehicles, with corrections for later Euro classes being provided for ‘urban’, ‘rural’ and ‘highway’ driving conditions. For the purpose of these comparisons an average emission function was derived from the values for these three driving conditions.

Full results for this analysed are available from Boulter and Barlow, 2005. The comparisons are summarised below, and an example for NOx emissions for Euro 3 vehicles is shown in Figure 56.

CO

Euro 0, Euro 1 and Euro 2 vehicles: The COST 346/COST 346/ARTEMIS emission factors are broadly equivalent to, or slightly lower than, those in COPERT. The COST 346/COST 346/ARTEMIS emission factors are higher than those in COPERT for the heaviest HGVs.

Euro 3 vehicles: The COST 346/COST 346/ARTEMIS emission factors are generally higher than those in COPERT, with the exception of HGVs <7.5 t.

Euro 4 and Euro 5 vehicles: The COST 346/COST 346/ARTEMIS emission factors are much lower than those in COPERT for all types of vehicle.

THC

Euro 0 vehicles: The COST 346/COST 346/ARTEMIS emission factors for coaches are lower than those in COPERT, and the emission factors for buses are higher than those in COPERT. The COST 346/COST 346/ARTEMIS emission factors for HGVs are broadly similar to those in COPERT.

Euro 1, Euro 2 and Euro 3 vehicles: The COST 346/COST 346/ARTEMIS emission factors are lower than or broadly equivalent to those in COPERT. The main differences relate to HGVs <7.5 t, for which the COST 346/COST 346/ARTEMIS emission factors are lower than those in COPERT, and buses and HGVs between 7.5 and 16 t, for which the COST 346/COST 346/ARTEMIS emission factors are lower at low speeds.

Euro 4 and Euro 5 vehicles: The COST 346/ARTEMIS emission factors are much lower than those in COPERT for all types of vehicle.

NO_x

Euro 0 vehicles: The COST 346/ARTEMIS emission factors are broadly similar to those in COPERT. For HGVs, the COST 346/ARTEMIS emission factors are lower than those in COPERT at speeds below around 20 km/h, and higher at speeds above 20 km/h.

Euro 1 vehicles: For buses the COST 346/ARTEMIS emission factors are slightly higher than those in COPERT, and for buses they are slightly lower. The emission factors for HGVs are broadly equivalent, though slightly higher in COST 346/ARTEMIS for higher speeds.

Euro 2, Euro 3, Euro 4 and Euro 5 vehicles: The COST 346/ARTEMIS emission factors are generally higher than those in COPERT by a factor of around two for all types of vehicle.

PM

Euro 0 vehicles: The COST 346/ARTEMIS emission factors are broadly similar to those in COPERT.

Euro 1 vehicles: The COST 346/ARTEMIS emission factors are broadly similar to those in COPERT, but are lower than those in COPERT for HGVs <7.5 t.

Euro 2 vehicles: The COST 346/ARTEMIS emission factors are broadly similar to those in COPERT, but are lower than those in COPERT for buses, HGVs <7.5 t and HGVs between 16 and 32 .

Euro 3, Euro 4 and Euro 5 vehicles: The COST 346/ARTEMIS emission factors are higher than those in COPERT for coaches, and slightly higher for HGVs between 16 and 32 t and HGVs heavier than 32 t. The COST 346/ARTEMIS emission factors are lower than those in COPERT for HGVs <7.5 t and HGVs between 7.5 and 16 t. The emission factors for buses are broadly similar to those in COPERT.

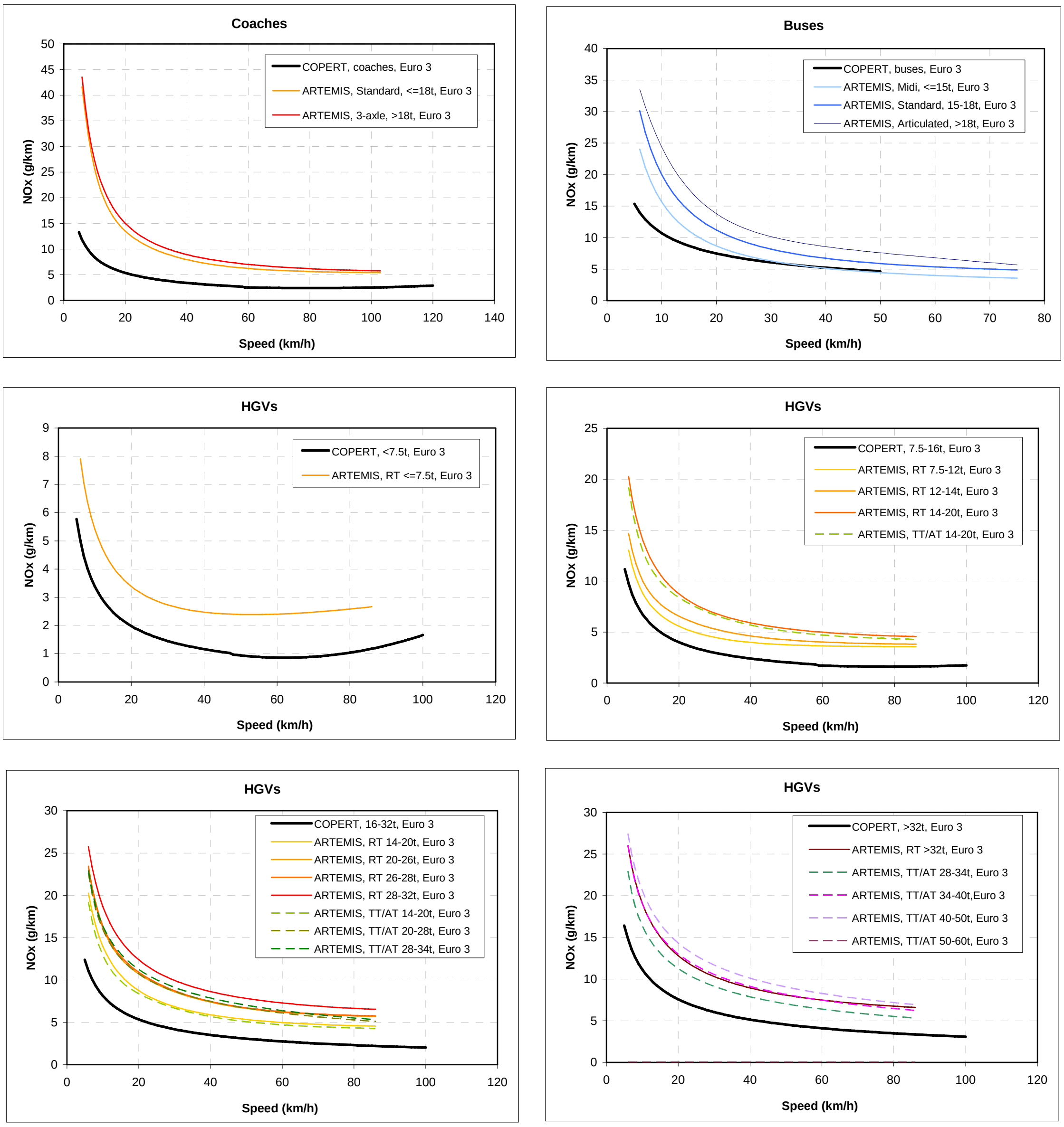

Figure 56: NO_x emissions for Euro 3 vehicles.

TRL recommends that the COST 346/ARTEMIS functions should replace those in COPERT III, as they are developed from real measurements from recently completed projects, and provide a greater level of detail in terms of the number of vehicle categories, gradients and vehicle loads included. However, it is not a trivial task to incorporate almost 12,000 emission functions into a model, and further work might help to simplify the form of the equations.

Reference:

Boulter P G and Barlow T (2005). COST 346/ARTEMIS: Average speed emission functions for heavy-duty road vehicles. TRL Report UPR/IEA/12/05. TRL Limited, Wokingham.

Ntziachristos L and Samaras Z (2000). COPERT III. Computer program to calculate emissions from road transport. Methodology and emission factors (version 2.1). Technical Report No. 49. European Environment Agency, Copenhagen.

Annex V. Members of the COST 346 Management Committee

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Each of the members of the MC has the duty to send the required copies to their Ministries of Transport, Ministry of Environment and Environmental Agency

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Annex VI. COST 346 Memorandum of Understanding

Brussels, 2 August 1999

COST 255/99

Memorandum of Understanding
for the implementation of a European Concerted Research Action designated as

COST Action 346

"Emissions and fuel consumption from heavy duty vehicles"

The Signatories to this Memorandum of Understanding, declaring their common intention to participate in the concerted Action referred to above and described in the Technical Annex to the Memorandum, have reached the following understanding:

1. The Action will be carried out in accordance with the provisions of document COST 400/94 "Rules and Procedures for Implementing COST Actions", the contents of which are fully known to the Signatories.
2. The main objective of the Action is to develop an improved methodology for estimating pollutant emissions and fuel consumption from commercial road transport operated with HDV´s in Europe. The methods should make it possible to estimate the emissions [g/km] from single vehicles as well as from vehicle fleets.
3. The overall cost of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 5 million at 1999 prices.
4. The Memorandum of Understanding will take effect on being signed by at least five Signatories.

The Memorandum of Understanding will remain in force for a period of five years, unless the duration of the Action is modified according to the provisions of Chapter 6 of the document referred to in Point 1.

TECHNICAL ANNEX

COST ACTION 346

Emissions and fuel consumption from heavy duty vehicles

1. Background

The greenhouse gas emission reduction targets agreed at Kyoto represent a first step to reduce emissions in the long term in order to stabilise the Earth's climate. The European Union has made an important contribution to the Kyoto agreement and the European Commission intends to develop a strategy to reach the Union's Kyoto target. This will require action in all sectors of the economy including the transport sector.

Of the six gases covered by the Kyoto protocol, carbon dioxide (CO_2) is the most important as it accounts for about 80% of the total global warming potential of all six greenhouse gases. In the European Union the share of transport CO_2 emissions in total increased from 19% in 1985 to 26% in 1995. Road traffic is the most important source, and largely determines the trend in the transport sector; and road freight accounts for about 35% of transport CO_2 emissions.

As well as CO_2, road freight transport causes considerable amounts of other pollutant emissions. With a share of approximately 75% of particulate (PM) emissions and about 60% of oxides of nitrogen (NO_x) emissions, road freight transport is the most important source of these pollutants within the total transport sector.

Up to now a huge number of measurements of road vehicle emissions have been made. But less than 1% of the available data is related to heavy duty vehicles. This means that, although the road freight transport is recognised as a major polluter, the knowledge about the real emission behaviour of this group of vehicles is very poor.

Due to the rapidly increasing demand for goods transport, the engine technology is not clean enough to meet the air quality targets. The intention to shift goods transport to other transport modes like rail will improve the situation, but cannot solve the whole problem.

There are three principal groups of measures to reduce pollution problems in the heavy duty transport sector, especially in commercial road transport:

(1) Technical emission reduction by legislation: Legislation obliges the vehicle and engine manufacturers to develop and produce cleaner vehicles and engines.

(2) Transport and traffic planning measures: Legislation and information that influences traffic and transport organisations or their activities.

(3) Measures that influence transport or traffic indirectly by generating or inhibiting certain transport activities (e.g. infrastructure programmes, administrative, legislative or tax incentives or restrictions).

To forecast and monitor the development of heavy duty vehicle (HDV) emissions and the effect of such measures, calculation methods must be provided which support the following tasks:

(a) Estimation of the effects of commercial road traffic with heavy duty vehicles on the environment to give decision makers the necessary input for planning and policy.

(b) Simulation and study of the effects of different road and traffic conditions on the energy consumption, emissions and transport efficiency of different vehicle types.

(c) Differentiation of the parameters that influence HDV emissions.

(d) Selection of an appropriate vehicle type for a particular transport operation.

(e) Optimisation of vehicle design with respect to engine type and power train.

(f) Operation of the vehicles with the most efficient driving behaviour (regarding energy consumption and emissions).

An increasing community is involved with transport, planning or environmental issues such as analysis of environmental effects of transport and traffic, and measures to reduce the impact. Besides the "classic" application of emission factors or emission calculations within environmental impact analysis, applications are increasing where traffic is only a minor source of impact but has to be considered anyway. This is the case e.g. in Technology Assessment or Life Cycle Analysis studies that focus on a product or an industrial plant. A typical application would be Council Regulation No 1836/93 of 29 June 1993 allowing voluntary participation by companies in the industrial sector in a Community eco-management and audit scheme [4] (EMAS regulation).

COST 346 deals with the subject of estimation of air pollutant emissions caused by heavy duty vehicles. International research should be structured to today's needs and a European data base of emission related information for heavy duty vehicles should be developed. Basic data for emission estimates, emission models and activity data will be included. This database can then be used to estimate the energy consumption and emissions of heavy duty vehicles as functions of vehicle types, traffic conditions and road/street characteristics.

The most recently finalised Europe-wide research activities concerning energy consumption and pollutant emissions from transport were COST 319 and MEET. COST 319 dealt with "Estimation of Pollutant Emissions from Transport"; MEET was a 4th Framework RTD Transport Programme project dealing with "Methodologies for Estimation of Emissions from Transport". One of the problems noted in COST 319 was that the database for HDV emissions has to be improved considerably, e.g. there are only few data available on engine emission maps and engine map data form the basis for estimating emissions from heavy duty vehicles.

Usage conditions of heavy duty vehicles differ greatly from the usage conditions of passenger vehicles. The same engine is used in different vehicles for different transport purposes. Therefore many options for power transmission layout and vehicle design exist for each engine. These varying usage conditions, combined with the variation of vehicle mass from unloaded to fully loaded (up to 60 tons), cause a wide range of operating conditions, and it is far too expensive to simulate them all on a chassis dynamometer. Therefore emission factors are mostly based on

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4 OJ L 168, 10.7.1993, p. 1.

information from engine emission maps using various vehicle simulation models. But these models have to be validated more thoroughly and model results have to be compared with each other. This validation has to be done under defined conditions, e.g. using measurements on a chassis dynamometer. The models calculate fuel consumption and emissions as a function of certain parameters, which are more or less aggregated depending on the application. However, the available emission data set is limited, and more or less the same problem is found concerning statistical data on driving behaviour, loading and activity of HDV's.

To improve the database on emission factors and activity, and the methodology, an international cooperation is proposed. It could result in more general availability of data of this kind and yield clear cost savings for all participants in the COST Action, compared with isolated research projects.

2. Objectives and Benefits

Objectives

The main objective of the Action is to develop an improved methodology for estimating pollutant emissions and fuel consumption from commercial road transport operated with HDV´s in Europe. The methods should make it possible to estimate the emissions [g/km] from single vehicles as well as from vehicle fleets.

The activities should be concentrated on improving the amount and quality of basic data on emissions and transport activity, as well as validating and improving existing models.

To achieve these objectives the following actions will be necessary:

Establish a protocol for HDV emission and fuel consumption testing. The protocol should include provisions for ensuring comparability between measurements made in different laboratories (quality assurance procedures, etc.).

Production of engine maps for calculating emissions and fuel consumption from HDV's. This should cover both static and dynamic operating conditions and a representative range of engines.

Because of the lack of existing data on particulate matter (PM) emissions and their important impact on health, the action should include measurements of PM size and number distributions.

To calculate emissions for single vehicles with the measured engine maps for different driving patterns, vehicle simulation models are necessary. For this task existing, improved or totally new models will be used.

The vehicle models have to be validated. The action will establish a protocol for validating the models, and will provide the necessary measurement data.

The use of aggregated emission models, aimed at the assessment of the overall emissions from a HDV fleet, requires detailed information on vehicles and vehicle operation (e.g. driving statistics) and more general traffic statistics (e.g. loading factors, fleet composition, mileage). COST 346 should consider this aspect and make recommendation on sources of information and methods of data acquisition.

Benefits

The main benefit of COST 346 will be the improvement of emission estimates for HDV's.

As a consequence the modelling of HDV emissions and the differentiation of vehicle types and driving conditions will provide an effective tool for political decisions within the European Union, as well as for traffic and transport engineering purposes. Furthermore, the database will give a comprehensive view of emissions under various driving conditions for HDV´s of different emission standards. Significant improvement of the knowledge on PM emissions can also be expected. The close cooperation between laboratories in different countries will improve the harmonisation of European scientific knowledge and testing facilities. The focus is on the quality and extension of HDV emission and activity data.

Moreover, the results and conclusions from COST 346 could be used in the context of legislative proposals by national authorities or by the European Commission, such as:

- Consolidation of European measurement facilities and programmes for HDV or other vehicle categories.
- Regulations regarding PM size and number distributions.
- Future emission legislation for HDV.
- Inspection and maintenance and field inspection programmes for HDV.

3. Scientific Programme

The scientific work programme is designed to improve emission estimates for HDV's. Therefore the quality and quantity of emission data and statistical data on the activities of HDV's has to be improved. The following steps will be undertaken:

1. Definition of the detailed work programme
    - review of programmes of related R&D projects and their budgets
    - review of existing models and essential parameters
    - review of existing emission data and on-going programmes
    - definition of the statistical data needed for emission estimates
    - definition of the necessary measurements (number of engines/vehicles, cycles, scope of analysis)
    - definition of a validation programme
    - definition and recommendations for national programmes to improve statistical data
    - review and final decision on the work programme and time table
    - distribution of the programme to the individual laboratories

- decision on model parameters to be considered for emission modelling
- interim report.

2. Preparation of measurement programme
   - definition of a protocol for HDV emissions and fuel consumption testing
   - definition of work plans for the individual laboratories according to their R&D programmes
   - reviewing and/or applying the QA procedure in the individual labs
   - final definition of the work programme of the individual laboratories
   - interim report
3. Measurement programme on emissions
   - strong coordination to improve the synergistic effects of the international cooperation
   - acquisition of the vehicles/engines
   - laboratory tests
   - validation programmes
   - data cross check between laboratories, statistical evaluation (error, deviation etc.)
   - integrate the approved data into a joint data base
   - interim report.
4. Data definition and collection programme - statistics
   - definition of the data needed
   - recommendations for data collection and measurements (driving resistance coefficients, fleet analysis, driving behaviour/driving cycles, loading factors, mileage, etc.
   - data cross check and QA
   - integration of the approved data into a joint data base
   - interim report.

5. Development of models and validation
   - integration of the data base into existing vehicle simulation models
   - validation and improvement of these models
   - final correction of models, input parameters and data base
   - draft documentation of the models, input data, and validation of the results
   - calculating on-road emissions or emission factors [g/km] with the models using the data on emission maps and driving patterns
   - aggregating average emission factors using the activity data
   - proposing optimised methodologies by the Action
   - interim report.

6. Final report and dissemination

- conclusions from the work in terms of recommendations for future legislative work
- executive summary, final report, final correction of interim reports
- recommendation of an improved European methodology for HDV emission estimates
- final documentation
- dissemination of reports, contents, results.

4. Organisation and timetable

Organisation

The work programme will be coordinated by the Chairman of the Management Committee (MC) with the support of the working group (WG) leaders. In order to organise the work programme the following WG will be established:

Emission group

Legislation group

Dissemination group.

In each WG, the WG leader will be responsible for the task of the WG and for reporting. The results will be disseminated according to the dissemination plan. The responsibility for this activity will be within a small group which will begin its work when the first results are available.

Timetable

The duration of the project will be 5 years with at least 2 MC meetings and 2 meetings of the individual WG per year. The tasks shown in the following table correspond with those given in the work programme. The importance of the reporting and the dissemination phase is strongly emphasised. It is planned to have one workshop per year to report on and evaluate the on-going activities. To minimise the costs, the workshops and MC meetings should be held at the same venue and time. The final results and findings of COST 346 will be presented at a major European conference on air pollution, e.g. the Transport and Air Pollution conference series which is held every 1 ½ years.

Table 29: Time table for the COST 346 Action

Duration	Year I				Year II				Year III				Year IV				Year V			
Task	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Definition of detailed work programme																				
Review on-going R&D activities	x	x			x				x				x				x			
Review of existing models	x	x	x																	
Review of existing emission data		x	x	x					x				x				x			
Review of existing statistical data		x	x	x	x				x				x				x			
Definition of measurement programme		x	x																	
Definition of verification programme		x	x																	
Preparation of Measurement programme																				
Definition of a protocol for HDV testing			x	x																
Definition work programmes in diff. Labs			x	x																
Measurement programme / emissions																				
Measurements				x	x	x	x	x	x	x	x	x	x	x	x	x	x			
Database								x	x	x	x	x	x	x	x	x	x	x		
Data acquisition statistics				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
Models and Verification																				
Application, validation of vehicle models							x	x	x	x	x	x	x	x	x					
Intercomparison of models											x	x	x	x	x	x	x	x		
Amendments of models													x	x	x	x	x	x		
Finalisation and dissemination																				
Reports				x				x				x				x			x	x
Dissemination activities		x	y	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Workshop/Progress evaluation				x				x				x				x			x	

5. ECONOMIC DIMENSION

The economic dimension of COST 346 is big. The reason is simply the high costs of emission measurements for HDV's. The estimated costs for the measurement of HDV emissions and fuel consumption are of the order of 50 KEURO/engine. But this can also be one of the strengths of this Action. If it is possible to coordinate research work on emissions in Europe the available money can be used for complementary measurements and investigations instead of duplicating work. From the economic point of view, this would be one of the biggest benefits of a successful COST 346 Action. The coordination of the research work on a European level is therefore essential for an effective development in this field.

National Costs

The following COST countries were involved in the preparation of COST 346 and indicated their interest:

Austria
Belgium
Czech Republic
Finland
France
Germany
Hungary
Netherlands
Sweden
Switzerland
United Kingdom

On the basis of national estimates provided by the representatives of these countries, and taking into account the coordination costs to be covered by the COST budget of the European Commission, the overall costs of the activities to be carried out under the COST 346 Action has been estimated, in 1999 prices, at EUR 5 million.

This estimate is valid under the assumption that all the countries mentioned above, but no other countries, will participate in the Action. Any departure from this will change the total cost accordingly.

If it is possible to concentrate the scientific and financial resources on coordinated projects a big step forward to an improved emission estimation for HDV´s can be made.

DISSEMINATION PLAN

The information produced by COST 346 will be used by an increasing community of scientists and researchers for all kind of traffic emission calculation. This information has to reach anyone who is involved in traffic and planning issues or environmental questions. The dissemination of the knowledge must necessarily involve a broad variety of users and provide detailed technical information and emission data.

Users

The potential users of the output of COST 346 include all those dealing with environmental problems of transport, who may have many roles in society. In general, they will belong to one of the following groups:

- public authorities like ministries, public departments, administrative bodies etc.
- Non-Governmental organisations (NGOs)
- scientific organisations like universities, research institutes etc.
- industrial and engineering companies
- associations that deal with traffic like driving schools, freight companies etc.
- interested individuals.

2. Application levels of emission calculation supported by COST 346

According to the desired application interested users will require more or less detailed information or data which must be met by the available documents as listed in F.3. The following application levels have to be considered:

- general information on emissions of road traffic or heavy duty vehicles
- technical information on emission measurements, modelling parameters etc.
- average or total emissions of (heavy duty vehicle) traffic
- detailed emissions down to local street level or individual vehicle types
- evaluation of driving behaviour of single engines or vehicles
- analysis of detailed or basic emission data

2.1. Methods of dissemination

Dissemination will take place throughout the Action. A continuous series of publications will document the progress and status of the work. In addition to the internal COST reporting activity the following methods of dissemination will be used:

- A yearly COST 346 Workshop will be held to present the progress of the work. The workshop - which will be open to all interested people from industry, transport and policy sectors - will be the basis for evaluation of the work done so far.
- Papers will be offered for publication in International Journals, e.g. Transactions, Atmospheric Environment, Transport Science, Journal of the Air and Waste Management Organisation, International Journal of Vehicle Design, Environmental Science and Technology etc.
- Papers giving detailed findings will be presented at International Conferences covering environmental or traffic issues, e.g. Transport and Air Pollution, SAE congress, European Road Research Conference, Air Pollution, Envirosoft, Urban Transport and the Environment, CRC-Workshop on Mobile Sources, Highway and Urban Pollution, Viennese Symposium on Internal Combustion Engines, ISATA, FISITA etc.

- Basic information about the content of the Action and sources for reports and data will be given in an internet Homepage via CORDIS (European Commission Research and Development Information System). At least Status and Final Reports and emission and activity data released by the COST Management Committee will be made available through this Homepage.

  - The findings concerning legislative issues will be presented to the responsible national and international bodies and the industry in separate meetings and workshops.
  - The final results and findings of the COST action will be presented in a major European conference on transport and/or air pollution as mentioned above.

Available Documentation

The results of COST 346 will be presented within the following generally available and actively published documents:

- Executive Summary (2-5 pages) which will give a short description of the programme, the major findings, description of available information and possible applications.
- Detailed Summary with some technical details and examples of emission factors (20-30 pages).
- Final Report describing the programme and the main results and available data (200 pages).
- Status report and other documents provided for the yearly Workshops.
- Technical essays or summaries as published in conference papers or journals.
- Emission factors (detailed and aggregated) as paper or data base versions.

Detailed technical information might not be important for the all interested parties, but necessary for scientific work or other specific questions. The following will therefore be available on special request only:

- Work Reports of the phases of the scientific programme which document the work performed and their outcomes.
- Working Group reports such as the final reports of the national measurement programmes.

Detailed knowledge about the generation of the data and its limitations is necessary to perform very detailed data analyses. Generally only the laboratory which performed the measurements provides such detailed information, which is not normally not available in written documents. Any aid provided by the laboratory usually entails significant consultation time and costs. Therefore the availability of very detailed data must be limited to those who have the necessary knowledge or who might pay for the service provided by the laboratory. Available on such special requests only will be:

- Engine maps to be used within models or for scientific purposes.
- Basic emission data base with detailed measurement data.

Annex VII. COST Actions in Transport & Urban Development

- 30 Electronic traffic aids on major roads*
- 30 bis Same aim as COST 30 but with demonstration action*
- 33 Forward study on passenger transport requirements between large European conurbations*
- 301 Shore-based marine navigation aid-systems*
- 302 Technical and economic conditions for the use of electric road vehicles in Europe*
- 303 Technical and economic evaluation of dual-mode trolleybus national programmes*
- 304 Use of alternative fuels in road vehicles*
- 305 Data system for the study of demand for interregional passenger transport*
- 306 Automatic transmission of transport data*
- 307 Rational use of energy in interregional transport*
- 308 Maintenance of ships*
- 309 Road meteorology and maintenance conditions*
- 310 Freight transport logistics*
- 311 Maritime traffic simulation*
- 312 Effects of the channel tunnel on the structure of traffic flows*
- 313 Socio-economic cost of road accidents*
- 314 Express delivery services*
- 315 Large containers*
- 317 Socio-economic effects of the channel tunnel*
- 318 Interactions between high-speed rail and air passenger transport*
- 319 Estimation of pollutant emissions from transport*
- 320 Effects of EDI on the transport sector (Electronic Data Interchange)*
- 321 Urban goods transport*
- 322 Low floor buses*
- 323 Weighing in motion of road vehicles*
- 324 Long-term performance of pavements*
- 325 New pavement monitoring equipment and methods*
- 326 Electronic sea chart for marine navigation*
- 327 Motorcycle safety helmets*
- 328 Integrated strategic infrastructure network in Europe*
- 329 Models for traffic and safety developments and interventions*
- 330 Teleinformatics links between ports and their partners*
- 331 Requirements for road marking*
- 332 Innovative methods of coordination between transport Actions and regional and local planning*

- 333 Development of new bituminous pavement design method*
- 334 Effects of wide single tyres and dual tyres*
- 335 Accessibility of heavy rail systems systems to elderly and disabled people*
- 336 Falling weight deflectometer*
- 337 Unbound granular materials for road pavements*
- 339 Technical and economic conditions for the European wide operation of intermodals transport units (Small containers)**
- 340 Towards an intermodal transport network : lessons from history**
- 341 Habitat fragmentation due to transportation infrastructure**
- 342 Parking policy measures and their effects on mobilty and the economy**
- 343 Reduction in road closures by improved pavement maintenance procedures**
- 344 Improvements to Snow and Ice Control on European Roads**
- 345 Procedures required for assessing highway structures**
- 346 Emissions and fuel consumption from heavy duty vehicles**
- 347 Pavement research with accelerated loading testing facilities**
- 348 Reinforcement of pavements with steel meshes and geosynthetics**
- 349 The Accessibility of Coaches and Long Distance Buses for People with Reduced Mobility**
- 350 Integrated assessment of environmental impact of traffic and transport infrastructure**
- 351 Water Movement in Road Pavements and Embankments
- 352 Influence of Modern In-vehicle Information Systems on Road Safety Requirements
- 353 Winter Service Strategies for Increased European Road Safety
- 354 Performance Indicators for Road Pavements
- 355 Changing behaviour towards a more sustainable transport system
- 356 Towards the definition of a measurable environmentally sustainable transport (EST)
- 357 Accident Prevention Options with Motorcycle Helmets
- 358 Pedestrians‘ Quality Needs
- C1 Control of the semi-rigid behaviour of civil engineering structural connections*
- C2 Large scale infrastructures and quality of urban shape*
- C3 Diagnosis of urban infrastructure*
- C4 Management and information application development in urban civil engineering*
- C5 Urban heritage - Building maintenance*
- C6 Town and infrastructure planning for safety and urban quality for pedestrians**
- C7 Soil-structure interaction in urban civil engineering**
- C8 Best practice in sustainable urban infrastructure**

- C9 Processes to reach urban quality**
- C10 Outskirts of European Cities**
- C11 Greenstructures and urban planning**
- C12 Improvement of buildings structural quality by new technologies**
- C13 Glass and interactive building envelopes**
- C14 Impact of wind and storm on city life and built environment**
- C15 Technical infrastructure and vegetation-improving relations and preventing conflicts by an Interdisciplinary approach**
- C16 Improving the quality of existing urban building envelopes
- C17 Built Heritage: Fire Loss to Historic Buildings
- C18 Performance assessement of urban infrastructure services: the case of water supply, wastewater and solid waste
- C19 Proactive crisis management of urban infrastructure
- C20 Urban Knowledge Arena – Developing a European Arena for Cross-Boundary Co-operation in Production of Knowledge and Know-how on Complex Urban Problems
- C21 Towntology – Urban Ontologies for an Improved Communication in Urban Civil Engineering Projects
- C22 Urban Flood Management
- C23 Strategies for a Low Carbon Built Environment
- C24 Analysis and Design of Innovative Systems for Low-EXergy in the Built Environment: COSTeXergy
- C25 Sustainability of Constructions: Integrated Approach to Life-time Structural Engineering
- C26 Urban Habitat Constructions under Catastrophic Events
- C27 Sustainable Development Policies for Minor Deprived Urban Communities
- G3 Industrial ventilation**

* Action completed before 2001

**Action completed before 31 August 2006

Please consult the COST Office homepage for more detailed information on the Actions: http://www.cost.esf.org/index.php?id=239