Methods of estimation of atmospheric emissions from transport: European scientist network and scientific state-of-the art

Robert Joumard

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action COST 319 final report

LTE 9901 report
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INSTITUT NATIONAL DE RECHERCHE SUR LES TRANSPORTS ET LEUR SÉCURITÉ

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13 Summary

The COST 319 action "Estimation of pollutant emissions from transport" involved co-operation between about a hundred European researchers between 1993 and 1998. This report presents the results of the action in terms of network development, inventory methods, and future research needs.

The complete Action network had over 200 members. Half of these played an active role in the various working groups. The network included most of the European specialists in the field of transport-related emission inventories. The addresses , phone numbers, and subject areas of the network members, whether they be researchers or users, are included in this report.

State-of-the-art European inventorying tools are presented in the report. A distinction has been made, according to the type of application, between disaggregated, central, or aggregated models. The four transport modes - road, rail, sea and air - are addressed using a set of sub-models and databases relating to various emission factors and traffic characteristics. The data used in the models, the assumptions that are made, and the model output are all analysed. The implications for emission modelling are reported.

In addition, an assessment was made of the research that would be required in the future to develop sufficiently precise and homogeneous inventorying models for transport-related emissions which could be used in various applications.

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12 Remarques

Rapport d'un groupe de travail, dont les nombreux auteurs signent les différents paragraphes

13 Résumé

Fruit de la collaboration d'une centaine de chercheurs européens de 1993 à 1998, les résultats de l'action COST 319 "Estimation des émissions de polluants par les transports" sont présentés en termes de réseau, de méthodes d'inventaires, et de besoins de recherche future.

Le réseau issu de l'action comprend plus de 200 membres dont la moitié a pris une part active dans les différents groupes de travail. Il représente donc l'essentiel des spécialistes européens dans le domaine des inventaires d'émissions des transports. Les coordonnées de chacun des membres, chercheurs ou utilisateurs, sont publiées ainsi que son domaine d'activité.

La partie purement scientifique du rapport présente l'état de l'art européen en la matière en distinguant les différent types d'application correspondant à des modèles désagrégés, centraux, et agrégés. Les quatre modes routier, ferré, aérien et maritime-voie d'eau sont traités, avec un ensemble de sous-modèles et de bases de données concernant les différents facteurs d'émission et les caractéristiques du trafic. La mise au point des résultats est analysée en priorité (analyse des données disponibles, hypothèses, conclusions en terme de modélisation), tandis que les différents modèles sont présentés en détail dans un rapport annexe.

Enfin les principaux besoins de recherche future ont été analysés, afin de tendre vers des modèles d'inventaire des émissions des transports suffisamment précis et homogènes pour leurs différentes applications.

14 Mots clés	15 Diffusion
transport, route, aérien, maritime, rail, émission, inventaire, polluant atmosphérique, méthodologie, facteur d'émission, caractéristiques du trafic, modèle, recherche future, coopération, Europe	restreinte libre X

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13 Kurzfassung

Dieser Bericht ist das Ergebnis einer Zusammenarbeit von etwa 100 Forschern im Zeitraum von 1993 bis 1998. Die COST Aktion 319 „Abschätzung der verkehrsbedingten Schadstoffemissionen“ führte dazu, daß ein Netzwerk von Wissenschaftern aufgebaut und Methoden zur Durchführung von Emissionsberechnungen entwickelt wurden. Zuzätzlich konnte der zukünftige Forschungsbedarf auf diesem Bebiet aufgezeigt werden.

Das im Rahmen der Aktion entwickelte Netzwerk umfaßt 200 Mitglieder. Die Hälfte von ihnen spielte eine aktive Rolle in den verschiedenen Arbeitsgruppen, die den größten Teil der europäischen Spezialisten auf dem Gebiet der transportbezogenen Emissionserhebungen repräsentieren. Die Adressen und Telefonnummern der Mitglieder des Netzwerks, Forscher oder Anwender, sind einschließlich ihrer fachlichen Schwerpunkte angegeben.

Im wissenschaftlichen Teil des Berichts ist der Entwicklungsstand in Europa auf diesem Gebiet dargestellt, wobei in Bezug auf die räumliche Auflösung nach verschiedenen Anwendungsbereichen der Modelle unterschieden wird. Die vier Transportarten - Straße, Schiene, Wasser und Luft - werden behandelt unter Einbeziehung von Teilmodellen, die verschiedene Datensätze von Emissionsfaktoren und Verkehrskenngrößen nutzen, die zunächst analysiert wurden (Analyse der verfügbaren Daten, Annahmen, Schlußfolgerungen in bezug auf Modellierung). Die verschiedenen Modelle sind in einem gesonderten Bericht detailliert beschrieben.

Schließlich wurde der wichtigste Bedarf an zukünftigen Forschungsstudien herausgearbeitet die das Ziel haben, hinreichend genaue und konsistente Modelle zur Erfassung transportbedingter Emissionen zu entwickeln.

14 Schlagwörter	15 Berichtsstatus
Transport, Straße, Luft, Schiene, Emission, Kataster, atmosphärische Schadstoffe, Methodologie, Emissionsfaktor, Verkehrskenngrößen, Modell, Forschungsbedarf, Kooperation, Europa	begrenzt frei X

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Content

Abbreviations

2W	two wheelers
CEC	Commission of the European Communities
CH_4	methane
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
COPERT	European computer programme to calculate emissions from road traffic
CORINAIR	core European inventory of air emissions
COST	European co-operation in the field od scientific research
DGV	Digitised Graz method
DME	dimethyl ether
DRIVE	Dedicated road infrastructure for vehicle safety in Europe
ECE 15	European urban driving cycle (also called UDC)
EEA	European environment agency
EMEP	Co-operative program for monitoring and evaluation of the long range transmission of air pollutants in Europe
ETC/AE	European topic center on air emissions
EU	European Union
EUDC	European extra-urban driving cycle
EV	electric vehicle
FC	fuel consumption
FCEV	fuel cell electric vehicle
FTP	United States federal test procedure
GDP	gross domestic product
HBEFA	Handbook of emission factors
HC	hydrocarbons
HDV	heavy duty vehicle
HEV	hybrid electric vehicle
HFO	heavy fuel oil
HGV	heavy goods vehicle
IPCC	Intergovernmental panel on climate change
LDV	light duty vehicle

LPG	liquefied petroleum gas
MEET	Methodologies for estimating air pollutant emissions from transport
MOBILE	United States Environmental Protection Agency's mobile source emission factor model
MODEM	Modelling of emissions and consumption in urban areas
NG	natural gas
NH_3	ammonia
N_2O	nitrous oxide
NMVOC	non-methanic volatile organic compounds
NOx	nitrogen oxides
O/D	origin-destination
PAH	polycyclic aromatic hydrocarbons
PC	passenger car
PM	particulate matter
RME	rapeseed methyl ester
RVP	Reid vapour pressure
SOx	sulphur oxides
TWC	three way catalyst
UDC	European urban driving cycle (also called ECE 15)
UNECE	United Nations economic commission for Europe
VOC	volatile organic compounds

1. Introduction

The first real European initiative for developing emission inventory methods, beyond local initiatives taken by a number of laboratories or at the request of national authorities, was the *CORINAIR* working group on emission factors for calculating emissions from road traffic. The working group, comprising five experts on car emissions, began in 1987 with the aim of developing a methodology, including appropriate emission factors, for the estimation of vehicle emissions in the reference year 1985 [Eggleston *et al.* , 1989]. The methodology was transformed into a computer program (*COPERT*) which was used by many European Union (EU) countries. In 1991 the same group of experts proposed a revised set of emission factors to be used for the 1990 inventory, including a partial revision of the underlying methodology [Eggleston *et al.*, 1993]. As for the 1985 methodology, the results of this work were translated into a computer program - *COPERT 90* [Andrias *et al.*, 1993]. A new version of the model was developed in 1997 (*COPERT 2*). This makes use of interim results from the current research.

COPERT is now being used not only by EU Member States but also by most countries of Central and Eastern Europe. Moreover, *COPERT* is providing emission estimates for other international activities such as the Intergovernmental Panel on Climate Change (IPCC) and the European Modelling and Evaluation Program (EMEP) of the United Nations Economic Commission for Europe (UNECE) - see annex 1. In the corresponding guidebook [EEA, 1996] as well as in the IPCC guidelines [IPCC/OECD/IEA, 1997], methodologies for estimating national emissions from other transport modes are also included (aircraft, ships, rail).

During a similar period, a consortium of three European laboratories developed a modal model for estimating emissions from passenger cars called *MODEM*.. This model was based on new measurements performed using various specially developed driving cycles [Joumard *et al.*, 1995a]. In 1989 Germany, joined later by Switzerland and Austria, initiated a project to provide a new and comprehensive data base of emission factors [Infras, 1995]. For passenger cars, this was an attempt to combine the *COPERT* method based on average speed with a method based on instantaneous emissions [Hassel *et al.*, 1994]. For heavy vehicles, the model is based on the results of a vehicle-related model combined with engine emission maps [Hassel *et al.*, 1995].

The small number of researchers who took part in the *CORINAIR*, *MODEM*, and other national or multilateral projects, initiated a wider network of co-operation aimed at reviewing the available knowledge of traffic emissions in Europe. This co-operation was included in the wider framework of the *COST* program, and its results are presented here.

1.1. COST 319 objectives

In general terms, the estimation of transport-related emissions can be based on the equation E = e . a, where E is the amount of emission, e is the emission rate per unit of activity, and a is the amount of transport activity. This equation applies at every level, from a single engine to a whole fleet, and from a single road to the whole of Europe. In order to obtain an estimation with acceptable accuracy, the collaboration of a number of experts is required. Experts on traffic engineering are required to provide data on transport activity and on the nature and pattern of this activity, and experts on engine and vehicle emissions are required to provide emission rates which suit the transport patterns.

In addition, the method of estimating emissions must be used to assess various policy options by developing different complex scenarios. It is therefore likely that experts in fields other than those already mentioned would also be required during the whole evaluation process.

The overall objective of COST 319 was to co-ordinate European research activities relating to emissions of regulated and unregulated pollutants, fuel consumption, and energy use of transport. Specific objectives were:

- To analyse the methods used and the results obtained,
- To make a synthesis of the available data and to develop appropriate tools,
- To co-ordinate research.

For the first time the 4 transport modes (road, rail, air and sea) were considered together, as were all levels of calculation - from local and instantaneous emissions to a world-wide estimation.

The COST initiatives

The *COST* program ("European Co-operation in the Field of Scientific Research") is a Europe-wide program for the co-ordination of national research, and is managed by 25 signatory countries and the European Commission. The program addresses areas of research where concerted action can bring benefit to the participating countries. With its emphasis on open participation, *COST* actively promotes the concept of "bottom-up working", with the research areas being defined by the participants themselves. *COST* 's open and adaptable approach brings many advantages. It enables avoiding duplication of effort, sharing of results by all participating countries, building of a scientific consensus, and efficient coverage of the complex field of European research, whilst still allowing the individual countries to focus on problems of particular interest.

1.2. Program of the COST 319 action

To fulfil these objectives, the *COST* 319 action "estimation of pollutant emissions from transport" was launched in May 1993 for a period of 4 years, later extended 5.5 years (i.e. until October 1998). The corresponding "Memorandum of Understanding" (see annex 2) was signed by 17 countries, including members and non-members of the European Union (Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, the Netherlands, Slovakia, Spain, Sweden, Switzerland and United Kingdom).

The wide field covered by the action, as well as the large number of experts involved (more than 80 from 24 countries), necessitated the formation of four main working groups, specialising in:

· *Road transport emission factors and functions*: quantification of emission rates per unit of activity and studies of the factors that influence them (engine maps, instantaneous

vehicle emissions, hot and cold average vehicle emissions, evaporative emissions, alternative fuels, new vehicle technologies, life cycle emissions),
- *Road traffic characteristics*: the operation of the road transport sector and how it is affected by technical, social, policy and economic factors (traffic management, driving behaviour, traffic composition, factor analysis and models of mobility),
- *Road inventory tools*: study and evaluation of procedures to assess road transport's environmental impacts (bottom-up and top-down approaches),
- *Non-road transport*: emission factors, traffic characteristics and inventorying tools specific to non-road transport (rail, air, and water-borne transport).

Each main group has been further divided into 22 sub-groups which were required to meet when necessary. An animator supervised the work in each working group or sub-group (see annex 3), the meetings of which are listed in annex 4.

1.3. The MEET project

The financial support for the *COST* action is very low for carrying out comprehensive research. The studies assessed by the action were very numerous and were usually funded by national and international bodies. Much synthesis of work was required for compliance with the objectives of the action. A specific project partially covering the program of the action was carried out by 16 of the participants. The European Commission funded this project under the transport research and technological development program as part of the 4th framework program. The 3 main objectives of the project, called *Methodologies for Estimating Air Pollutant Emissions from Transport (MEET)*, were:
- To provide a set of data and models, allowing various users of the project to calculate the pollutant emissions and the fuel or energy consumption of the various transport modes at strategic level.
- To provide a comprehensive method of calculation using the set of data and models.
- To make sure that this comprehensive method corresponds to the requirements of the potential users in terms of accuracy, simplicity and input data availability.

The project has now been completed. It covers a large part of the action program, but does not cover the engine emission maps or transport analysis and models, and contains only written methodologies. No software packages have been developed.

1.4. Outputs

The results obtained were used to develop a set of methodologies for the calculation of emission which have been accepted by most of the European experts. The methodologies are presented in this report. The use of common methods to evaluate emissions and energy consumption levels all over Europe and possibly more widely will make the different studies and assessments comparable. Simultaneously the actions undertaken allowed the participating laboratories to compare and co-ordinate their research methods, and the European countries to co-ordinate their research programs in order to fill in the knowledge gaps.

For the COST 319 action, and the MEET project which is a part of it, a large number of reports were written, each of them being a synthesis of the European knowledge available, expressing a common opinion of the involved scientific circles. These reports, listed in the literature list at the end of this report, are summarised in section 3. They are readable on the web at http://www.inrets.fr/infos/cost319/index.html. The final inventory methodologies with all the necessary data concerning the emission factors and the traffic characteristics are presented in the final MEET report (see its publication data form in Annex 11). It allows any user to carry out an inventory.

The aims of the present report are quite different: it discusses the available data and their accuracy, and it presents the synthesis methods and the assumptions. It should be considered as a scientific report, especially useful for those interested in the building of methods of estimation of pollutant emissions from transport, rather than for users.

In addition, the report presents the scientific and user network, which can be used to contact European experts, and also the future research needs in the fields covered by the action.

1.5. Fields of application

The methods that have been developed for calculating pollutant emissions and are considered as state-of-the-art by the COST action, cover all possible applications and user needs. They range from calculations at a microscopic scale (i.e. for a single vehicle, or for a street) to a macroscopic calculation (i.e. regional, national and global levels) through the inventory of an urban transport network. In some cases, such as when calculating input emission data for a physio-chemical model, an absolute estimation of vehicle emissions is required. But in most applications, only a relative estimation is required - for example when comparing two traffic types, or when calculating the impact of traffic management or the emission evolution over the years.

Therefore, the state-of-the-art has been established for the various types of application. The applications can be categorised according to the level on which they operate and the transport mode considered. The types are

- Disaggregated modal road transport models required for accurately assessing the impact of changes in vehicle speeds. A comparative and critical analysis of the available models has been performed.
- Base emission models for road transport which use a detailed fleet description, and take into account vehicle kinematics through the average speed. They are suitable for most of the recorded needs. A comprehensive model has been developed (MEET) and is presented in this report.
- Aggregated or simplified road models, corresponding mainly to macroscopic uses, are not detailed in this paper. Simplified models should be calculated by simple integration of the base model.
- Non-road models (air, rail, waterborne): a model is developed for each transport mode from currently available knowledge.

Therefore the field of application covered in this report is wide and is liable to be of interest to most specialists and experts in the transport-related emission field.

2. Scientific and user network

The first outcome of the COST action is the formation of a new or stronger co-operation between many European experts, whose outputs are presented later.

2.1. European expert network

The result of this co-operation was the establishment of a network comprising over 200 experts from Europe and, to a lesser extent, from non-European countries. The network therefore extends further than 17 signatory countries. Two types of expert are involved: specialists (generally researchers) in developing inventory methods for transport-related emissions (emission factors, traffic characteristics, models and tools), and inventory models users whose requirements have been analysed [Carrié & Noppe, 1997].

The specialists' network is listed by country in Annex 5. The list covers about 130 active members of the COST action who agreed to benefit from the mutual exchange of knowledge and results, either by participating in the working group sessions, by making available data or models, or by taking charge of synthesis work. Their spheres of activity are given in terms of the structure of the working groups listed in Annex 3, corresponding also to the structure of section 3 (scientific approach) of this report. This provides easily accessible information on most of the European researchers specialising in a given field.

The whole network is presented in Annex 6, where a distinction is made between active researchers and users, specifying their addresses, contact details, and the scientific field in which they are working.

2.2. Exchange of emission data

The first task of the network was to put together the knowledge, data, and results available in the European laboratories involved. A synthesis has been made and a set of inventory methods has been drawn up. This work is presented in section 3.

It soon became apparent that the available data were not homogeneous. This is not surprising since the data were obtained from various independent research projects carried out over a number of years. The aim of the present research was not to carry out measurement campaigns, but to analyse existing data and knowledge. The possibilities of analysis and synthesis were limited by the inconsistency of the data in terms of traffic characteristics (see section 3.2) and emission factors. In the latter case, the experimental conditions were often not available or were incomplete.

In order to avoid these problems during further exchanges of data, a minimum list of parameters to be measured and included in the data files has been proposed for all emission measurements relating to road vehicles (Annex 7). These are conventional parameters which can be easily obtained. They must be considered during the planning of the measurements and data files in order to make further co-operation between laboratories more useful.

3. Scientific approach

In addition to the measures taken for structuring the research studies, the working groups, and the data exchanges, the principal objective of this European co-operation was to assess the state of the art by reviewing all of the data and information available in Europe. This synthesis study was carried out by each working group under the control of a supervisor. Then, other experts in the particular field made critical observations either through bilateral exchanges or through more formal meetings (Annex 4).

The findings of each working group are presented in this report. The working groups are specified in the introduction and in Annex 3. This structure also corresponds closely to the structure of the MEET project, which cannot be dissociated from the COST action, at least from a scientific standpoint. Thus, each sub-section of this review corresponds to a MEET report or, for the few topics that were not considered in MEET, a COST report. For these reasons the name, address, and other contact details of the author of each section are mentioned at the beginning of this document. Each item, and the whole scientific approach adopted, have been agreed by all the active members of the action.

3.1. Road emission factors and functions

3.1.1. Engine emission maps and vehicle simulation models

By Olavi H. Koskinen and Robert Joumard

An engine map is primarily a research and development tool that allows engineers to characterize the fuel consumption and emissions of an engine. More recently, simple engine maps (like the ECE 13-mode test) have been used by legislators to determine the approved limits of emissions for engines of heavy duty vehicles.

An engine map can be used to assess pollutant emissions and fuel consumption on the basis of vehicle parameters which are distinct from engine parameters. It is necessary to review the advantages and disadvantages of using engine emission maps to determine emissions for vehicles rather than just for engines.

3.1.1.1 Description and availability of engine maps

Engine mapping occurs normally on test benches. Fuel consumption and emissions depend on the operational state of the engine, which can be presented on a 2-dimensional plane. One dimension is the engine speed and the other is the torque. The third dimension represents the fuel consumption or the emission rate [kg/h]. These can be represented as isocurves (surfaces of constant value) on the map. In general, the specific fuel consumption or emissions [g/kWh] are expressed as isocurves, but they can also be stated as constant flow rate [kg/h] values (see an example Figure 1). The latter approach is better suited to those cases where engine maps are used for vehicle motion simulation purposes (see next section).

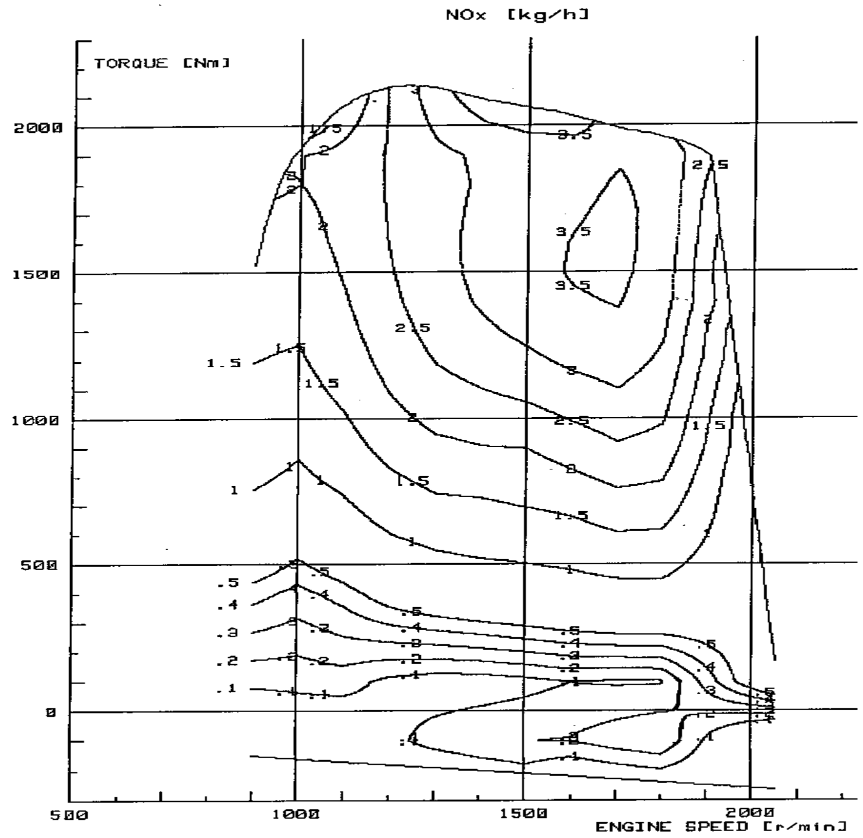

Figure 1: Example of NOx engine map in kg/h.

As a general definition of an engine map it can be said that it describes the fuel consumption and the emissions as functions of the engine speed and the engine torque. The denser the grid of measurement points, the better the accuracy of the engine map. A complete and accurate map requires tens of measurement points.

For the type approval of engines the following test types are of interest:

- stationary tests (e.g. ECE 13-mode test, see below new ECE test). Emissions are measured at different steady states for given engine speed and torque (load) values. A weighted average for the specific emission [g/kWh] is calculated, and this must not exceed the legislative value for each pollutant.
- emissions in transient cycles (e.g. US transient cycle, future ECE test). In this case average emissions during the cycle (bag values, integrated modal values) are evaluated, or instantaneous values are recorded.

These approval tests do not yield engine maps directly. In general, more measurement points and/or more work are required for proper engine mapping. Engine mapping using bench tests is quite time consuming because of the preparatory work required. Work can be reduced if the vehicle is tested on a chassis dynamometer. However, the accuracy of the results is not as good because power train losses must be estimated. This could be done at zero and full load with some assumptions, together with a linear interpolation for the intermediate loads.

Another problem concerning heavy duty vehicle measurements of this kind is that heavy-duty chassis dynamometers are very expensive and not widely available.

The present European legislation requires a set of steady-state tests: the specific emissions [g/kWh] of an engine for a heavy duty vehicle must not exceed certain values. These represent the weighted averages of 13 steady-state measurements conducted at two engine speed values and five engine load (torque) values, plus three measurements made at idle (i.e. there are 11 measurement points in total). This is called ECE 13-mode test. The authorities require the maximum values for the weighted averages, but not for the individual measurement points. In a few years the 13-mode test will be changed slightly: the total number of measurement points will remains at 13, but the test will cover three engine speed values and the load/torque values will be scattered. However, the new test will only be temporary, because after five years it is intended that a transient test will be introduced. The transient test will be similar to the one currently being used in the United States.

In order to accurately characterize the emissions from an engine, 11 or 13 measurement points are not sufficient. Additional points should be tested for research purposes.

During the period of the COST 319 action 48 engine maps became available, containing usually fuel consumption, CO, HC, NOx, CO_2 and particulate measurements. These covered:

- 9 passenger cars, either from the Neste Oil Company (FIN, mainly on vehicle bench), or from VTI (S)
- 39 heavy duty vehicles on engine bench, mainly from TÜV Rheinland (D), but also VTT (FIN), Neste Oil Company, Cummins (UK) and KTI (H).

In addition there are numerous data dealing only with the fuel consumption of heavy duty vehicle engines; they can be used for calculation the fuel consumption in different road and traffic conditions. But for emission calculations the number and the quality of the available engine maps are surely not enough, especially when it is the only way to assess emissions.

3.1.1.2. From engine maps to vehicle emissions

The use of engine maps for determining emission factors is particularly relevant for heavy duty vehicles. The first reason for this is that the same engine type is usually installed in a lot of vehicle types; the number of combinations engine/ vehicle type is very great. In addition, the conditions under which they are operated - from motorways to bad forest roads or construction sites - differ from the conditions under which passenger vehicles are operated. This requires the consideration of various power transmission ratios, even for the same engine, and leads to an incredible number of combinations of engine/transmission ratios and vehicle type. Also, with the variation of vehicle mass from unloaded to fully loaded (e.g. a road train from 18 to 60 tons in some European countries), and with the variation in rolling and wind resistances due to the different number of axles and body shapes in use, such a wide a range of engine operation states exists that it is far too tedious and expensive to simulate them all on chassis dynamometers. The road gradient also plays a very important role (it is as important as the speed in terms of power consumption). Thus, vehicle mass, engine power, road slope, and vehicle speed are also strongly connected. Therefore consideration of road gradient would increase further the necessary number of direct measurements of vehicle emissions.

The most promising way of using engine maps is in combination with vehicle motion simulation. A vehicle with predefined technical characteristics is driven on a road that also has predefined characteristics. The way of driving is also defined and the output of the simulation can be used to derive engine speed and torque (load). Engine maps can be used to calculate instantaneous fuel consumption and emissions, and average values if necessary. As steady-state engine maps are usually used in the simulation models, it is assumed that the actual engine operating conditions (i.e. transient modes) are equivalent to a succession of steady-state modes. The differences (i.e. the influence of the dynamic driving behaviour) must be analysed in depth and taken into account in the development of the models. For instance, it was taken into account through empirically -derived correction functions by [Hassel, 1995]. Such work forms the basis of the assessment of emission factors for heavy duty vehicles (see section 3.1.7).

Even so, several vehicle simulation models also exist. These should be analysed, compared and validated. A validation under controlled conditions, such as on a chassis dynamometer, is necessary. When considering emissions from a vehicle, the engine-related information has to be adjusted to account for power train losses, road resistance, wind resistance (due to vehicle body size and shape), etc. Chassis dynamometer (= vehicle bench) tests can be used to measure the emissions of the whole vehicle according to very well defined boundary conditions. Such conditions include real-world driving cycles, vehicle loads, etc. On-board (or on-the-road) measurements can also deliver vehicle-related emission information, although the boundary conditions cannot be defined as accurately as they can for chassis dynamometer tests (especially with respect to the repeatability of test conditions). On the other hand, the representativity of the driving and environmental conditions is very good. This means that certain vehicles have to be tested on a chassis dynamometer, and that, in addition, their engines have to be measured on a stationary -as performed in [Infras, 1995]- or transient test bench. If possible, the same vehicles should also be tested on the road.

Driving resistance (wind resistance and rolling resistance) play a very important role in determining fuel consumption and emissions. The air resistance coefficient may vary widely from one vehicle type to another, especially for heavy-duty vehicles. A comprehensive contribution in this respect has been given by Hammarström (1998), who compiled a literature review on air resistance factors. His conclusion was that there are sufficient data for passenger cars, if data from manufacturers are accepted as representative. For other vehicle types the available data are not sufficient to estimate representative air resistance coefficient values, and consequently representative emission factors.

3.1.1.3 Conclusion and outlook

Because it is difficult to measure and analyse directly emissions from heavy-duty vehicles, and because many heavy-duty vehicles that have different body shapes and masses can be equipped with the same engine, emission and fuel consumption models based on engine-related emission data alone must be used. Therefore, it is essential to improve the database of engine emissions, including the transient state. This can be done by mapping the emissions from a large number of engines on test benches or, possibly from vehicles on chassis dynamometers (vehicle benches).

The next step will be to compile the available vehicle simulation models developed by the research laboratories and other bodies and experts in order to check their assumptions and methods of calculation. By comparing them methodological improvements will be possible. Subsequently, inter-comparisons will be made and the models will be validated (i.e. compared to vehicle bench or on-the-road emission measurements).

3.1.2. Instantaneous vehicle emissions

by Peter Sturm

At the moment the majority of road traffic emission estimates are based on average speed information. However, this is often not sufficient to characterise the emission level of real-world driving behaviour because any number of different driving situations with different dynamics and emissions can have more or less the same average speed. The introduction of additional parameters to describe driving dynamics, and hence emissions, may improve the quality of emission estimates in some circumstances -for example when the introduction of traffic calming measures results in changes in driving behaviour. For such purposes, instantaneous emission models can result in much more reliable estimates. In the context of the work described here "dynamics" refers to the severity of the driving cycle in terms the demand it imposes on the engine. A driving cycle having "high dynamics" would tend to include frequent gear changes and many rapid and prolonged accelerations and decelerations, whereas a cycle having "low dynamics" would be less severe.

Therefore, the COST 319 working group A2 "Instantaneous emissions" has dealt with the methodological aspects, applications, and possible improvements of the "instantaneous emission modelling" approach. This report is a summary and conclusion of work which was carried out in the frame work of the COST 319 action [Höglund, 1999] and mainly the MEET project [Sturm *et al.*, 1998].

To determine emissions from road traffic it is necessary to describe the emission behaviour of vehicles according to real-world driving behaviour. The approach adopted to obtain emission functions or factors varies.

One method is based on chassis dynamometer tests which are carried out using different driving patterns for an extensive number of vehicles. These driving patterns represent the driving behaviour for categorised driving situations on specific types of roads. The emission factors derived using this procedure are then taken to be representative for that certain driving situation.

The other approach uses instantaneous emission modelling (modal modelling). This means that emission quantities are recorded continuously during chassis dynamometer tests and stored in a two-dimension matrix as a function of vehicle (engine) load, defined by parameters such as velocity and acceleration. Having the two-dimensional emission matrix on the one hand, and recorded driving patterns (defined by analogous modal values of acceleration and speed) on the other, it is possible to calculate the emissions corresponding to different driving patterns. This technique of filling instantaneous emission records from an emission matrix, and mapping the latter with a driving pattern is called “modal modelling”. Using this methodology emission factors for statistically-derived driving patterns, as well as estimates of emission quantities for certain driving situations can be obtained.

3.1.2.1. Instantaneous emissions approach (modal modelling)

In what is termed ”modal modelling” (or modal analysis) emissions are measured continuously at the exhaust during chassis dynamometer tests and stored at a particular time interval (usually every second). The operational condition of the vehicle - defined in current models by instantaneous driving speed and acceleration (calculated from the speed – time curve) - is recorded simultaneously with the emission rate. In this way, it is possible to generate emission functions by assigning exactly-defined emission values to particular operational conditions. For example, the emission function for each pollutant can be defined as a two-dimensional matrix, with the rows representing a velocity interval (in km/h units), and the columns being assigned to an interval of acceleration times velocity (in m^2/s^3 units). All instantaneous emission data are put into one cell of the emission matrix, according to the velocity and acceleration of the measured vehicle at that time. The emission function is the arithmetic mean of all emission quantities in each cell of the emission matrix. Hence, the emission function is stepwise and two-dimensional, assigning a mean emission level to every pair of velocity and acceleration values. Once such an emission matrix exists for a vehicle, it should then be possible to calculate emission amounts for any driving pattern which is defined as series of modal value-pairs of speed and acceleration.

3.1.2.2. Differences between existing emission calculation methodologies

The average speed approach is the commonly used method to estimate emissions from road traffic, e.g. COPERT II [Ahlvik *et al.*, 1997]. This approach is based on aggregated emission information for various driving patterns, whereby the driving patterns are represented by their mean speeds alone. All this information is put together according to vehicle technology, capacity class and model year and a speed dependent emission function is derived. This means that in addition to vehicle type, the average speed of the vehicle is the only decisive parameter used to estimate its emission rates. This restricts the approach to regional and national emission estimates. The dynamics of a driving pattern - which are especially important during urban driving - are only taken into account implicitly.

A comprehensive application of an instantaneous emission model was performed to establish the Emission Factor Workbook [Hassel *et al.*, 1994; Keller *et al.*, 1995]. Real world driving behaviour was recorded on the road. From recorded real-world driving behaviour, representative ”real-world” driving patterns were derived by statistical means. Using emission functions based on continuous emission measurements from various chassis dynamometer tests, emission factors for real-world driving patterns were derived. The parameters used in the Workbook to calculate emissions are a qualitative description of the road and traffic situation combined with quantitative information concerning the cycle dynamics (e.g. inner-city stop and go behaviour; the mean velocity would be 5 km/h), rather than the average speed of that specific driving profile.

In general, emission factors serve to describe the emission behaviour of vehicles in those road networks where the traffic is densest. For local traffic, this naturally refers to the main street traffic. It is not the aim of emission factors to estimate emissions when the driving behaviour is quite different from that from which the emission factors are derived (e.g. within specific road sections, crossings, etc.). This belongs to the field of instantaneous emission models, whereby it should be possible to calculate emissions even when small changes in driving behaviour have to be taken into account.

3.1.2.3. Methodological aspects and discussion of the instantaneous emission approach

The use of arithmetical models based on modal emission data should make the calculation of emissions for real-world driving conditions possible. However, since a great number of different vehicle categories are to be found in road traffic - differentiated by engine type, engine capacity, model year, etc. -, the corresponding information must be available for all of them.

Indeed, modal emission data are currently available for a great number of private motor vehicles [Hassel *et al*., 1995; Joumard *et al.*, 1995a; BUWAL, 1994; Reiter, 1997]. These data records have mostly been generated on chassis dynamometers using special driving cycles. Parameter studies with these data are restricted, since legislative driving patterns are used, and details regarding emissions relating to actual driving behaviour are missing, or vice-versa

Since restrictions are encountered when obtaining the basic emissions data set , the extent to which the emission data, and the models developed from the data, are applicable must be clarified. For this purpose, studies were carried out to systematically investigate the following parameters:

- The influence of the measurement set-up
- The influence of measurement programme
- The influence of model parameters

The nature of the measurement set-up and vehicle sample used for testing result in uncertainties which are typical of all methodological approaches, and which influence the quality of emission estimates for standard (average speed) approaches as well as for instantaneous ones. The measurement program for creating the emission matrices seems to have the biggest influence on the quality and usability of instantaneous emission data. Therefore, the investigations focussed mainly on the selection of appropriate driving patterns for the chassis dynamometer tests used to generate instantaneous emission values, and also on the application range of currently available emission data and models.

3.1.2.4. Application range of currently available emission data and models

The investigations were mainly based on gasoline vehicles equipped with a three-way catalyst and diesel cars (model years 1992 to 1994). At the moment, only hot emissions can be calculated using instantaneous emission models. The following conclusions arose from the work:

- All the calculations made in this report show that the quality of the emission matrix used (i.e. which driving patterns were used to generate the emission data) plays an important role. For many applications the uncertainty of the emission estimation is in the range of ±10 to 20 %.
- The use of instantaneous emission approaches (modal modelling) is recommended when emissions have to be estimated in situations where driving behaviour and dynamics are of major interest. Standard average speed models are not appropriate for such tasks.
- However, it has also been shown that for single applications (particular driving cycles) the uncertainty is much higher, and it is even possible for an instantaneous emission model to predict wrong trends when evaluating measures which result in minor alterations to driving behaviour. For such applications the predicted changes in emissions must be significant to be reliable. If this is the case it can be expected that at least the indicated trend is reliable.
- During highly dynamic real-world driving cycles all vehicles had high CO and HC emissions. The use of emission information derived using legislative cycles resulted in low values in the emission matrix, and therefore caused a remarkable underestimation of the emissions over real-world driving cycles.
- When using modal modelling certain requirements must be met when constructing the emission database (emission matrix).
- In the case of real-world driving cycles it turned out to be imperative to include emission data from such cycles in the emission matrices, or to exclude data from legislative cycles.

- The generation of emission matrices has to be based on driving cycles which cover the whole region of relevant emission matrix cells.
- The cycle dynamics, which are implicitly taken into account when creating the emission matrix, have to be similar to those in the real-world driving pattern for which the emission estimate is being made. This means that an additional parameter (in addition to modal values of acceleration and velocity) has to be taken into account to describe the dynamics of such a driving pattern.

In the near future the task will be to improve instantaneous emission models by introducing an additional parameter to classify the driving dynamics and to assign it to proper emission matrices. The basic idea is to develop emission matrices which fulfil the requirements of normal driving behaviour, and special functions for high and low dynamic situations. However, at the moment it is not clear how to define the dynamics as an additional parameter. Due to the different engine management concepts and gear-shift philosophies, which are adapted and specific to each model, it will be difficult to develop a universally applicable estimation of emissions based solely on the dynamics of the driving pattern (e.g. engine enrichment functions for 3-way catalyst).

Which calculation methodology is the most appropriate depends upon the application. For the majority of applications emission factors will allow emission estimates with sufficient accuracy. But there are certain application ranges were driving dynamics plays an important role and emission changes due to changes in driving dynamics have to be estimated (e.g. traffic calming). In such cases the use of instantaneous emission models will lead to more reliable results, not necessarily in the quantitative way but qualitatively (trend). However, at present the changes in driving behaviour have to be significant if reliable results for the emission estimates are to be obtained.

3.1.3. Average hot emission factors for passenger cars and light duty trucks

by Zissis Samaras and Leonidas Ntziachristos

This part of the report focuses on the production of hot emission factors which can be considered representative for large scale road traffic applications. It was carried out in the frame of the MEET project and the COST 319 action, which has made available a large number of emission measurements to MEET: see the whole report in [Samaras & Ntziachristos, 1998]. The objectives of the specific task were:

- to collect European hot start emission data measured as average (bag) values for passenger cars (PCs) and light duty vehicles (LDVs) over a number of different driving cycles
- to analyse these raw data and process them in order to understand the main parameters which explain the variation of emissions
- to build emissions sub-models specific for different vehicle categories.

The final product should be harmonised with the CORINAIR/COPERT activity of the European Environment Agency (see Annex 1). Then, it has been decided that it should fully adopt the methodology developed by MEET for the Road Transport sector. To meet this aim, emission factors dependent only on average speed were thought as constituting the best approach. This expression of the emission factors is considered to be sufficient for calculating total emissions for a relatively low spatial and temporal resolution (e.g. city over a day) and requires a low degree of input information. However, emissions of finer resolution, or the influence of driving dynamics on emissions described by the modal approach discussed in section 3.1.2, cannot be modelled using this approach.

Speed dependent hot emission factors presented in [Samaras & Ntziachristos, 1998] correspond only to PCs and LDVs falling in the following vehicle categories:

- Gasoline PCs complying with EURO I (91/441/EEC) emission standards
- Diesel PCs complying with EURO I (91/441/EEC & 88/436/EEC and US83) emission standards
- Conventional Gasoline LDVs
- Conventional Diesel LDVs
- Gasoline LDVs complying with EURO I (93/59/EEC) emission standards
- Diesel LDVs complying with EURO I (93/59/EEC) emission standards

In order to provide a consistent set of emission factors covering all categories, conventional fuel types and emission control technologies for four-wheel vehicles, emission factors developed in the frame of MEET are combined with those developed in earlier programmes (e.g. COPERT 90). Thus, the set of emission factors presented in the Report enables the potential user to calculate emissions from all gasoline, diesel or LPG PCs and LDVs from the introduction of the first ECE Directive (1971) and on.

Only the so called conventional pollutants are covered (CO, NOx, HC, CO_2). Non regulated pollutants (such as NH_3, N_2O, PAHs, CH_4, NMVOC species, etc.) have not been treated because of the lack of available data. Moreover, fuel consumption has been derived based on the carbon balance between tailpipe emissions and engine-in conditions. All emission and consumption factors are expressed in g/km.

3.1.3.1. Vehicle sample and driving cycles

A database was created including emission data from PCs and LDVs tested in the following laboratories:

- EMPA, Switzerland: data from the Swiss/German project for the production of representative emission factors
- INRETS, France: data from various national and international projects
- LAT/AUTh, Greece: data from an international project
- MTC, Sweden: data from various national projects, specifically compiled for this purpose
- TNO, the Netherlands: data from national and international projects
- TRL, United Kingdom: data from national and international projects
- TUG, Austria: data from a national project
- TÜV Rheinland, Germany: data from national and international projects.

A total of 2522 vehicles, and the results from 9039 emission tests conducted over several cycles, are included in the database. Only the data corresponding to cycles not used in vehicle type approval were used in order to avoid possible emission underestimation due to the low driving dynamics of legislative cycles. Thus, the emission factors are considered to originate from real-world representative cycles developed by different laboratories to describe actual driving situations in the corresponding countries. In this respect, results have been obtained over 41 different real-world cycles covering an average speed range of 5.2 km/h to 130 km/h. Moreover, vehicles not randomly selected (e.g. high emitters from remote sensing tests) were excluded so as not to bias the representativity of the sample. Figure 2 presents the number of vehicles and the respective number of measurements conducted over real world cycles by each laboratory.

*Figure 2**:** Number of vehicles and respective tests in real-world cycles (for acronyms see bullet list above).*

Based on the previous criteria, the data used for the production of the emission factors include results from 2164 emission tests on gasoline PCs, 313 tests on diesel PCs, 62 tests on gasoline LDVs and 74 tests on diesel LDVs. 82% of gasoline PCs comply with Directive 91/441/EEC while almost equal numbers of tests on diesels fall under ECE1504 and again 91/441/EEC. The remaining vehicles are distributed according to different emission standards, with a few of them complying with Directive 94/12/EEC but not in sufficient numbers to derive emission factors for this vehicle category. Table 1 summarises the number of PCs and LDVs and respective measurements over real world cycles included in the database. The classification is based on the fuel used (gasoline, diesel) and compliance with the respective emission regulations. Vehicles of the pre EURO category comply either with the ECE 150x regulations or with the intermediate "Improved Conventional" and "Open Loop" technological levels.

*Table 1**:** Summary of vehicles and tests in real world cycles included in the database.*

Category	Gasoline PCs		Diesel PCs		Gasoline LDVs		Diesel LDVs	
	Vehicles	*Tests*	Vehicles	*Tests*	Vehicles	*Tests*	Vehicles	*Tests*
pre EURO	182	*455*	39	*179*	16	*26*	20	*50*
EURO I	399	*1766*	55	*128*	19	*36*	15	*24*
EURO II	8	*24*	2	*6*	0	*0*	0	*0*

3.1.3.2. Methodology

Emission functions relating to average speed were obtained by first plotting the individual emission measurements conducted over different cycles vs. the average speed of the cycle. Then, the best-fitting curve was drawn to correlate emissions with speed. Based on the distribution of the emissions, binomial regression analysis was applied to give the best correlation coefficients. The different steps and decisions taken during the production of the emission factors included:

- An attempt to improve the correlation coefficients by distinguishing between different speed regions, which would potentially be described by different equations, had no effect except for CO_2. In the case of CO_2, and consequently fuel consumption, a discrete change in the emission (consumption) behaviour was found below the region of 13 km/h and was described by a different equation.

- No distinction was made between early catalyst PCs and more recent ones, since initial studies gave no distinct differentiation between such vehicles.
- The split between the three different engine capacity classes (i.e. ≤ 1.4 l, 1.4 to 2.0 l and > 2.0 l) was kept for EURO I cars, with different emission factor equations for each of the three capacity classes. This has been done for compatibility reasons with the CORINAIR/COPERT methodology.
- It was not possible to make any distinction between engine capacity classes for the diesel passenger cars. This was also the result of the small available sample of these vehicles.
- It was not possible to differentiate LDVs by weight. Therefore it was decided to provide equations for all LDVs of a weight less than 3.5 tonnes.

Some of the decisions taken are considered only as compromises imposed by the limited sample, especially for LDVs. Therefore they should be reconsidered and possibly revised if future relevant studies are based on a more consistent and complete data set.

3.1.3.3. Analysis of the results

Low correlation coefficients were observed for most of the emission curves, despite the efforts to provide emission factors in close correlation with the individual measurements. This implied that there were large inconsistencies between the sample values which were probably induced by parameters other than those selected for the classification of the vehicles. Therefore, an analysis of the available sample was conducted to reveal if significant differences existed between vehicles meeting different criteria. Specifically, the effect on emissions of engine size, the total mileage driven, and the laboratory conducting the emission test was studied to see if such parameters can be considered responsible for discrepancies in the data.

The analysis was mainly based on legislative cycles, over which a large number of vehicles have been measured. It is assumed that the parameters listed above will have an equal impact on emissions over both legislative and real-world cycles.

This analysis did produce conclusive results because large gaps existed in the data between the different classes, and the sample was not specifically compiled for the purposes of such activity. However, definite trends were observed, and these can be summarised as follows:

- Large differences in the average emissions resulted from measurements carried out in different laboratories, even in the case of legislative cycles. At maximum, a factor of 3.5 was found between the upper and the lower average emission level between samples of vehicles with similar characteristics, as measured by different laboratories. Such discrepancies can either be the result of differences in the testing conditions (including driving cycles) or just reflect the overall condition of the laboratories national vehicle populations.
- Mileage had a significant effect on emissions for all pollutants other than CO_2, especially in the case of legislative cycles. To a large extent, the high dispersion of emission rates, which is responsible for the low correlation of the emission factors, can be attributed to the effect of mileage. Differences in average emissions from samples with different mileage classes was as great as a factor of 5.
- The effect of engine capacity was not that evident, as might have been expected for CO, NOx and HC. No consistent variation in emissions with engine capacity was found in case

of the UDC and EUDC, with only a minor variation about an average value. Moreover, emissions of the above pollutants over real world cycles were also found to be at the same level for all capacity classes, if the vehicles fell into the same mileage class.

3.1.3.4. Mileage effect

The observation that mileage has a significant effect on average sample and, consequently, fleet emissions led to the need to correct the proposed emission factors according to mileage. The quantification of mileage effect on emissions will help the potential user to the following:

- To accurately compare emissions from European countries with different average fleet age. The total mileage driven in the life of the vehicles differs between countries and this should be taken into account.
- To provide information for the evolution of emissions for different fleet renewal scenarios. The promotion of fiscal incentives for the replacement of older vehicles is a widespread strategy in European countries and its effectiveness should also be seen in the light of mean fleet mileage reduction.
- To make possible emission predictions based on the current fleet composition.

The problem associated with such an approach is that although the increase in emissions with mileage is obvious, the increase is different at different speeds, probably because the mileage effect is also dependent on average speed. This has led to the decision to provide a partial speed-dependent mileage correction for the emission factors, based on the emission degradation observed over the UDC and the EUDC, with respective speeds of 19 km/h and 63 km/h. Initially, the emission degradation over these cycles was quantified. Then, the emission degradation proposed for a specific mileage and for the speed region lower than 19 km/h was considered to be equal to the one over the UDC and equal to that over the EUDC for the region higher than 63 km/h. A linear interpolation between the degradation values corresponding to those two cycles was proposed for the intermediate speed region to provide a continuous emission degradation correction over the whole speed range.

However, the original emission factors proposed in the first part of the report should be used to calculate emissions from different national fleets. Correction for mileage should only be applied to compare relative trends, as is demonstrated by the bullet list in this paragraph. It is interesting to note that emissions seem to stabilise after a mileage point which can be defined in the region of 120 000 km. Based on the method developed, emissions are predicted to be up to 3 times higher than the original values for vehicles having travelled for more than 120 000 km.

3.1.3.5. The effect of "external" parameters

The effects of ambient temperature and cabin air-conditioning on emissions were also studied. The application of the hot emission factors in European countries having a different yearly average temperature might require correction. The data showed an increase in emissions as ambient temperature reduced (down to -20 °C), but the increase did not occur in a consistent way for different vehicles. However, linear correlation showed that average emissions increase up to 108 % between -20°C and 22.5 °C in the case of CO emissions over the stabilisation phase of the FTP 75 cycle. Thus, linear equations independent of speed were proposed for CO, NOx and HC. These may be used to show the relative effect of ambient temperature on emissions.

Moreover, the increasing penetration of air-conditioned vehicles into the new car market provides a potential risk to accurate estimation of fleet emissions if its effect is neglected.

Data collected over the EUDC with and without the air-conditioning in operation were compared for 12 gasoline and 12 diesel PCs. In both cases, CO_2 emissions seem consistently to increase by about 20% when the air-conditioning was operating. All other emissions from gasoline vehicles increased but not in a consistent way, whilst CO and HC emissions from diesel vehicles actually decreased. Although air-conditioning operation results in differentiation of hot emissions, any correction is subject to the limitations imposed by the large scatter in the data.

3.1.4. Start emissions

by Robert Joumard, Eric Sérié and John Hickman

Excess start emissions are an important part an emission inventory model for two principal reasons. Firstly, the average trip length of passenger cars in Europe is about 5 to 8 km [Laurikko *et al.*, 1995; André *et al.*, 1999], whereas urban trips are even shorter (2 to 4 km). Consequently, a high proportion of mileage is driven under cold start conditions. Secondly, the engine temperature affects the emission rate, and the ratio of cold start emissions to hot start emissions has been shown to vary between around 1 and 16 according to the vehicle technology, the pollutant, and other parameters [Joumard *et al.*, 1995b].

The methodology developed previously in Europe for calculating cold start emissions was based on a very small set of measurements. The approach was to introduce a relative cold start emission factor (cold/hot emission ratio) which was dependent upon ambient temperature and trip length (CORINAIR/COPERT: Eggleston *et al.*, 1993), as well as parking time and average speed (HBEFA: Infras, 1995). The present model is also empirical and is based upon available data (see the full report: Sérié & Joumard, 1997).

3.1.4.1. Data

In January 1994 39 European laboratories studying vehicles emissions were asked to supply data obtained under cold start conditions. We obtained original data from INRETS (France - see Joumard *et al.*, 1995b), LAT (Greece), TNO (The Netherlands - see TNO, 1993), TRL (England), TÜV Rheinland (Germany - see Hassel *et al.*, 1994). The data related to gasoline cars with and without a 3-way catalyst, and diesel cars with and without an oxidation catalyst. The parameters of interest were test vehicle type and characteristics, driving cycle, ambient temperature, start condition, and emissions. Emission measurements were taken with each vehicle being driven from both cold start and hot start over the same cycle. For each vehicle, 3 types of cold and hot cycles were followed: standardised cycles (ECE15, FTP 72-1), short Inrets cycles (nearly 200 sec long, repeated 15 times), and long TRL cycles.

If a single measurement is defined as one made with a vehicle operated over the same cycle from both a hot and cold start, irrespective of the pollutants measured, the total number of measurements obtained was 2568. This total comprised 460 gasoline cars without a catalyst, 1784 gasoline cars with a catalyst, 315 diesel cars without a catalyst, and 9 diesel cars with a catalyst. At each test laboratory, all the vehicles were selected so that the distribution was representative, to some extent, of the fleet composition in the country: the whole sample can therefore be considered to be representative of the whole European fleet.

Most measurements were carried out within the temperature range 13.0 to 19.6 °C. Data measured at different ambient temperatures (-9 to 26 °C) were used to assess the influence of ambient temperature on cold start emissions.

The data from different studies showed a large amount of variation. Before analysis, it was necessary to standardise the data in two ways. Firstly, a large number of measurements had been obtained using FTP cycles (with non representative conditions), and a small number of measurements had been obtained using representative real-world driving cycles. Excess cold start emissions obtained during real-world driving cycles were therefore standardised by adjusting the measured values according to how far they deviated from measurements made over the FTP cycle. Secondly, because at the end of a standard cycle the engine is not always hot, a light adjustment was made for each pollutant.

3.1.4.2. Influence of various parameters

Excess emissions as a function of the cycle speed - Emissions were measured at different cycle speeds just using the Inrets short representative cycles. A linear regression was applied in order to determine the excess emission [g] as a function (f(V)) of the average speed V [km/h]. It should be noted that the regression was calculated using only three data points, with each point corresponding to an average of ten measurements.

Excess emissions as a function of ambient temperature - In order to assess the influence of ambient temperature, only the data obtained over complete cold starts (i.e. when the engine start temperature corresponds to the ambient temperature) were used. The data were very scattered. An example of CO emissions from catalyst-equipped cars is shown in Figure 3. A linear relationship g(T) was established between the excess emission (g) and the ambient temperature T. A good correlation was not observed between emissions of CO_2 and NOx and ambient temperature for gasoline cars, and g(T) was thus assumed to be constant. These results are comparable to those found by Lenner (1994) and Joumard *et al.* (1990). Concerning CO, HC, and FC, a reasonable correlation was found, and it could be seen that, in most cases, the increase in excess emission corresponded to a decrease in ambient temperature.

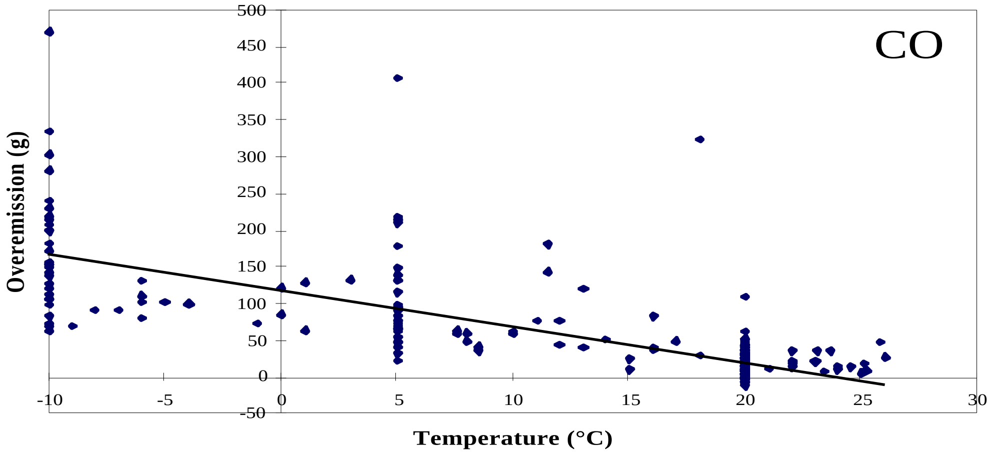

Figure 3: Excess emissions of CO (g) as a function of ambient temperature for gasoline cars with a catalyst. A point represents a data and the line the regression curve associated to these data.

Excess emissions as a function of distance travelled - So far, absolute excess emissions have only been modelled during the whole cold start period (i.e. over the distance required for the stabilisation of emissions). But if the distance travelled is lower than this cold start distance, excess emissions are lower. In order to determine the relationship between excess emissions and distance, the cold start distance d_c was calculated as a function of vehicle speed, technology, temperature and the studied pollutant [Joumard *et al.*, 1995b] . The distance travelled was then made dimensionless by dividing it by the calculated cold start distance, and the equation describing excess emissions was determined as a function of the distance travelled.

From the only three measurement points available, the functions were obtained by linear regression. Thus, if the travelled distance was higher than d_c then the excess emission was equal to the calculated one in previous sections. Otherwise, it was necessary to calculate the excess emission as a function of the distance travelled d, which had been made dimensionless by dividing it by the cold start distance d_c ($\delta = d/d_c$). We proposed one equation per pollutant and per vehicle technology.

3.1.4.3. Calculation method for light-duty vehicles

Using the aforementioned methods, the excess start emission for gasoline cars and for diesel cars without catalysts could be expressed in terms of the mean speed - f(V), the ambient temperature - g(T), and the travelled distance - h(δ). The parameters f and g could be combined by either multiplicative or additive extrapolation. The main drawback of multiplicative extrapolation is error multiplication. Additive extrapolation was therefore preferred so that the total errors were minimised. This assumption was necessary because no cross-distribution value for these two variables has been made available. The excess emission in g could then be expressed as:

$$\text{excess emission} = \omega\ [f(V) + g(T) - 1]\ h(\delta), \text{ with } h(\delta) = [1 - \exp(-a\ d/d_c(V))]/(1 - \exp(-a))$$

where f and g are undimensionalised by their values at 20 °C and 20 km/h, h is dimensionless and ω is the total reference excess emission (at 20 °C and 20 km/h) expressed in g.

For diesel cars equipped with an oxidation catalyst and light-duty vehicles, the model has been greatly simplified.

Excess emissions for trips starting with the engine at an intermediate temperature - The results of the DRIVE-MODEM and Hyzem studies [André *et al.*, 1999] showed that only 19% of trips are actually started with a completely cold engine (i.e. with the engine temperature equalling the ambient temperature), and about two fifths are started with the engine temperature lying between ambient temperature and the normal operational engine temperature (70°C). It has been assumed that excess emissions are not dependent on ambient temperature, but on engine temperature at start-up, or in other words that excess emissions for an intermediate engine temperature are equivalent to excess emissions from a completely cold start at an ambient temperature equalling the intermediate temperature. This amounts to considering that the parameter T above corresponds to engine temperature at start-up rather than to ambient temperature.

Inventory of cold-start-related excess emissions - In a number of cases (e.g. for some micro - scale inventories) assessing excess cold start emissions for a single trip is sufficient. However, most emission inventories require a calculation of cold start emissions for the whole traffic. The formula initially applied to a single trip must be extended to the whole traffic using the available statistical data relating to characteristic traffic parameters (see section 3.2.2). The proportion (in kilometres) of the distance travelled on trips started with a fully warmed-up engine (i.e. not including cold start emissions) must be determined. This percentage depends on the season and the global average speed [André *et al.*, 1999].

In a second step, only trips started under cold or intermediate engine temperature conditions were considered. The formula given above was applied to these trips. A relationship was established between the variables above and the input variables of the general emission model:

- average speed distribution under cold conditions versus overall average speed,
- distribution of engine start-up temperature (in number of trips) versus ambient temperature class,
- cold start trip distribution versus trip length. Such a distribution depends both on average speed with a cold engine and on the season.

Finally the traffic excess emission E_c for a given pollutant (in g) was calculated using:

$$E_c = \sum_i \left(tf_i \; \frac{cm(s, v_i)}{100} \; \omega_i \; \sum_j \sum_k \sum_m \left[\frac{p_j \; p_k \; p_m}{10^6 \; d_m} \left(f(V_j) + g(T_k) - 1 \right) \; h\left(\frac{d_m}{d_c(V_j)} \right) \right] \right)$$

where tf_i, v_i, i and s are external data, and other parameters correspond to model internal data:

tf_i	=	traffic flow for the studied vehicle type i (in km.veh)
v_i	=	traffic overall average speed for the studied vehicle type i (km/h)
i	=	vehicle type
s	=	season (winter, summer, middle)
cm (s, v_i)	=	percentage of mileage recorded under cold start or intermediate temperature conditions for season s and overall speed v_i (%)
ω_i	=	reference excess emission for vehicle type i (g)
j	=	speed class with a cold engine
k	=	class of start-up engine temperature
m	=	trip length class
p_j	=	percentage of the trips travelled at speed j with a cold engine, for the overall average speed considered (%)
p_k	=	percentage of the trips travelled with a start-up engine temperature T_k (%)
p_m	=	percentage of trips started with a cold engine and distance d_m, for speed V_j with a cold engine (%)
d_m	=	average distance of the trips under cold start conditions of class m (km)
V_j	=	average speed with a cold engine corresponding to class j (km/h)
T_k	=	average start-up temperature of class k (°C)

f, g, h and d_c are functions defined above.

3.1.4.4. Heavy goods vehicles and buses

There are very few relevant data for this type of vehicle. Nevertheless, it is possible to give a rough estimate of their excess emissions based on the analysis of results from tests on ten heavy duty engines using the US heavy-duty transient tests cycle [Kurtul & Graham, 1992]. Tests were carried out with a cold engine (approximately 20 °C start temperature) and repeated with a hot start. The coolant temperature was usually found to reach the hot start value around 600 - 800 seconds after a cold start. The total test duration was 1200 sec. It may therefore be assumed that the tests included the whole of the cold start period, and that the difference between the emission from the hot and cold tests gave a measure of the cold excess emission. Because the measurements only used one operating cycle and were only performed at one ambient temperature, it was not possible to determine whether the excess emission was affected by these parameters, as it is for passenger cars. The influence of the engine or vehicle size was calculated and only found to be systematic for CO_2 and NOx. The results of this exercise were excess emissions in grammes per cold start for the main regulated pollutants and the four classes of HGV used in the MEET classification system.

Due to the lack of operational data for HGVs, and the frequency of cold starts, it has been assumed that each vehicle makes, on average, just one cold start per day. This assumption is made on the basis that the commercial use of HGVs is likely to mean that they are started from cold at the beginning of each working day, and then used throughout the day without being stopped for long enough for their engines to cool down significantly.

Buses and coaches are powered by the same diesel engines as HGVs. The cold excess emissions may therefore be assumed to be the same as for HGVs of the same weight class. Whilst there are significant variation in the weights of buses and coaches, depending on their size and seating capacity, the most common weight class is probably 16 to 32 t. In the absence of precise information, it can again be assumed that each vehicle makes just one cold start per day.

3.1.4.5. Conclusion

This model can be applied on different geographic scales: on a macroscopic scale (national inventories) using road traffic indicators and temperature statistics, or on a microscopic scale for one vehicle and one trip. Where a model user cannot access the necessary statistics, it is recommended that statistics recorded at national level are integrated into the model in order to further the model use and obtain a national average excess emission directly.

In the future, this model could be improved by using new data as soon as it becomes available, by considering crossed distributions for different speeds and ambient temperatures, and by considering intermediate engine temperatures - i.e. when engine start temperature does not correspond to ambient temperature ("cool starts").

3.1.5. Evaporative emissions

By Zissis Samaras and Rudolf C. Rijkeboer

Evaporative emissions occur as a result of fuel volatility combined with the variation in the ambient temperature during a 24-hour period or the temperature changes in the vehicle's fuel system which occur during normal driving.

In general there are four types of evaporative losses:

- Filling losses occur when the vehicle's fuel tank is filled and the contents of saturated vapours are displaced and usually vented to the atmosphere.
- Diurnal breathing losses are the result of the night-day temperature cycle, causing the contents of the fuel tank to expand, pushing saturated vapour out on expansion.
- Hot soak losses occur when a vehicle is switched off and the equalisation of the temperatures leads to the evaporation of the fuel in certain parts of the engine.
- Running losses. These evaporative losses occur during the operation of the vehicle.

Filling losses are usually attributed to the fuel handling chain and not to the vehicle emissions. They are not covered by this study. Hot soak and diurnal losses constitute the main part of evaporative losses. In newer vehicles these losses should largely be captured by vapour traps (carbon canisters). Depending on the temperature of the engine at switch off, one can differentiate between warm-soak and hot-soak losses. For a short period plastic fuel tanks were introduced. However, these suffered from diffusion of fuel through the plastic, and in later years covered plastics (so called "sealed" plastic tanks) were used for fuel tanks to counteract this effect. Running losses are the least documented source of evaporative emissions. On cars equipped with carbon canisters the canister should capture any running losses but there are reports which show that running losses would occur nevertheless. On vehicles without carbon canisters running losses are a reality, but little is known about such cases. Evaporative losses from vehicles are known to depend on four major factors:

- vehicle technology (equipped with or not with carbon canisters)
- ambient temperature and its diurnal variation
- gasoline volatility (depending on the temperature variation)
- driving conditions (average trip length, parking time etc.)

The effects of these factors on evaporative emissions were the subject of a number of research studies. The first study at European level was carried out by CONCAWE in 1985. The results from this project formed the basis of a more sophisticated methodology developed in the framework of CORINAIR. An updated methodology was proposed in 1990 by CONCAWE [McArragher *et al.*, 1987; Concawe 1988, 1990] and was incorporated in the CORINAIR methodology of 1993 [Eggleston *et al.*, 1993] and included in the COPERT programme. A methodology was also developed by RWTÜV [1993] based on a specifically designed test programme and was included in the German/Swiss Emission Factor Handbook [Infras, 1995].

Another methodology, called MOBILE 5a [USEPA, 1991], was also developed by the U.S. Environmental Protection Agency. MOBILE incorporates a more detailed procedure for the estimation of evaporative losses. Nevertheless, this methodology was developed taking into account all special characteristics of the vehicle fleet of the United States and requires a number of appropriate modifications for its application in European conditions.

3.1.5.1. Comparison between the CORINAIR, CONCAWE and German/Swiss methodologies

Table 2 summarises the options available in the three methods for estimating evaporative emissions. CORINAIR distinguishes between warm and hot (concerning soak and running losses) emissions, and provides appropriate equations for the estimation of all types of evaporative emissions. CONCAWE provides more aggregated expressions than CORINAIR for the estimation of hot soak and running losses. Finally, RWTÜV for the estimation of diurnal and hot soak emissions, takes into account regional driving and climatic characteristics.

Table 2: Proposed options in evaporative emission estimation.

Motor Vehicle Evaporative Losses	Methodologies		
	CORINAIR	CONCAWE	RWTÜV
Diurnal	✓	✗	✓
Hot Soak	✓	✓	✓
Warm Soak	✓	✗	✓
Hot Running	✓	✓	✗
Warm Running	✓	✗	✗

(✓ = calculation method available, ✗ = calculation method not available)

Since the CONCAWE and CORINAIR methods are very similar, the comparison was just performed between CORINAIR and German/Swiss Handbook. This showed that:

- The estimated total evaporative emissions do not vary significantly, especially, when CORINAIR running losses are left out. Nevertheless, significant differences are observed between the specified evaporative emissions types, especially where the variation of fuel volatility affects the evaporative emissions (CORINAIR method) in contrast with RWTÜV, in which the Reid vapour pressure (RVP) does not (directly) influence the emission estimation.

- The efficiency of the evaporative control system in all cases varies between 90% and 99% except in the cases of diurnal emissions estimated according to the CORINAIR method, where an 80% efficiency of the carbon canister is introduced.

In order to understand the differences between the three methods, it has to be stressed that:

- CORINAIR methodology enables the estimation of diurnal, hot soak and running evaporative losses, while CONCAWE provides appropriate expressions for hot soak and running losses calculations and RWTÜV for diurnal and hot soak emissions.
- The evaporation control system exercises the most important influence on evaporative emissions. The evaporative control system efficiency depends on fuel properties or ambient temperature variation (CORINAIR and CONCAWE hot soak emissions, RWTÜV diurnal losses), or on driving conditions (RWTÜV hot soak emissions) or an overall control system efficiency is assumed irrespective of RVP or temperature properties (CORINAIR diurnal and running losses).
- CORINAIR provides the same expressions as CONCAWE for hot soak and running losses. CORINAIR also provides a separate expression for warm soak losses. The only difference is that running losses in CORINAIR are a linear function of mileage, whilst CONCAWE uses a constant daily rate based on average driving conditions.
- In the CORINAIR and CONCAWE methods the basic parameters are fuel volatility and daily variation of ambient temperature, while RWTÜV provides a driving conditions dependent expression with no obvious connection to fuel or climatic properties. Furthermore, the RWTÜV method is modified for the evaporative emission estimation for Germany and several parameters (e.g. the correction factors k_n and k_f, describing seasonal and operational influences) are not directly available or easy to estimate.
- The estimation of hot soak emissions according to the RWTÜV method requires a large number of modified data (frequency distribution of trip length and parking time), while the use of average trip lengths and parking times, which the RWTÜV method was not designed for, leads to a significant overestimation of hot soak emissions. Furthermore, the expressions provided by RWTÜV do not normally respond to the boundary values of their parameters (parking time, daily ambient temperature changes).

3.1.5.2. Comparison between the calculated emissions and measured data

A number of actual tests were performed by TRL. The resulting figures were compared to the calculated values according to CORINAIR and RWTÜV reports. The results show a wide dispersion of measured data. The resulting average figure for the hot soak losses (uncontrolled situation) did, however, agree with the calculations. The resulting average figure for the diurnal emissions (equally the uncontrolled situation) showed a significant discrepancy relative to the calculated figures, by a factor of about 4 relative to the CORINAIR figure and a factor of about 1.5 relative to the RWTÜV figure. There are no measured data concerning controlled cars, however.

3.1.5.3. Proposal for the selection of an appropriate methodology

The following conclusions have been drawn:

- There are significant differences between various models in the estimated evaporative emissions of each type; all models, however, lead to emission factors of the same order of magnitude - and this is valid for the MOBILE 5a emission factors too.
- There were significant differences between the various models in the estimation of the different types of evaporative emission. However, all models, including MOBILE 5a, produced emission factors that were of the same order of magnitude.
- When it came to total evaporative emissions, individual differences between the models were eliminated. The aggregated results of CORINAIR and RWTÜV were similar, particularly for emissions from controlled cars. This is important because uncontrolled vehicles are continuously being phased out.
- RWTÜV may be more suitable for the estimation of spatially and temporally disaggregated emissions, because it makes use of detailed "microscale" data (distribution of trip length and parking time).
- RWTÜV does not account for running losses, which are not negligible and must therefore be included in the calculation procedure to be adopted by MEET.
- The CORINAIR method is transparent, whereas that of RWTÜV has some uncertain points (e.g.: How is the correction factor for diurnal emissions defined? Which are the actual values of the correction factor for hot soak losses?).
- Finally, there is no method that is based on a comprehensive experimental data set (which would be the most important advantage of a calculation procedure). This is further demonstrated by the comparison of experimental data from TRL, which are greatly dispersed among different vehicles, with the calculations of CORINAIR and RWTÜV.

Taking into account the above considerations, it seems reasonable to propose to use the CORINAIR methodology for estimation of evaporative emissions in the framework of MEET (see [Samaras *et al*., 1997] for a more detailed approach).

3.1.6. Gradient influence for light-duty and heavy-duty vehicles

by Dieter Hassel and Franz-Josef Weber

See [Hassel & Weber, 1997] for a more detailed approach.

The gradient of a road has the effect of increasing or decreasing the resistance of a vehicle to traction. As has been shown during the development of emission functions, the power employed during the driving operation is the decisive parameter for the pollution emission of a vehicle. Even in the case of large-scale considerations, however, it cannot be assumed that - for example - extra emissions when travelling uphill are balanced by a corresponding reduction in emissions when travelling downhill.

Because of the higher vehicle mass the gradient influence is even more important for heavy duty vehicles. Within the frame of the German Emission Factor Programme methods have been developed for the calculation of emission factors for gradient classes. The methods are different for light and heavy duty vehicles and will be described in the following chapters.

For light duty vehicles a special test programme was carried out on the exhaust gas stand of the Rhineland TÜV. In the so called basic test programme the emission measurements were based on the following cycles:

- New European Driving Cycle
- US FTP 75
- US Highway Driving Cycle
- Special German Autobahn Cycle

Taking account of the gradients usually encountered in the Swiss and German road networks, it was decided to undertake the emission measurements for gradient classes of -6%, -4%, -2%, 0%, 2%, 4% and 6%, where the numbers given designate the centre of the class in each case. The traction resistance line simulated by the roller-type test stand is displaced in parallel to correspond with the specified gradients.

In the case of slight gradients - in the range between -2% and 2% - it can be assumed with sufficient accuracy that these do not affect the driving behaviour. In the case of steeper gradients, this assumption is no longer permissible. For this reason, special surveys have been undertaken in Switzerland on sections whose gradient is within the classes from ±4% and ±6%. So special driving patterns could be derived for gradients beyond +2 % resp. -2 %.

The measurements were based on nine passenger cars with 3 way-catalyst and controlled air/fuel mixture, three conventional spark-ignition passenger, cars and three diesel passenger cars.

Emission factors for the gradient classes were calculated by multiplication of a gradient factor with an emission factor for gradient class 0 %.

The gradient factor is an emission ratio. The gradient factors for the pollutant components and fuel consumption were calculated for the vehicle concepts investigated as a function of the gradient classes and the average vehicle speed of all the driving patterns and speed classes for uphill and downhill sections.

The development of the emission and consumption functions for heavy duty vehicles is described in detail in the final report of the German Emission Factor Programme [Hassel *et al.*, 1994]. The parameters of the function are L_{WR} which is the power for overcoming the wind, rolling, and gradient resistance and L_B which is the power for overcoming the inertia of the mass during acceleration. In contrast to the parameters of the functions for the passenger cars the parameters of the function for heavy duty vehicles include gradient resistance according to the equation for L_{WR}:

$$L_{WR} = \left[\frac{\rho}{2}\, c_w\, A\, v^2 + m\, g\, (f_r + \sin\alpha)\right] v$$

where

ρ = air density
c_w = drag coefficient
A = cross sectional area of vehicle
g = acceleration due to gravity
f_r = coefficient of rolling friction
α = gradient angle

The heavy-duty vehicle fleet is analogous to the passenger car fleet in that it can be divided into layers (strata). The definition of the layers takes into account for each heavy duty vehicle category the following parameters:

- vehicle mass,
- body style,
- model year.

Layer-specific emission factors were calculated by using the appropriate emission function and the L_B and L_{WR} distribution functions of different driving patterns. These distribution function were derived for all vehicles in a layer. Using the equation of motion and the vehicle data sets, the driving patterns were transformed into L_B and L_{WR}-distribution functions. The emission factors of each single vehicle in a layer were combined unweighted for the emission factor of the layer.

The layer-specific emission factors were obtained for six road categories. Each category was divided into four types of traffic flow condition, and each of these conditions was split into five classes of gradient with two different load factors per gradient class. The set of layer-specific emission factors for the heavy-duty vehicle fleet consisted of about 5200 data per component.

As described earlier, the gradient factors were derived for Swiss and German driving patterns which are representative of special traffic situations on different road categories. Where information on detailed driving behaviour is not available, gradient factors can only be calculated on the basis of the mean speed.

For light-duty vehicles it is possible to use these gradient factors in connection with country-specific emission factors. The minimum information needed for local emission assessments is the composition of the vehicle flow, the mean gradient of the road, and the mean vehicle speed.

For heavy-duty vehicles the Swiss and German model for the calculation of emission factors includes the gradient influence, so that no special gradient factors have to be derived. Nevertheless, it is possible to determine gradient factors by calculating the ratios of the emission factors at different gradients referring to gradient class 0 %. Thus, gradient factors can be determined on the basis of the mean speed alone. Local emission assessments than can be done in the same way as for passenger vehicles.

As the mean speeds in different countries, and for different road categories, may be different, one option for representing the gradient factors is to conduct a regression analysis on the basis of the emission data from the German work-book. The mean speed of several driving patterns is not identical for the different gradient classes and for level terrain. By means of the following method it is possible to formulate general relationships for the gradient factors:

- regression analysis for level terrain, so that emissions on level terrain can be calculated for every speed of the driving patterns on different gradients
- calculation of the emission ratio for each driving pattern in relation to the emission at gradient 0 %
- regression analysis for each gradient class, based on the calculated emission ratios

Due to the regression analysis there will be a certain smoothing of the ratios, though this can be neglected.

3.1.7. Hot emission factors for heavy duty vehicles

by John Hickman

Only relatively few data are available on emissions from heavy duty vehicles, and it is not therefore possible to derive emission factors to the same level of detail as for passenger cars. Compared with cars and light goods vehicles, heavy duty vehicles are more diverse in some ways: they include a large range of weights and sizes (from 3.5 tonnes gross weight to around 40 tonnes in most EU countries, but as much as 60 tonnes in some), and their operations range from very disrupted trips (such as refuse collection and urban bus journeys) to high speed transport of goods and passengers on long motorway journeys. In other respects, though, there is less variation: almost all heavy duty vehicles use diesel engines and the history of their emission control standards is shorter than for light duty vehicles, so there is less diversity of engine and emission control technology.

The European type approval test for this class of vehicle is based on the engine's performance, and not the whole vehicle. It involves the measurement of emissions under 13 steady-state operating conditions defined in terms of the speed and load of the engine, and many of the available emission data have been measured in that way. This has prompted the development of procedures by which emission factors representing the on-road performance of a vehicle may be derived from the steady-state engine emissions, some aspects of the vehicle's specification and some representation of the on-road conditions to be simulated. Models have been developed by TNO and TU Graz and are summarised in [Cost, 1996].

The most recent thorough compilation of emission factors is that presented in the Swiss/German handbook of road traffic emission factors [Infras, 1995]. The Workbook provides emission factors for all types of vehicle, including heavy lorries and buses, for a variety of driving patterns. Other features taken into account are the road gradient and, for heavy goods vehicles, the load state of the vehicle. These factors are more important in the case of heavy duty vehicles because the load carried by a lorry, as a proportion of the total weight of the vehicle is much greater than for light duty vehicles, and their low power to weight ratios make the effect of the road gradient significant. In the Workbook, both heavy goods vehicles and buses are subdivided into a number of classes according to their weight. The emission factors were derived using data from engine test-bed measurements that provided emission data for thirty steady-state engine conditions; the influence of the dynamic driving behaviour has been taken into account by empirically derived correction functions [Hassel, 1995].

The emission factors from the Workbook have been compared with data derived from vehicle-based measurements performed by TRL in the early 1990s, and with the two emission models, developed by TNO and the TU Graz. The comparisons in each case showed an acceptable level of agreement, bearing in mind that each of the data sets is based on limited measurements on different samples of engines and vehicles and following different experimental procedures. The comparison is described in more detail in the corresponding MEET report [Hickman, 1997]. Because of their comprehensiveness and because their general level of accuracy was largely confirmed through the comparisons, the factors from the Workbook have been used as the basis for the derivation of average speed related emission functions, with correction factors for the vehicle load and gradient. These functions apply only to heavy duty vehicles manufactured before the introduction of EC directive 91/542/EEC

(EURO I). No experimental data were available for more modern vehicles, so their emissions are estimated by applying reduction factors to the pre-EURO I factors (see Section 3.1.9).

3.1.7.1. Basic speed-emission functions

The Workbook provides emission factors for each of a number of discreet, pre-defined driving patterns. However, when they are displayed as a function of the average speed of each of the driving patterns, the emission factors tend for the most part to fall on a reasonably smooth curve (see, for example Figure 4). It was therefore possible to generalise the Swiss/German emission factors as continuous functions depending on the average vehicle speed.

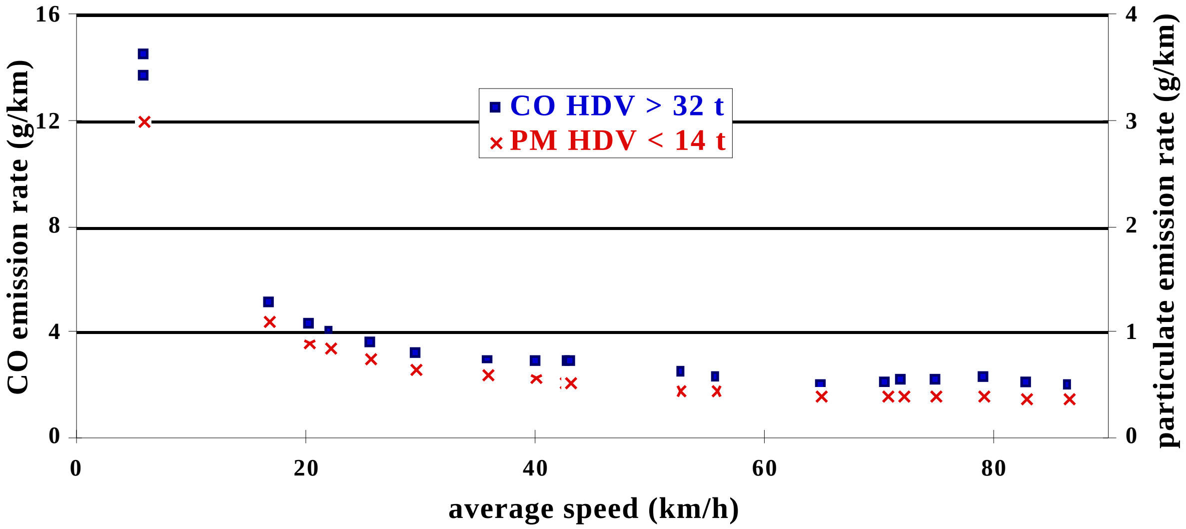

Figure 4: Examples of emission factors from the Swiss/German Workbook plotted as a function of average vehicle speed.

The functions were derived by statistically fitting the data to curves of the form:

$$\varepsilon = K + av + bv^2 + cv^3 + \frac{d}{v} + \frac{e}{v^2} + \frac{f}{v^3}$$

where:

- ε is the rate of emission in g/km for an unloaded goods vehicle, or for a bus or coach carrying a mean load, on a road with a gradient of 0%
- K is a constant
- a - f are coefficients
- v is the mean velocity of the vehicle in km/h

The procedure that was used was able to determine the statistical significance of each of the terms in the equation, and in many cases only a few of them were needed to give a close fit to the data, resulting in zero values for a number of the coefficients (*a* - *f*). Equations were derived for four classes of heavy goods vehicle (3.5 to 7.5 tonnes, 7.5 to 16 tonnes, 16 to 32 tonnes and 32 to 40 tonnes) for urban buses and for coaches. The pollutants considered were carbon monoxide, carbon dioxide, hydrocarbons, oxides of nitrogen and particulates. For heavy goods vehicles, the equations give emission rates for vehicles with no load, and travelling on a road with zero gradient. For coaches and urban buses, the emissions are also for roads with zero gradient, but for vehicles with a medium load. Correction factors for load (HGVs) and gradient (all classes) may be applied for other situations, and are described below.

For situations other than the base case (no load, zero gradient for goods vehicles and mean load, no gradient for buses and coaches) corrections factors may be applied to the standard functions so that:

$$\varepsilon_{\lambda\gamma} = \varepsilon \times \Phi(\lambda) \times \Psi(\gamma, s)$$

where:

$\varepsilon_{\lambda,\gamma}$	is the emission rate corrected for the load (λ) and the gradient (γ)
ε	is the base emission factor
$\Phi(\lambda)$	is the load correction function
$\Psi(\gamma,s)$	is the gradient correction function

3.1.7.2. Correction factor functions for gradient

Hassel and Weber (1997) provide gradient factor functions of the following form (see also section 3.1.6):

$$\Psi(\gamma, s) = gv^6 + hv^5 + iv^4 + jv^3 + kv^2 + lv + m$$

where:

$\Psi(\gamma,s)$	is the correction factor for gradient class *s*
g - m	are coefficients
v	is the mean velocity of the vehicle in km/h

These functions are given for gradient classes of 2%, 4%, 6%, -2%, -4% and -6%, and for the same vehicle size and type classifications as the basic speed-emission functions.

3.1.7.3. Correction factor functions for load

Load correction factor functions ($\Phi(\lambda)$) are of the form:

$$\Phi(\lambda) = \kappa + n\gamma + p\gamma^2 + q\gamma^3 + rv + sv^2 + tv^3 + \frac{u}{v}$$

where:

$\Phi(\lambda)$	is the load correction factor
κ	is a constant
n - u	are coefficients
γ	is the gradient in percent
v	is the mean velocity of the vehicle in km/h

The functions provide factors by which the base emission rate (zero load) may be corrected to that for a fully loaded vehicle. Data for intermediate load states are not available, but if necessary, it may be assumed that the emission rate varies linearly between the zero and full load values.

3.1.7.4. Validity of the functions

The emission functions, and those for the load and gradient correction factors are in some cases rather complex, and it is important that they should not be extrapolated beyond the ranges of the variables from which they were derived. For example, some of the emission functions for urban buses give negative results if they are used in the high speed range. The functions are, however, valid for most, if not all, of the normal operating conditions encountered by these types of vehicle (again taking the example of urban buses, they do not normally travel at high speeds, so the performance of the functions at high speeds is unimportant). In general, the emission functions for heavy goods vehicles are valid over a speed range from 5 to 85 km/h, those for coaches are valid between 5 and 100 km/h and those for urban buses between 5 and 40 km/h. The range of gradients for which the functions are valid is, in all cases from -6% to +6%. In recognition that vehicles will travel more slowly on roads with steep gradients, the valid speed ranges reduce as the gradient (positive or negative) increases.

3.1.8. Emission factors for mopeds and motorcycles

by Rudolf C. Rijkeboer

See the full report for a more detailed analysis [Rijkeboer, 1997].

3.1.8.1. Mopeds

For mopeds there is an ECE Regulation (ECE R47), valid since 1981. But not all Member States of the European Union have adopted this Regulation. Switzerland has a more stringent legislation, known as FAV 4, valid since 1988. Austria has a similar legislation. For the European Union more stringent limits are planned, but not yet valid. The emission factors have been determined for the following stages:

- Unregulated
- According to ECE 47
- According to FAV 4

The emission factors for the unregulated mopeds are based on the CORINAIR figures of 1989, modified on the basis of TNO in-house experience. The exact values are difficult to establish, however, since this category of vehicle is subject to a large degree of do-it-yourself maintenance and modifications ("tuning") which obviously influences the emission behaviour. Real data are scarce and the figures given should be assumed to indicate the general order of magnitude, with a large degree of uncertainty as to their actual value.

The emission factors of the regulated mopeds have been derived from a Swiss-German investigation [Keller *et al.*, 1995]. These data are somewhat better based than those of the unregulated vehicles, but the sample measured was still small and the degree of uncertainty still substantial. Also, depending on the country concerned, there may be a large degree of "tuning" performed in the field. According to in-house experience at TNO this may especially influence the emission of HC, which may increase as much as an order of magnitude when exhaust systems are changed.

The figures given for the emissions of mopeds are speed-independent figures, since it is assumed that the use of mopeds is influenced very little by the traffic or the environment in which it is operated, and as a rule it is almost always operated to its maximum capabilities. So there seemed little point in a differentiation between different operating conditions, even if there had been information available.

3.1.8.2Motorcycles

With regard to motorcycles the only source of information found was the Swiss-German investigation mentioned above [Keller *et al.*, 1995]. A significant problem with motorcycles is the large variety in vehicles in terms of mass, power, configuration (motorcycle / motorscooter, off/on-road), working principle (2/4-stroke), etc. The report concerns 24 different vehicles divided over 6 different categories, which still makes for an average of only 4 vehicles per category.

The legislative situation is similar to that with mopeds. There is an ECE Regulation (ECE R40) valid since 1979, amended in 1988. There is a Swiss national legislation, known as FAV 3, and there is an EU proposal. Since the exhaust gas limits for ECE R40-00 and even for ECE R40-01 were not in any way restrictive, most countries have not adopted this legislation. The motorcycles have therefore been divided into two categories only:

- Unregulated
- FAV

The category unregulated has been subdivided into

- 2-stroke
- 4-stroke < 250 cm^3
- 4-stroke 250 - 750 cm^3
- 4-stroke > 750 cm^3

The category FAV has been subdivided into:

- 2-stroke (< 125 cm^3)
- 4-stroke (> 125 cm^3)

The data measured in the Swiss-German programme were related to a small number of standard driving cycles and some constant speeds under motorway conditions. By splitting the cycles into their constituent parts a number of points with different average speeds were created. Together with the constant speeds, 10 speed points per vehicle were obtained (8 for the smaller 2-strokes), ranging from about 20 to 140 km/h (110 km/h for the 2-strokes). As stated earlier, existing driving cycles were used. These cycles were actually derived for cars. No attempt was made to measure the vehicles under driving conditions that would be more representative for actual motorcycle use, since no operational information is yet available. This will probably mean that the figures given will underestimate the real emissions from motorcycles. For the moment there is nothing that can be done about this.

So that the data could be handled more easily during calculations, trends have been fitted to the data points. Second order polynomials were fitted to the speed ranges 20 - 60 km/h and 60 - 140 (110) km/h respectively. In the case of Nox emissions this procedure produced ambiguous results. Because of the small number of vehicles per class, and the peculiar behaviour of some individual vehicles, the calculated trends of different classes overlapped in an illogical way. In this case an average shape of the general trend was therefore determined and combined with the average level of each class in order to determine the actual trends per class.

3.1.9. Alternative fuels and future technologies

by Zissis Samaras, Robert Coffey and Franz-Josef Weber

This section considers alternatives to current technologies and fuels as well as those being developed for the future, including the near future. It looks at the emissions factors for these technologies and fuels and considers those most likely to emerge.

3.1.9.1. Near future fuels and vehicles

Improved fuels

New fuels (both gasoline and diesel) that are likely to reduce emissions are expected to appear on the market by the turn of the century. Additional legislation will also come into force by the year 2005, with stricter specifications for the conventional market fuels. However, for the calculation of the effects of these improved fuels on exhaust and evaporative losses, few data exist. These data are to be found in the results of the EPEFE [Acea and Europia, 1996] programme and the evaluation of the American Auto/Oil activities conducted by the first working group of the European Auto/Oil programme [Acea *et al.*, 1995]. Despite the fact that these data refer exclusively to new and well tuned engines and emission control systems, they can be used as an indicator of the expected effects on the emissions of actual vehicles.

The improved market fuels of the near future will have the following characteristics: for gasoline reduced lead, sulphur content, aromatics, benzene, olefins, Reid vapour pressure, and increased oxygenates, mid range and tail end volatility; for diesel reduced sulphur content, polyaromatics, back end distillation, and increased cetane number. The effects of a change of each of these properties are deduced from the aforementioned studies and presented in [Hickman *et al.*, 1999].

Near future vehicle categories

The assessment of the emission factors of the near future vehicle categories is possible if the future emissions standards are known. This is the case for passenger cars, light and heavy duty vehicles, but not for two-wheel vehicles.

For passenger cars and light duty vehicles, in order to comply with the standards the automotive manufacturers can either reduce the hot emission level or the cold start excess emission, or both. Therefore our intention is to assess reduction rates for both hot emission factors and cold start excess emissions from a reference standard to a future one. The method used consists of 3 steps:

- Calculation of an average hot emission factor for the driving cycles ECE15 and EUDC, and an average cold excess emission for the ECE 15, for each pollutant and each vehicle technology complying with the reference standard. As the emission factors given in sections 3.1.3 and 3.1.4 concern EURO 1 vehicles, EURO 1 is the first reference standard considered. The data bases of the Swiss/German emission factor programme [Hassel *et al.*, 1994; Infras, 1995] and of the Inspection / Maintenance project [Samaras *et al.*, 1998b] of the European Commission were used.
- Application of the hot emission factor and the cold excess emission a priori specific reduction rates. Thus new emission factors over the whole NEDC were produced, corresponding to the vehicles complying with the future standard.

- Calculation of the overall reduction rate of the emission factors over the NEDC for vehicles complying with the reference standard and those complying with the future one. This reduction rate was then compared with the reduction rate of the emission standards themselves as they appear in the legislation. In order that the distance to the standard remained constant, when the two rates were different, the a priori specific reduction rates were proportionally modified into the final specific reduction rates.

A very specific case is the assessment of reduction rates for EURO 3 vehicles, since the test procedure will be modified. To account for this modification, which will result in an increase in emissions, an additional step was used. Firstly, new emission factors for the modified procedure for the vehicles complying with EURO 2 were calculated on the basis of the EC directive for future emission standards. For comparative reasons this directive contains corrected EURO 2 standard levels for the modified test procedure. Assuming that the difference between the standards relates to an additional excess emission in the cold phase, the EURO 2 excess emissions for cold start were increased. Then the corrected EURO 2 standard levels were taken into account instead of the real ones for the calculation of the reduction rates between vehicles complying with EURO 2 and EURO 3.

This way, the reduction percentages of the emission level which can be achieved by introduction of future steps of legislation were calculated [Samaras *et al.*, 1998c]. Some of them are presented Figure 5.

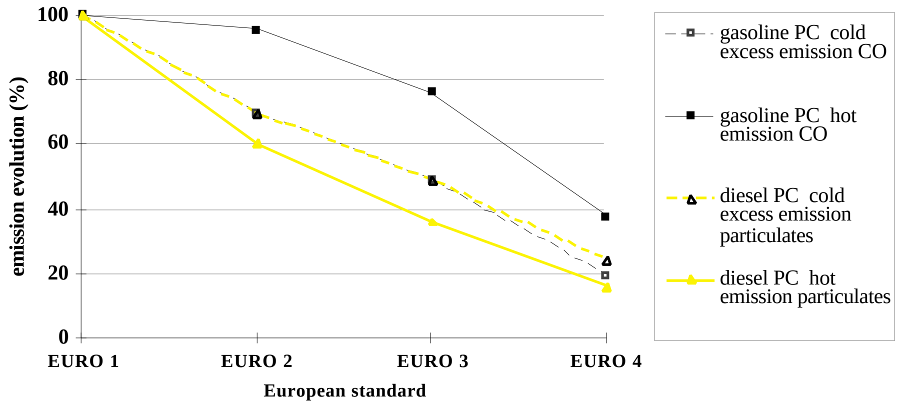

Figure 5: Proposed evolution of some emission factors for the near future passenger cars.

For heavy duty vehicles and buses, the basic emission factors (see section 3.1.7) apply to EURO 0 vehicles. By analogy to the passenger vehicles reduction factors have to be derived in such a way as to follow the evolution of the standard levels. Firstly, average values of the emission factors of the 13 mode test were evaluated from available measurements. This allowed us to assess firstly the reduction rates from EURO 0 to EURO 1 vehicles by comparing the above calculated emission factors with EURO 1 standard levels, and then the reduction rates corresponding to the future standards. The reduction rates between the standards levels are not automatically translated into reductions in the emission factors: in some cases different reduction rates were assumed because of the foreseen technology evolution, or for other reasons. The proposed reduction rates are presented in [Hickman *et al.*, 1999].

3.1.9.2. Alternative fuels

An area that shows an important potential for the reduction of emissions from engines (in particular diesel engines) is the use of alternative fuels. The following alternative fuels were considered:

Natural gas

One fuel proposed is natural gas (NG), most commonly in the compressed form (CNG) but also liquefied (LNG). Its use was demonstrated on both gasoline (light-duty applications) and diesel engines (both light and heavy duty applications). Especially as regards heavy-duty diesel engines, NG requires the replacement of the diesel with a spark ignition gas engine. Gas engines can run either with a three-way catalytic converter (TWC) or in the lean burn mode

Alcohols

Alcohols, such as methanol and ethanol are widely promoted as 'clean fuels', as they have many desirable combustion and emission characteristics, including good lean burn combustion characteristics, low flame temperature. With an octane number of 110+ and excellent lean combustion properties, methanol and ethanol are good fuels for lean-burn Otto-cycle engines. Due to cold starting problems, pure alcohols are not suitable for automotive use; blends of up to 85% methanol (M85) or ethanol (E85) are used instead. These fuels are not well suited as diesel fuels, and require the use of specially designed engines or the addition of expensive ignition improvers. Methanol can be produced from natural gas, crude oil, biomass, and urban refuse. Ethanol can be produced by processing agriculture crops such as sugar cane or corn.

Dimethyl ether (DME)

Partially oxygenated hydrocarbons produced from natural gas have been shown to be viable alternative fuels for the diesel engine, showing favourable combustion characteristics, similar to that of diesel fuel. Dimethyl ether (DME) has recently emerged as an attractive alternative for diesel engines. DME can be made from a wide variety of fossil feedstock, among which natural gas and coal, and from renewable feedstock and waste. DME is currently produced in smaller quantities, primarily as a cosmetic propellant.

Biodiesels

Biodiesel is defined as the mono alkyl esters of long chain fatty acids derived from renewable lipid feedstock, such as vegetable oils and animal fats, for use in compression ignition (diesel) engines. Many vegetable oils and animal fats have been suggested and investigated as diesel fuel substitutes. They are renewable energy sources and, as such, have been supported by several pieces of legislation and government sponsored initiatives in the USA and in Europe. These oils are converted into methyl esters, before they are used as diesel fuel. Biodiesels, which are currently under investigation, include rapeseed oil methyl ester (RME) and soy methyl ester (SME).

Liquefied petroleum gas (LPG)

Data for light duty applications already exist in section 3.1.3. LPG has also been used in bus applications with similar benefits as with natural gas, but its efficiency is even lower than that of natural gas engines.

The literature survey [Samaras *et al.*, 1998c] concluded to the summaries presented in Table 3 and Table 4. Table 3 presents an overview of the main advantages and disadvantages of the alternative fuels. Table 4 shows the effects on the regulated emissions as reported in the literature.

Table 3: Advantages and disadvantages of alternative fuels.

Alternative fuel	Advantages	Disadvantages
Natural gas	· Very low particulate emissions compared to diesel · Low NOx emissions compared to advanced diesel engines · Zero sulphate and SO_2 emission	· More complex refuelling system · 4 times larger tank size requirement · Engine efficiency in bus operation is approximately 20 % lower than that of the diesel engine · Lean burn NG engines often have problems with methane emissions, but at very low NOx emission levels.
Alcohols	· High octane number · Low NOx emissions · Zero sulphate and SO_2 emission · Low evaporative losses	· Cold start problems · Increased aldehydes · More corrosive than hydrocarbons · Larger fuel tanks · Safety and handling problems
Dimethyl ether	· Little modification to the diesel engine required · Very low particle emissions · Zero sulphate and SO_2 emission · Lower engine noise · Low NOx levels without after-treatment	· Lower viscosity · The injection system needs to be developed
Biodiesel	· Higher cetane number · Good lubricity · Zero sulphate and SO_2 emission · Particulates of lower toxicity (same mass emissions)	· Their corrosion properties · Lower heating value · Higher freezing point · Increased NOx emission · Increased odour

3.1.9.3. Emissions factors for new technology vehicles

The following new vehicle categories have been introduced by this report:

- Electric vehicles (EVs): - Passenger car,
  - Light Duty Vehicle
- Hybrid electric vehicles (HEVs): - Gasoline passenger car,
  - Light Duty Vehicle
- Fuel cell electric vehicles (FCEVs): - Methanol passenger Car,
  - Light Duty Vehicle,
  - Urban Bus

To help understand the factors that have been given in the report, the emissions have been calculated and compared for each new technology passenger car. Where possible this has been done over two speed ranges, assuming an average vehicle weight of 1.5 tonnes. The values calculated here could be used as simplified emissions factors. However, for the original factors and a full description of the methodology and assumptions one must refer to [Samaras *et al.*, 1998c].

Table 4: Effects of alternative fuels on the regulated emissions. In parentheses the range of scale factors is indicated as ratio of the emissions with the alternative fuel over the emissions with the conventional fuel.

alternative over conventional fuels	vehic. type	CO	HC	NOx	PM
NG over gasoline	TWC LDV	Decrease (0.4 - 0.5)	Increase (1.5 - 2.0)	Decrease (0.4 - 0.6)	n/a
NG over diesel	HDV(1)	Decrease (0.1 - 1.0)	Increase (0.2 - 6.0)	Decrease (0.1 - 1.0)	Decrease (0.05 - 0.2)
Methanol over gasoline	TWC LDV	No change (0.7 - 0.9)(2)	Decrease (0.7 - 0.8)(2)	Decrease (0.8 - 1.0)(2)	n/a
Ethanol over gasoline	TWC LDV	No change (0.4 - 1.4)(2)	Increase (1.0 - 1.3)(2)	Decrease (0.4 - 1.0)(2)	n/a
Methanol over diesel	HDV	No change (0.8 - 3.0)(2)	No change (0.6 - 3.0)(2)	Decrease (0.2 - 0.4)	Decrease (0.2 - 0.6)
Ethanol over diesel	HDV	Increase (1.1 - 1.3)(2)	No change (0.7 - 1.5)(2)	Decrease (0.87 - 0.9)	Decrease (0.2 - 0.6)
DME over diesel	HDV	n/a	n/a	Decrease (0.2 - 0.5)	Decrease (0.05 - 0.3)
Biodiesel over diesel	HDV	Decrease (0.75 - 0.8)	Decrease (0.2 - 0.8)	Increase (1.1 - 1.2)	No change (0.6 - 1.2)

(1) Range reflects operating principle (lean burn or stoichiometric)
(2) A much larger scatter is indicated by the U.S. data

Table 5: Vehicle emission factors from new technology vehicles in g/km., with the spread of data for the HEV.

	HEV	FCEV	EURO I gasoline car <1.4 l	
speed range	20-100 km/h	20-100 km/h	20-50 km/h	50-100 km/h
CO_2	112 ±31	113	175	120
CO	0.17 ±0.12	0.00	3.00	1.00
NOx	0.02 ±0.01	0.00	0.30	0.40
HC	0.01 ±0.01	0.00	0.25	0.10

Table 6: Full energy cycle emission factors for new technology vehicles: average factor and spread of data in g/km.

	Electric Vehicles		Hybrid Electric Vehicles	Fuel Cell Electric Vehicles	
speed range	20-50 km/h	50-100 km/h	20-100 km/h	20-50 km/h	50-100 km/h
CO_2	122 ±55	94 ±39	126 ±34	150 ±17	140 ±10
CO	0.02 ±0.01	0.02 ±0.01	0.17 ±0.12	0.04 ±0.02	0.03 ±0.01
NOx	0.31 ±0.14	0.24 ±0.10	0.09 ±0.03	0.16 ±0.07	0.12 ±0.04
HC	0.29 ±0.13	0.05 ±0.02	0.13 ±0.04	0.25 ±0.11	0.18 ±0.07
SO_2	0.71 ±0.32	0.55 ±0.23	0.36 ±0.09	0.03 ±0.01	0.02 ±0.01
PM	0.04 ±0.02	0.21 ±0.09	0.00 ±0.00	0.01 ±0.00	0.01 ±0.00

Table 7: Average energy consumption values for new technology passenger cars of 1.5 tonnes weight in Wh/km.

	Speed range	
	20-50 km/h	50-100 km/h
Electric Veh.: electricity cons. for recharging	266	206
Hybrid Electric Vehicle: gasoline	442	442
Fuel Cell Electric Vehicle: methanol	471	343

The vehicle emission factors have been shown in Table 5. These represent the pollutants being emitted at the point of use. Obviously, the EV has not been included as the point of use emissions are zero. Due to the lack of data, both the HEV and FCEV emissions estimates have been given as constants and only one speed range has been used. The spread of data has been shown where possible. Note that only one set of data was used for the FCEV, and therefore no spread has been given. The average emissions of a EURO I car [Samaras & Ntziachristos, 1998] over two different speed ranges have also been included for comparison.

The analysis would not be complete without understanding the full energy cycle emissions. These include the pollutants incurred at every stage of fuel production and usage and are shown in Table 6.

To calculate the non-vehicle emissions for each EV the energy consumption data within a given speed range has been averaged (Table 7), and, in each case, this figure has been used to derive the emissions figures from fuel and electricity production emissions factors. Where vehicle emissions have been incurred these have been included. Both the average emissions and the ranges have been summed to give the overall figures. The range in HEV emissions, for example, includes the spread due to both the vehicle emissions data and the variation in fuel production emissions owing to differences in energy consumption.

The quantity of pollutants incurred by the electric vehicle are simply proportional to the energy consumption and thus reduce with higher speed up to a point. These values represent the pollutants being emitted from the average European power station.

It should be noted that the vehicle emissions and energy consumption data used for both the HEV and FCEV was very limited and represent tests with average speeds within the 20-50 km/h range. Hence, estimates are likely to be more valid for the lower speed range.

3.1.10. Life-cycle emissions analysis of fuel use

By Paul Davison

This section presents a review and analysis of the methodology for preparing air pollutant emissions from the production of a range of fuels for use in the transportation sector (see Lewis (1997) for a more detailed analysis). The fuels considered are diesel, gasoline, liquefied petroleum gas (LPG), kerosene, heavy fuel oil (HFO), compressed natural gas (CNG), electricity and rapeseed methyl ester.

3.1.10.1. Crude oil based fuels

The crude oil based fuels, namely gasoline, diesel, LPG, kerosene and heavy fuel oil can be considered together due to their similar production routes, consisting of :

- Extraction (of crude). The analysis is based on crude oil extraction in the North Sea, as data for this are easily obtained. These data have also been applied to Middle Eastern production, and the split of crude oil is assumed to be 60% from the North Sea and 40% from the Middle East.
- Transportation (of crude). It is assumed that all North Sea and Middle East crude oil is transported by tanker, typically in the size range of 70,000 and 250,000 tonnes respectively. In addition to emissions from marine engines, hydrocarbons (HCs) are emitted through evaporative losses during loading, unloading and transit and an estimate of these is included in emissions calculations.
- Refining. The refinery process involves a range of complex steps that can be optimised to meet the product mix required. To analyse the energy use, emissions and economics of refining, it is necessary to consider a number of issues:
  - the crude oil feedstocks; in this case Brent Blend and Arabian Light crude.
  - the refinery configuration; a standard typical configuration was defined for each refinery type (using the three most common units, namely simple, FCC and hydrocracking)
  - the demand for products; the products that the refinery model optimises on are: LPG, naphtha, unleaded gasoline, kerosene, diesel, gas oil, heavy fuel oil and bitumen.
  - the specifications of products. Gasoline specifications were based on 95 octane (‘premium’) unleaded grade as it is the dominant specification in Europe

  These elements were modelled using least-cost linear optimisation modelling. The throughput of each process was then allocated to each of the final products, and the energy and emissions for that process were allocated to the relevant product (Gasoline, Diesel, LPG, Kerosene, HFO). Small variations were observed between the results for different countries. The variations relate primarily to the types of refinery that are used in each country, as certain types of refinery are more suited to certain products than others. No account has been taken of trading of refined products between countries, as this would necessitate a higher level of demand modelling.
- Distribution. It has been assumed that all fuels are transported by pipeline from the refinery to a terminal, where the fuel is then transferred to a road tanker for onward transportation to the point of end use. A characteristic distance is then taken for each country to represent the distance travelled from the terminal to the point of end use. Energy use during pumping is also included, as are VOC emissions through evaporative loss.

In calculating total production emissions, the summation stage has been carried out without reference to the location of the emission. Therefore emissions which occur away from population centres, such as during the extraction or tanker distribution phases, are added directly to those originating in highly populated areas, for example during road distribution.

3.1.10.2. Compressed natural gas

Compressed natural gas (CNG) is dissimilar to the other fuels in that the final product requires much less processing than the other alternatives considered here. The processing is limited to removal of impurities, including water. A much higher proportion of the emissions come from the distribution stage for CNG compared to the other fuels. This is due to its gaseous nature, which also gives rise to a greater potential for fugitive hydrocarbon emissions. Transportation is via pipeline which is assumed to be powered by in-line gas turbines, with negligible emissions consequences.

An investigation of the conformity of the distribution systems between different countries was outside the scope of the research: the UK distribution system is taken as the typical model.

In addition to energy consumption (and emissions consequences) of gas pumping, there are four types of gas loss that need to be considered when assessing the total losses from the system:

- uncontrolled continuous (fugitive) gas leaks;
- maintenance related losses;
- regular or operating losses, such as natural gas in compressor exhausts;
- isolated losses from accidents and pipeline fractures.

Gas losses from operations in the filling station are considered to be negligible, although energy is required for operation of compressor-filler units.

Although based on UK operating parameters and conditions, the emissions data calculated for CNG should be considered as generic values for all countries in Europe, as few data are available on the differences between the fuel supply networks in different countries.

3.1.10.3. Electricity

The main stages in the production of electricity for use as a transport fuel are:

- feedstock extraction and transportation of fuel;
- processing of fuel;
- transport of finished fuel to the power station;
- electricity generation;
- transmission and distribution of electrical energy.

The emissions from the production of electricity are much greater than for the production of other fuels. However, electric vehicles produce no emissions at the point of use, so the actual environmental impact of electricity emissions (usually in rural areas) may be substantially lower than the impact of equivalent internal combustion engine emissions in more densely populated areas. The data show wide variations in the emissions per useful energy output between the countries considered. This is because a wide range of energy sources are used for the production of electricity depending on local conditions. Furthermore, even for one fuel type, there are variations in the emissions abatement technologies used in different locations. The mix of fuels and emissions reduction technologies employed in the European electricity supply industry has undergone significant change over the last few years, and will continue to do so into the future as a result of the complex relationships between the technical, economic, political and environmental factors that shape this market. The data available for most countries date from around 1994, and so the COST 319 research should be seen as a ‘snapshot’ of the position at that time. In the longer term the possible introduction of new legislation on emissions from power stations would clearly reduce the life-cycle emissions of electric vehicles.

Specific individual examples of electricity generation, such as lignite combustion in Germany and Greece, peat burning in Ireland and the combustion of waste gases from blast furnaces in Luxembourg have been included in the analysis.

It is anticipated that electric cars would be recharged at night, when electricity demand is at its lowest and when vehicles tend to be inactive. Electricity producers tend to operate their plant under two regimes: base load plant tends to run 24 hours per day, whereas peak load plant tends to operate only at periods of peak demand. This results in differences in the fuel mix during the night compared with times of high demand. Data on these two regimes were not available within the time-scale of the research and therefore this aspect has not been fully investigated. A exercise for the UK (in 1993) indicates that emissions of all pollutants (except NOx with a 2% increase) would be reduced if most charging is carried out at night.

3.1.10.4. Biofuels - RME

Biodiesel can be produced from a range of vegetable oils. Rapeseed oil is considered as one of the main oilseed crops grown in the European Union and the most frequent feedstock for conversion to a transport fuel. The fuel produced from rapeseed oil is known as rapeseed methyl ester (RME), or more commonly, biodiesel.

The main stages in the life-cycle of RME for use as a transport fuel are:

- agriculture - production of oilseed rape;
- transport - rapeseed to crushing plant to produce oil;
- transport - rapeseed oil to processing plant;
- processing - rapeseed oil to rape methyl ester;
- distribution and storage - RME to filling station.

Main emissions arising from oilseed rape production are from fuel used in farm machinery and from the production and use of fertilisers and pesticides applied to the crop. Results show that the emissions from the production of RME are highly dependent on the assumptions made regarding the intensity of agricultural inputs to the growing of oilseed rape, especially in the degree of straw use as heat source in processing.

The distribution of biodiesel is assumed to be independent of the mineral diesel network and therefore will involve greater distances of travel by tanker. This is because mineral diesel is piped to distribution terminals and then tankered relatively short distances. Evaporative losses from RME are also assumed to be negligible.

3.2. Road traffic characteristics

3.2.1 Traffic management

by John Hickman

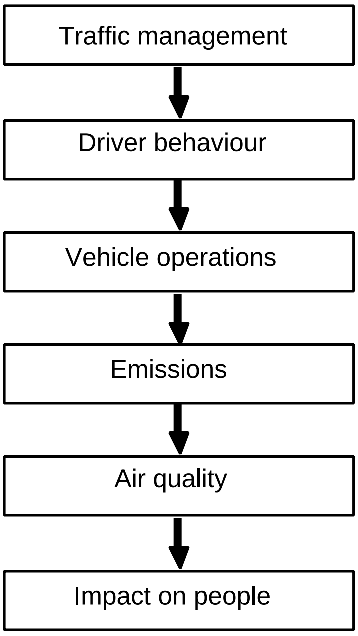

Figure 6 : Links between traffic management and air pollution impacts

Traffic management systems are usually used to try to reduce congestion and improve road safety. Recently, though, an interest has developed in their effect on vehicle emissions and air pollution. In this context there are two main objectives: firstly, where a traffic management system's function is to address a safety or congestion problem, it should also be designed so that it does not increase emissions unduly, and secondly, systems may be developed specifically to reduce emissions. The design and optimisation of a low-emission traffic management system depends on an understanding of several links in a rather complex process, since the management system itself does not directly affect rates of emission. A simplified schematic of the various stages is shown in Figure 6. The initial impact of a traffic management system is on the driver, and often involves a number of decisions. Depending on the type of traffic management system, drivers may choose whether or not to obey a speed limit, they may change their route or mode of transport if priorities are given to public transport vehicles, and so on. Any change in the behaviour of drivers will result in a change in the way their vehicles are operated, and will perhaps also influence the operation of other vehicles. In any case, changes in vehicle operation will cause changes in emissions. There are various ways in which this could take place; there may, for example be a change in the total number of vehicle kilometres driven, in the composition of the traffic or in the speed profiles of the vehicles, and each of these, or any combination of them, can affect the emissions produced by the traffic. The emission changes will modify local air pollution levels, but there will not be a change that is directly proportional to the change in emissions as air pollution levels are also influenced by many other factors such as non-traffic sources, background concentrations, photochemical transformations and the weather. Finally, by altering their exposure to air pollution, or their perception of it, changes in pollution levels will have an effect on people nearby. Because the COST 319 Action was concerned with the modelling of vehicle emissions, the last two stages in this sequence were not explicitly considered, but they are important nevertheless.

3.2.1.1. Types of traffic management system

Many different types of traffic management system are available. Some of the most common types are very briefly reviewed in the following paragraphs, with an indication of assessments that have been made of their likely effects on vehicle emissions and fuel consumption.

Urban traffic control

A number of studies have shown that improved urban traffic control can reduce fuel consumption. Fixed systems such as TRANSYT have shown improvements of up to about 15% [Abbot *et al.*, 1995; Skabardonis, 1994]. Systems that are responsive to traffic conditions (*e.g.* SCOOT and MOVA) may provide additional savings of 5 to 10% compared with a fixed system [Mulroy, 1989; MMT, 1993; Busch, 1996]. Evidence of reductions in pollutant emissions is less well documented but may be up to 15% [Krawac, 1993; André *et al.*, 1996; Robertson *et al.*, 1996]. As urban traffic control systems are already in use in many cities, there may be limited potential for further improvements.

Control of on-street parking

Reducing on-street parking can reduce congestion and journey times, and allows vehicles to travel more smoothly than if their progress is impeded. The effect on rates of emission was studied by Wood and Smith (1993) and Seika (1996) who estimated reductions between 1 and 17% using an emission model.

Parking control in urban areas

Reducing the number of parking places, reducing parking duration or charging high fees can reduce the number of journeys made by private cars. The doubling of parking fees in Gothenburg reduced car park occupancy by 20%, but within a year it had almost returned to the previous level [OECD, 1994]. Dasgupta *et al.* (1994) modelled the effect of halving the number of parking places in the central area of a city and found a 36% reduction in car use. However, much of the travel was redistributed outside the central area and the overall reduction was only 3 to 5%. In Enschede (Netherlands), parking management measures including restricting the number of spaces, increased charges and improved enforcement caused the number of inner city visitors to fall by roughly 50%.

Park and ride

Park and ride schemes aim to reduce city centre traffic by providing a facility on the outskirts where motorists can transfer to public transport. Park and ride scheme may encourage additional and longer trips and may cause some trips formerly made entirely by public transport to be transferred in part to cars. No long term reductions in traffic levels (or, by implication, emissions) have been identified in any existing scheme.

The effect on cold starts and the associated excess emissions is important for any traffic management system that influences parking behaviour.

Central area traffic restraint

Restraint of traffic in cities can take a number of forms, such as pedestrianised areas from which traffic is permanently excluded, selective exclusions including schemes in which access is allowed on alternate days based on vehicle number plates (*e.g.* Turin, Athens) and schemes allowing access only to cars with advanced emission control systems (*e.g.* Graz). Restrictions may be permanent or invoked only when pollution levels are expected to be high (*e.g.* Paris).

Vincent and Layfield (1977) reported that a system in Nottingham was discontinued after a year as it failed to reduce car traffic or increase bus patronage. Pedestrianisation in Chester was estimated to reduce emissions in the centre, but to increase network emissions by about 5% because overall journey lengths were greater [Chiquetto, 1997]. The alternate number plate scheme in Turin reduced traffic by about 10%; that in Athens produced initial benefits that were eroded as there was a large increase in the number of vehicles (suggesting that many people acquired a second car with a number plate complementary to that of their first car).

Public transport systems

A new or improved public transport system has the potential to reduce emissions by replacing car trips and reducing congestion. Experience has shown that this is not always achieved. One reason for this is that many passengers transfer from modes of transport other than cars. The new London Underground Victoria Line (opened in 1984), drew about 80% of its passengers from other public transport modes [Younes, 1995], and an extension of a rapid rail system in Berlin caused a major shift from buses but only reduced car traffic by about 3%.

Public transport fare reductions might also attract passengers from other modes. Dasgupta *et al.* (1994) suggested that halving fares might reduce car use by 1 to 2%, with a corresponding reduction in emissions (although they also estimated that walking would reduce by 7%). A subsidised bus card scheme in Finland was found to increase bus travel by 20 to 30% with a shift from car use of 15 to 25%. The average reduction in energy use was estimated as around 1 MJ per passenger kilometre [Pekkarinen and Dargay, 1996].

Bus priority schemes can reduce journey times and improve the reliability of services. This may have a direct effect on emissions from the buses and may attract additional passengers. Possible systems include bus lanes and selective vehicle detection at intersections. However, unless the total road or junction capacity is increased, such schemes will delay other traffic. Studies in Southampton and Eastleigh [TRL *et al.*, 1997a, b] showed reduced delays for buses, and emission reductions of around 20%, but increased delays to other traffic (mainly cars) occurred, and their emissions generally increased, so no overall improvement was achieved.

Road tolls, area licensing and congestion charges

Pricing policies aim to reduce car travel by increasing its cost, and the driver's awareness of the cost. A toll introduced in Oslo, where car and lorry drivers must pay to enter the city was introduced primarily to finance improvements to roads and public transport in the area, and did not reduce traffic volumes, though a similar scheme in Trondheim produced a slight reduction in car traffic. The Singapore Area Licensing Scheme has been more successful, and has reduced by half the number of work trips into the city by car. It was also reported that average pollution concentrations were reduced by 10% [OECD, 1994].

Emissions in congested traffic are high, and there may be some benefits from charging motorists according to the level of congestion. Guensler and Sperling (1994) proposed that speeds should be maintained in the range between 25 and 65 km/h to give reduced emissions.

Traffic calming schemes

Traffic calming schemes are used to reduce vehicle speeds and improve road safety (a speed reduction of 1.5 km/h can be expected to reduce the number of accidents by 5%). They may include many features such as reduced speed limits, road markings and physical restraints (road humps, chicanes, *etc*). The effect on emissions of a calming scheme will depend on how the scheme influences the average speed of the traffic and the amount of acceleration and deceleration. A number of theoretical and experimental studies have examined these effects, and Table 8 [Boulter, 1997] summarises some of the available literature.

Table 8: Summary of reported effect of traffic calming schemes on vehicle emissions

Country and reference	Type of measure	Type of vehicle	Change in emissions			
			NO_X	HC	CO	CO_2
Single road sections with road humps						
Australia [Van Every & Holmes, 1992]	5 road humps, 100 m spacing	n/a	n/a	n/a	n/a	+36 to +73%
UK [Webster, 1993]	Road humps, 75 m spacing	Petrol car,	-20 to 0%	+70 to +100%	+70 to +80%	+50 to +60%
UK [Boulter, 1996]	2 road humps, 60 m spacing	Petrol car, catalyst	-10 to +20%	0 to +30%	+5 to +35%	+15 to +35%
		Petrol car, non- catalyst	-35 to -10%	+35 to +60%	+30 to +60%	+10 to +30%
Sweden [Höglund, 1995]	1 road hump	Petrol car, catalyst	+18%	n/a	+20%	+4%
		Petrol car, non- catalyst	+22%	n/a	+11%	+5%
	10 road humps	Petrol car, catalyst	3 fold increase	n/a	3 fold increase	+37%
		Petrol car, non- catalyst	3 fold increase	n/a	2 fold increase	+51%
Austria [Züger & Blessing, 1995]	6 road humps, 200 m spacing	Petrol car, catalyst	10 fold increase	n/a	3 fold increase	+25%
Speed limits and traffic calming schemes						
Austria [Sammer, 1992]	30 km/h limit	1992 fleet average	-24%	no change	+4%	no change
Germany [GFMPTE, 1992]	30 km/h zone, limited calming	Petrol car, non-catalyst	-31 to -5%	-23 to +2%	-20 to +28%	-6 to +14%
	Extensive calming	Petrol car, non-catalyst	-60 to -38%	-25 to -10%	+7 to +71%	+7 to +19%
	50 km/h limit on main road	Petrol car, non-catalyst	-33 to -15%	-20 to +2%	-10 to +7%	-13 to -4%
Denmark [Herrstedt, 1992]	40 km/h limit with calming	n/a	n/a	n/a	n/a	-9%
Denmark [Vejdirektoratet, 1997]	21 towns, various calming	Average car fleet, 1995	-4 to +6	0 to +20	0 to +20	+1 to +11

While these results vary widely, and in some cases conflict, it seems likely that road humps will generally increase rates of emission. This is not surprising since the driving pattern they encourage is one of alternate decelerations and accelerations as each hump is negotiated. On the other hand, the less well defined schemes shown in the second half of the table, involving speed limits and various other calming measures are shown often to give emission reductions. There remains, however, considerable uncertainty and, further research is needed.

3.2.1.2. Estimating the effect of traffic management schemes on vehicle emissions

To estimate the effects of a traffic management system on emissions, it is necessary to know how the system will modify the operation of the traffic, and how those modifications will affect rates of emission. Fundamentally, this information could be derived from experimental observations, but the wide range of possible traffic management systems and the different circumstances in which they may be implemented mean that a comprehensive measurement programme would be almost impossible. Thus, models are necessary to simulate traffic management systems and their impacts.

For some types of traffic management system, there are well established models that can predict the behaviour of the traffic (indeed, some urban traffic control systems are responsive to traffic conditions and use computer models optimise their operation). In many other cases, though, current generation models are unlikely to be able to estimate changes in vehicle operation with sufficient accuracy, and the same is also true of vehicle emission models. Much effort has been devoted to the determination of vehicle behaviour and emissions under normal and representative driving conditions, whereas the intention and effect of some traffic management systems are to modify normal driving. In section 3.1.2, it has been shown that emission models based on a certain type of driving behaviour are not able to predict emissions accurately from vehicles operated differently.

It is clear, therefore, that further studies are necessary to improve the models so that they are able to assess the impacts of traffic management with greater precision and accuracy. Because this requirement applies equally to both vehicle operations and emissions, co-ordination of the research of traffic engineers and emissions specialists would be useful to ensure compatibility between their respective developments.

3.2.1.3. Conclusions

Most traffic management systems have been designed and used to improve road safety and congestion, but their effects on vehicle emissions are receiving greater attention. However, few thorough evaluations of this aspect have been conducted. Improvements are necessary to both vehicle operation models and emission models to increase the accuracy with which they predict the effects of traffic management.

3.2.2. Traffic and driving characteristics

by Michel André and Ulf Hammarström

A wide range of traffic-related statistics is required for estimating air pollutant emissions from road transport: traffic quantity and composition, driving behaviour, usage and operating conditions of the vehicles. Such data can be either derived from statistics, if they exist, or using models. In a European inventory, or for international comparisons, it is necessary to ensure that the statistics provided by the members are consistent (methods used, data quality). With this aim, research has been conducted to define accurately which statistics are necessary, to make sure of the data availability and of its compatibility with the objectives, and to analyse it. A detailed analysis of traffic-related statistics from a limited number of countries was proposed in [André *et al.*, 1999], and this work is summarised here.

A knowledge of micro-scale driving behaviour (speed and acceleration profiles, gearbox handling, etc.) can be necessary as input data (in fact, it is also necessary to set emissions factors) for precise emissions estimations (e.g. to assess traffic management, very local situations, etc.). Vehicle instrumentation and driving modelling tools contribute to the available data. The work conducted in this area has been summarised.

3.2.2.1. Traffic related data analysis

Data requirements and approach

An estimation of total road traffic emissions - the sum of hot emissions, cold start emission evaporative emissions - requires firstly the quantification of the transport activity (number of vehicles, traffic volume, number of starts, fuels quantities, etc).

Pollutant emissions are influenced by a number of parameters : vehicle type and age, driving patterns, vehicle load, fuel volatility, thermal conditions, usage characteristics. Driving patterns are themselves linked to road characteristics, geographical location (urban, motorway, etc.), time period, etc. For emissions estimations, some of these variables are envisaged as categories (vehicle categories, geographical location), other as correction factors (gradient, load transported, etc.), and emissions functions can be speed and temperature dependent.

Then, for each of the different categories (vehicle types, geographical location, as well as a function of gradient or surrounding conditions), a description of the previous variables and the distribution of the transport activity is needed (Table 9). Correction factors have to be applied to statistics, if they exist, such as gradient distribution, load statistics, etc.

Table 9: Crossed configuration of the traffic-related data requirements.

	BY : - Geographical area (by country and according to : urban - road motorway), - Road characteristics (gradient, size, speed limits), and as a function of surrounding conditions and time periods
BY : - Transport mode, - Vehicle type (technology and age)	Traffic quantity (vehicle x kilometre), annual mileage, etc. Driving patterns (speed, speed profiles, accelerations, veh. load) Vehicle usage (description of trips, parking conditions, etc.) Operating conditions (ambient and engine temperatures, etc.) Fuel characteristics

To determine the availability of data and to collate it, a questionnaire has been sent to international and national organisations and statistics offices. [André *et al.*, 1999] provides a comprehensive list of these statistics, a characterisation of the investigation methods (surveys, vehicle instrumentation, etc. see also [André, 1998a]), and a detailed analysis of traffic-related statistics.

International sources provide harmonised, easy-to-manage, but macro-scale data (yearly, per country), as well as trends and comparative indices. The methods and results of national surveys and specific studies are not harmonised. Data is often dispersed between many institutions, and is difficult to obtain and to understand as most often results are expressed in the national language and relate to particularities of the country.

Apart from the discrepancies observed between different sources within the same country, and the difficulty in obtaining data for each country, vehicle category, and road type, a significant number of results and conclusions has been derived using mainly data from France, Sweden, Great-Britain, Switzerland and Germany.

Road network description and usage

Although the road network seems to be well understood, roads are not always defined in the same way. In addition, whilst there is a differentiation between public and private roads, traffic statistics only relate to public roads, though the private ones can represent a high share of the total length (50% in Sweden and Austria) and traffic volume (35% in Finland). Most often, the network description does not allow us to distinguish between urban and non urban roads. Where available, the urban / non urban rates indicate that there are clear differences in the definition of urban areas.

Given that a harmonised classification is required to combine emissions data and traffic data, it is surely preferable to adopt internationally recognised classifications and definitions. Even if this approach can result in some inconsistencies, it is desirable for international assessment and comparison.

Traffic quantification and distribution

An assessment of the available statistics has revealed the weaknesses in the data: for goods vehicles and 2 wheel vehicles data were very variable from one source to another one. Large gaps were observed between different estimations of urban traffic volume. This contributes to the difficulty in estimating the urban part of the road network. A large proportion of urban traffic included motorway and main road traffic.

Passenger cars account for 75 to 90% of the total traffic volume (in vehicle.km), whilst goods vehicles represent 9 to 20 % depending on the country. Buses and two-wheelers account for about 1 to 2%. Light-duty vehicles seems to represent a high share (9% in Great-Britain, 15% in France).

The crossed distribution by vehicles categories and road types (or geographical areas) is rarely available and is seldom harmonised. However, it does indicate the differences in usage profiles : heavy-duty vehicles are more often used on motorways, whilst small cars seems to be used more in urban areas.

Driving conditions, vehicle speeds

The large amount of data has allowed us to improve significantly our knowledge of speeds.

A network and traffic assignment model based on Swedish data has been used to estimate speed as a function of vehicle type, road configuration (urban or rural roads, motorway, junction density), and traffic flow. Such a tool allows us to estimate speeds locally, even for a whole network. The proposed figures and speed measurements, which correspond to the road and traffic classification in Switzerland and Germany, provide a large set of reference data for cars and duty vehicles. The analysis of real-world speed profiles has also allowed us to characterise vehicle usage in the form of typical driving cycles.

The statistics have highlighted the impact of numerous factors on speed: road characteristics, weather conditions, time-period, gradient, etc. The significant variations in speed according to the time of day and area of a city, and the large dispersion of the values for a given situation, raise the question of using a single average value rather than a distribution, and its subsequent effect on the emissions estimation (see Table 10).

Table 10: Urban vehicle speeds (km/h) and variations with routes and time-period.

	Average speed (km/h)	variation according to the area or the routes	variation according to the time period
London (UK)	25 - 31	18 to 37	(18 to 37)
Thessaloniki (GR)	25		23 to 35
Graz (A)	20	18 to 21	16 to 22
Amiens (F)	22	16 to 30	17 to 28
Niort (F)	29	23 to 35	(22 to 46)

Finally, the estimated "overall average speeds" (i.e. including urban and rural roads and motorways) for passenger cars ranged between 35 and 50 km/h. An estimation using the "reference values" (average speeds, annual mileage and split into urban, rural and motorway areas, proposed in [Kyriakis *et. al*., 1998] for each of the European countries by the respective national experts) lead to overall speeds ranging between 50 and 70 km/h. These estimates are - in all likelihood - too high, and indicate the necessity of a validation.

Usage conditions and other operating conditions

Detailed analysis of annual mileage and trip characteristics have also been conducted. This has highlighted the numerous factors affecting these parameters, and the discrepancies between methods of investigation (Figure 7). Some data concerning load factors and gradient is also proposed.

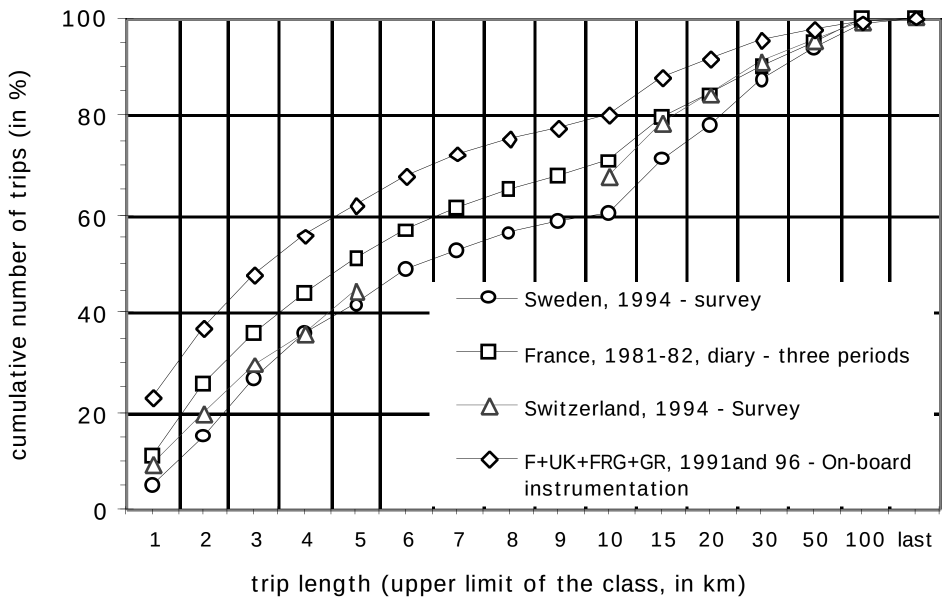

Figure 7: Trip length distributions from various surveys and vehicles instrumentation.

On-board measurements including temperatures have been analysed for the modelling of the cold start impact and for evaporative emissions estimation. Statistics on engine and ambient temperatures at engine start, trip length, distance travelled with a warming-up engine, driving speeds and daily usage have been established.

3.2.2.2. Driving patterns through modelling

Traffic simulation models have been widely used for many years in road planning. Such models normally include some description of driving behaviour. The description may range from a complete driving cycle to approximate data on average speed.

The main idea when using a model is to reduce the amount of measurements which else must be performed. The condition for this is that there is a good correlation between driving behaviour and factors describing the road, traffic situation etc. One example could be a network flow model, which can be used to describe the frequency of “events” in a road network. For these events measurements can be used to describe the driving profiles for stops, etc. [Edwards, 1997].

An advantage of a model is its ability to simulate and evaluate various future scenarios, including traffic management measures. With the aid of models, new driving cycles can be simulated as a function of the future conditions applied in the scenarios.

An inventory [Hammarström, 1996] has shown that there are many models potentially suitable for driving behaviour simulation and for calculations of vehicle exhaust emissions. In many cases these models include routines for exhaust emission calculations.

When modelling driving behaviour, the following definitions are used:

- Micro, i.e. a complete driving cycle for each vehicle
- Macro, i.e. a simplified description as an average for groups of vehicles.

The calculation of total exhaust emissions uses a combination of direct driving behaviour data and emission functions. There is no definite boundary between data needed for micro and macro models. The closer a model comes to “macro”, the more the driving behaviour data will have to be integrated into the emission functions.

A model could probably never describe a complete driving cycle influenced by all the variables that exist in reality. With this restriction, the designation “complete driving cycles” is used here.

Micro simulation models for free-moving vehicles corresponds to the original project idea of COST 319. In this type of model the description of both the road environment and the vehicle is comparatively detailed. Driving attitude could be described as follows:

- Desired speed in relation to vehicle type, road width, speed limit, horizontal radius, wearing course and road condition
- Deceleration level as a function of speed in different situations
- Changing gears as a function of engine speed
- Proportion of throttle opening used in different situations.

For rural roads with traffic flows not too close to capacity, this type of model should be acceptable in most cases.

Micro simulation models including vehicle interactions are available both for urban and rural roads. The basic data is the same as for free- flow models, but is extended to include routines for car following, overtaking, and interactions in junctions.

Macro models and especially network flow models are frequently used. The road network described could represent a town or a region. An application for describing average speed as a function of area type, road type, speed as a function of area type, road type, speed limit, junction density and traffic flow is presented in [André *et al.*, 1999].

3.2.2.3. Conclusions

The synthesis of traffic-related statistics has allowed us to highlight various aspects:

- Significant discrepancies were observed between the statistics provided by different international organisations and institutions within the same country, and between the methods used. Even data that appear to be "normal" (network length, traffic volume distribution by transport modes, etc.), can be shown to be highly unreliable. Difficulties were encountered in obtaining data for the detailed vehicle categories and categorising traffic volumes and driving conditions according to urban - rural - motorway areas, to gradient, etc.
- A high number of speed values have been observed. These show the impact of numerous factors, and also the necessity to validate the reference speed values used in emissions inventories.
- Finally, a very large quantity of diverse traffic-related statistics have resulted from this work, highlighting the complexity of the subject. Further work should be conducted to extend this synthesis and to set the methodological basis of further data collection and ensure the harmonisation and quality of the results collected by the European countries.

The overview of traffic simulation models has shown that there are many types of model available, and in many cases they include subroutines for exhaust emissions. Probably due to a lack of contact between experts in road planning and specialists of exhaust emissions inventories, it has been difficult to combine both types of work.

3.2.3. Road traffic Composition

by Nikos Kyriakis

For the purposes of COST 319, road traffic composition refers to the breakdown of the vehicle fleet into a number of categories, which are defined in terms of emission factors and/or usage.

In theory, it should be possible to achieve the breakdown using statistical data. However, these data are usually not available, at least at the level of detail required. Therefore, some kind of modelling is needed to fill the unavoidable gaps.

Existing European vehicle fleet data and breakdown methodologies were reviewed by the working group B3 of COST 319. This work was finalised in MEET project, were it was enriched with a forecasting methodology that allowed road traffic composition to predicted up to the year 2020. The overall work is presented in detail in [Kyriakis *et al.*, 1998]. The text that follows is a summary of this deliverable, presenting comparative results.

3.2.3.1. Vehicle categories

The emission factors (see section 3.1) and the activity data (see sections 3.2.2 and 3.2.4) vary significantly according to the vehicle category. The categorisation of the vehicles is therefore a synthesis of the needs of the emission description and the possibilities of the activity data description.

The first, gross, split of vehicle pool is based on usage. Accordingly, the vehicle categories recognised are: passenger cars (PC), light duty vehicles (LDV), heavy duty vehicles (HDV) and two wheelers (2W). Each of these major categories is further divided in sub-categories, based on engine fuel and/or engine size (PC, LDV, 2W) or gross weight and usage (HDV). Each sub-category is further subdivided, according to the emission standards at the year of production.

On this basis, the vehicle fleet is finally divided into a large number of sub-sub-categories. This categorisation is made possible with the aid of appropriate models operating on a national level, and in certain cases on smaller scale (major cities etc.).

3.2.3.2. Fleet evolution / turnover

A large number of attempts to simulate the ageing and technology substitution processes of automobiles can be found in the literature. These either use economic parameters as explanatory variables for the vehicle ownership and technology substitutions forecasts, or apply system dynamics approaches - see for instance [André, 1998b]. Alternatively, an engineering approach can be used, whereby forecasts are based on phenomenological analysis of past trends. This approach was adopted for the MEET purposes.

A key feature of this approach is the sigmoid shape of the vehicle density curve (vehicles per inhabitants) as a function of the calendar year. The parameters of this curve, as well as its saturation value, can be determined as long as sufficient and reliable statistical data exist for the past. Based on the same data, the probability of a vehicle of a certain age being present can also be determined. The combination of the above allows the road traffic composition to be predicted.

3.2.3.3. Results

Figure 8 presents the passenger car densities of the European countries in 1970 and 1995, and the forecast for the year 2020 since this results from the application of the forecasting methodology described in outline above.

Figure 9 presents the mean passenger age of the European countries for the year 1995.

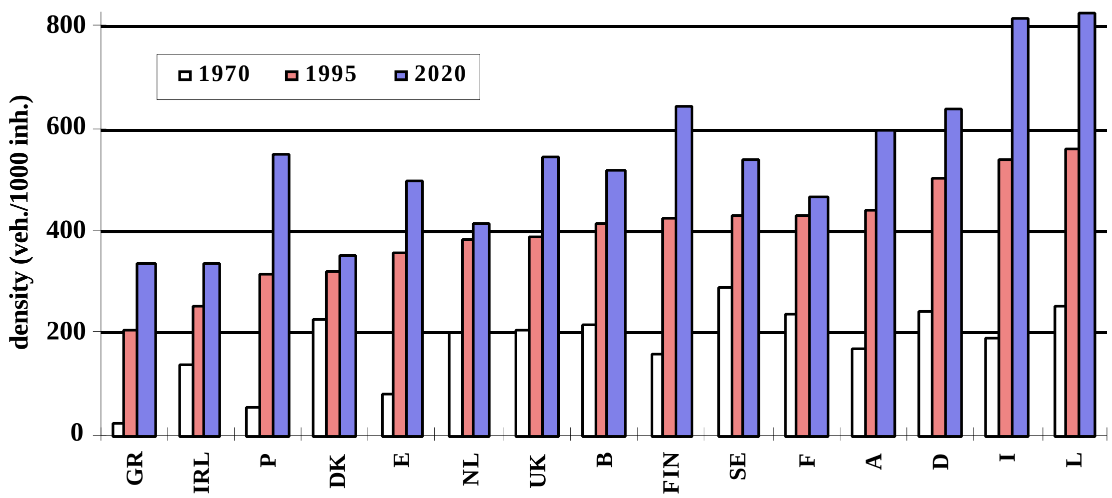

Figure 8: Passenger car densities of the European countries.

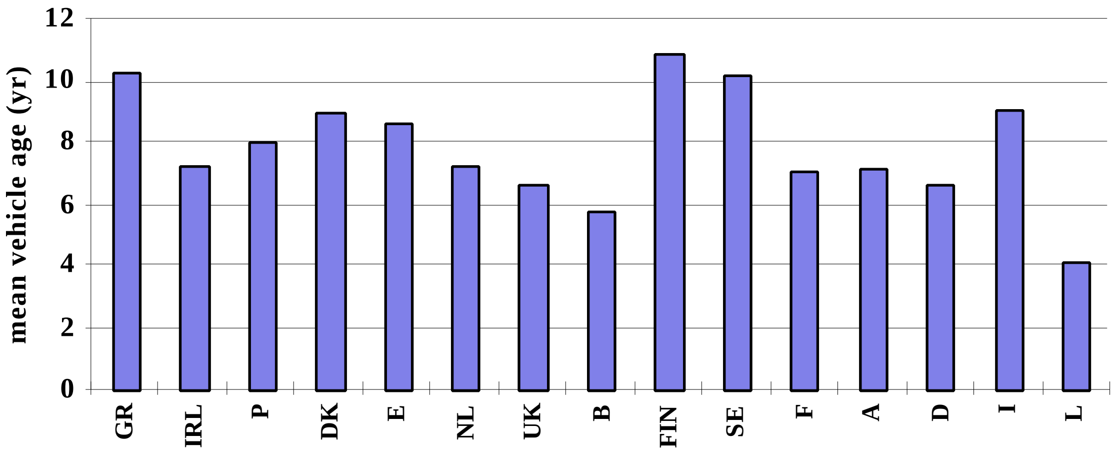

Figure 9: Mean passenger car age of the European countries (1995 data).

As it can be seen in Figure 8 and Figure 9, there are significant differences between the European countries. Regarding the passenger car density (Figure 8), it is clear that there is a factor of almost 3 for the year 1995 between Greece and Luxembourg. About the same factor exists between the mean passenger car age of Luxembourg and Finland for the same year.

Annex 8 shows the effect of vehicle age on the average annual mileage of the passenger cars (1990 data). There is a sufficient trend towards usage reduction with car ageing. Also, there is a general trend for more intense usage of the diesel and the larger gasoline passenger cars. Complementary data on annual mileages and age effects can be bound in [André *et al.*, 1999].

Figure 10 presents the passenger car fleet distribution over the main engine type categories (gasoline < 1.4 l, gasoline 1.4 - 2.0 l, gasoline > 2.0, diesel and LPG). As it can be seen, again the distribution is strongly depended on the country, in general the most popular category being the gasoline < 1.4 l. It is of interest to note that LPG vehicles have an important participation only in Italy and the Netherlands. Similar comments can be made for the commercial vehicle (light- and heavy duty vehicles) split, the less populated category being that of the HDV > 32 t (see Annex 9).

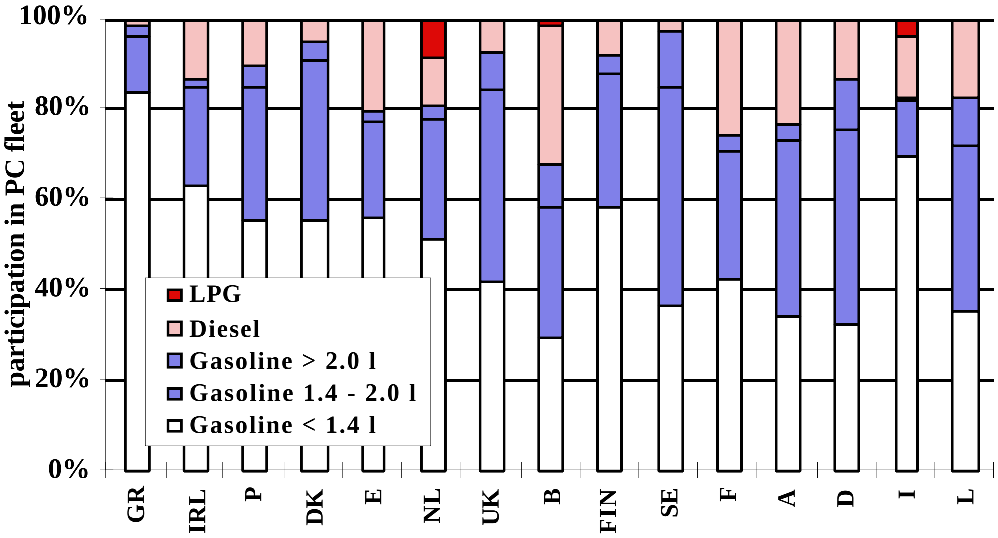

Figure 10: Passenger car fleet distribution (1995 data).

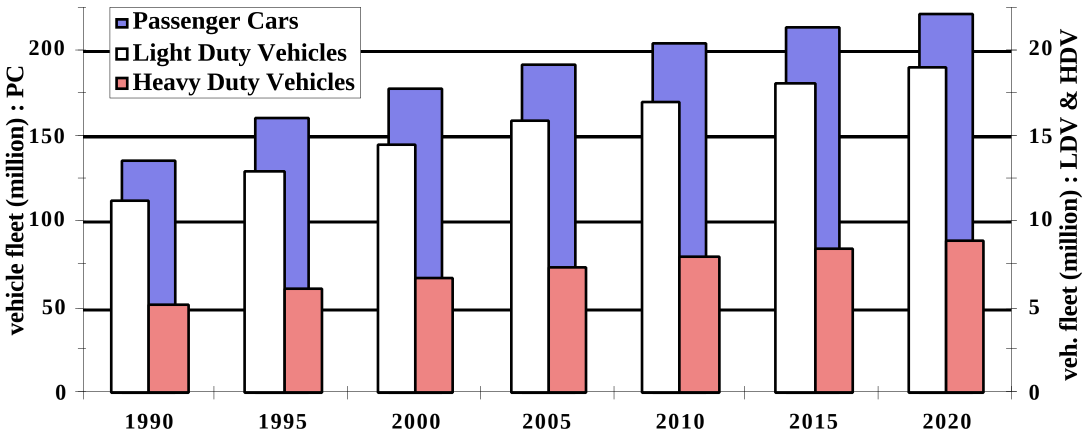

Figure 11: The evolution of Passenger Cars and Light- and Heavy Duty vehicles in the EU 15 countries.

The forecast evolution of the three main vehicle categories for all EU 15 is shown in Figure 11. On the basis of this forecast, it is expected that LDVs will continue to be less than 1/10 of the passenger cars, the heavy duty vehicles (trucks and buses) being about half the LDVs.

3.2.4. Links between the mobility and emission models

by Benoit Gilson, Vincent Favrel and Walter Hecq

See [Gilson *et al.*, 1997] for a more detailed report.

3.2.4.1. Overview of Mobility Models

Transport demand is induced by economic, demographic, political, and social factors. These factors influence transport demand with different orders of magnitude and follow complex mechanisms.

To predict transport demand, two main types of model are available. On the one hand, econometric models can be used to explain a variable related to mobility as a function of the most significant socio-economic variables. On the other hand, mobility models (often called network flow models) can be used to model traffic flow on a transport network. Mobility models are more dis-aggregated and provide more a detailed output than the econometric models.

Econometric models

Econometric models are stochastic. They explain a variable of interest (dependant variable) as a function of socio-economic variables (explanatory variable) which are time series. Times series can be either yearly, monthly or quarterly. The goal of these models is the understanding of the main determinants of the dependant variable studied over the considered time period.

There are three types of econometric model. They differ according to the dependant variable studied : either an indicator of mobility, fuel consumption, or a variable related to car fleet. In the case of modelling indicators of mobility, the dependent variable is a measure of the volume of transport, e.g. number of passenger-kilometres, vehicle miles travelled, miles travelled per car (or light trucks or lorries) etc [Greene, 1992]. For fuel consumption, the dependant variable is aggregated and can be expressed in gasoline, diesel or LPG consumption per capita, per household, or per vehicle [Epsey, 1996]. Finally, in the case of car fleet analysis, the dependant variable can be the motorization rate (the mean number of cars per adult). The methodology for the latter case is somewhat different to that of previous models as a demographic approach (longitudinal analysis) is used. This last approach is based on household expenditure surveys and panel data estimation techniques [Madre, 1995].

All of these models consider income and price/cost as main *explanatory variables*, introduced as exogenous inputs. Only a few other socio-economic variables are taken into account in these models but they are weakly significant (e.g. driven licence in the case of passenger-kilometre analysis). Data (explanatory and dependant variables) are, in general, easily available and predictable[1], but only on a broad aggregated (national) scale.

Network flow models

"Network flow models" are, unlike econometric models, based on more dis-aggregated data. These models model transport demand by taking into account a defined transport network structure, and by means of the estimated origin-destination (O/D) matrices. The main goal is to simulate traffic on a geographic network per time period. These models consider a defined area which is split into several zones. Trips between zones are modelled. Areas covered can be local (e.g. urban level) and on a wider scale (e.g. regional or national level). The zoning system is, in general, at NUTS (Nomenclature of Territorial units of Statistics) 0,1,2 or 3 level.

The network is represented by links and nodes. Usually links are physical and logical (e.g. transfer between transport modes) connections. Two types of nodes are used : nodes representing a junction where three or more links meet or when a route changes its characteristics and the centroid nodes which represent origin zones and destination zones.

Each link of the network includes a start node, an end node, and a link type. Different parameters can be coded on the link: distance, capacity, travel time/speed, even delays for custom formalities, etc. Representations of links for road, rail, and air networks are dependent upon the level of detail covered by the model. O/D matrices represent the number of trips between each centroid node.

Classical transport models are made up of 4 main steps (sub-models): generation, distribution, modal choice and assignment steps. For a more detailed description, see Transport Research-APAS 22 studies [CEC, 1996].

The first step, which is called the *generation/attraction model*, estimates the number of trips leaving a zone (generated trips) and entering a zone (attracted trips) on the basis of socio-economic variables. Passenger and freight transportation are handled separately.

The second step is the *distribution model*, for which O/D matrices are built. These models estimate where the produced trips will go to, and where the attracted trip comes from.

The *modal choice model* constitutes the third step in transport modelling. The share of trips following the transport mode used is estimated. This results in the division of the O/D matrices built in the previous step into several sub-matrices, one for each transport mode.

The final step of the 4-step model is the *trip assignment model* where route choices are modelled. Trips, calculated in the previous steps, are assigned to a network. This results in a loaded network. The outputs are calculated for each O/D pair as path flows, junction delays, O/D travel costs. The assignment procedures can be either deterministic or stochastic.

[1] Variables can be forecast using various existing statistical techniques on the basis of the available observations.

Travellers choose paths which minimise their generalised cost (or utility) functions (mainly the time parameter). In the stochastic case, a random term is added to the assignment algorithm.

Finally, a *validation* procedure is often added. Note that some models include explicitly the assignment phase by taking O/D matrices as exogenous input.

The four-step transport model scheme is used by the most well-known modelling tools. APAS 22 give an overview of the strategic or multi-national models available in the European Economic Area. The APAS database describes 62 passenger models and 43 freight models, collected with several criteria (e.g. for passenger models) : scale (part of country, one country, part of Europe, European Union, Europe); area (in square km^2) ; scope ((part) of the home country, international); number of O/D matrices (for cars, public transport, air, sea, bicycle, pedestrian, others); number of trip purposes (0, 1, 2, ≥ 2); number of zones (0-200, 22-500, 55-1000, >1000); number of links in a road network (no network, 0-5 000, 5 000-10 000, 10 000-50 000, >50 000); time basis (year/month, day, morning peak, evening peak, day + peak, parts of the day average weekday); etc..

One important aspect for emission assessment is that these models can infer average speed on the links in relation to the traffic flow (number of passenger cars per hour and number of lorries per hour). The speed-flow function depends on link characteristics : capacity, number of lanes, terrain characteristics (slopes, bends).

3.2.4.2. Emission models

As a remainder, numerous emission models have been developed to assess emissions from transportation in function of explaining variables. The section 3.3 presents an extensive overview of the bottom-up emission models describing their main characteristics (e.g. time scale, traffic input, fleet description, pollutant involved, kind of output, etc.). Emission modelling focuses mainly on hot emissions but specific methodologies are proposed to take into account cold start emissions (see section 3.1.4), evaporative emissions and the influence of road gradient or load factor (see sections 3.1.5 and 3.1.6). Most of these elements are found in the COPERT II methodology [Ahlvik *et al.*, 1997] and the German-Swiss model [Hassel *et al.*, 1994; Keller *et al.*, 1995] which can be considered as references. Therefore, we have chosen these two models to consider linking between emission models and mobility models.

Numerous emission models have been developed to assess emissions from transportation as a function of explanatory variables. Section 3.3 presents an extensive overview of the bottom-up emission models, describing their main characteristics (e.g. time scale, traffic input, fleet description, pollutant involved, kind of output, etc.). Emission modelling focuses mainly on hot emissions, but specific methodologies are proposed to take into account cold start emissions (see section 3.1.4), evaporative emissions, and the influence of road gradient or load factor (see sections 3.1.5 and 3.1.6). Most of these elements are found in the COPERT II methodology [Ahlvik *et al.*, 1997] and the German-Swiss model [Hassel *et al.*, 1994; Keller *et al.*, 1995]. Therefore, we have chosen these two models to consider linking between emission models and mobility models.

Concerning non road transportation, models for the calculation of non-road transport emissions have not been specifically considered in a linking perspective in this study.

3.2.4.3. Linking emission models and mobility models

Mobility models and emission models represent two components of one modelling process. These components have been largely developed independently from one to another and few studies have focussed on linking them [Hammarström, 1996]. This is one of the reasons why, currently, mobility models cannot directly provide usable data to emission models.

Data required for the road emission calculation

From a linking perspective, the main data lacking for hot emission calculations are the following: the number of vehicles per category, the kilometres driven per vehicle category on different road section types, and the average speed per road type taken into account (COPERT), or allocation of typical traffic situations to the road network with respect to different road section types (German/Swiss model).

Considering cold start emissions, apart from meteorological parameters and fuel properties, the data required that could possibly be supplied by mobility models concern : the average trip length per vehicle trip and the total annual kilometres driven by the vehicle of each category (referring to COPERT) or the distance travelled by the vehicle, the number of starts per day and per vehicle and parking duration before the trip (referring to the German/Swiss model).

COPERT II suggests a methodology for evaporative emission calculation. It requires many parameters that are, most of the time unavailable and have to be estimated. These parameters are the following : the fraction of trips finished with hot engines, the fraction of trips finished with cold engines or with the catalyst below its light-off temperature, the yearly average number of trips per vehicle per day and the total annual mileage of each vehicle category. Referring to the German/Swiss model and for the same purpose, other parameters have to be estimated : the number of times the engine is turned off, the frequency distribution of the travelled distance before the engine is turned off and the frequency distribution of the parking duration after the engine is turned off.

Linking considerations with econometric models for road transport

The ability of econometric models to predict future changes in fuel consumption, vehicle kilometres, or vehicle fleet composition can be considered for the assessment of future air pollution reduction measures. However, some major disadvantages remains from a linking point of view : the aggregated character of data (mobility is modelled as a whole) and these models do not deal intrinsically with any measure of mean speed (which is completely exogenous).

The aggregated character means that we do not have predictions of mobility per transport mode, per vehicle category, etc. Other econometric models could be built to split, for example, urban from non urban vehicles, provided statistics are available. Further investigation would be required to assess this possibility. The existing econometric models, which have been developed with goals other than emission assessment, partly satisfy the requirements of emission models provided simplifying assumptions are made.

When based on fuel consumption, models do not differentiate between different fuel types. Once again, if data on total annual fuel consumption for each type of fuel were available, models could be built on a time- series basis. These models can be linked with emission models, such as COPERT II, which calculates the total annual fuel consumption as a calibration parameter for estimating uncertain parameters (e.g. average annual mileage driven on each road class and for each vehicle category).

Furthermore, econometric models could provide information on car fleet composition or motorisation rate, which is of great interest for all types of emissions, using age cohort models. But these models provide once again only aggregated information on the car fleet as a whole. In fact, emission models require not only the total number of cars per country/region but also the structure of the car fleet, i.e. : the share of diesel, gasoline and LPG cars, or the share of different vehicle cubic capacities and the age categories of each vehicle.

Linking considerations with complex “Road network flow” models

From mobility models, it is possible to infer for each O/D trip : the number of vehicles travelling per mode and the average speed from the origin to the destination (knowing the average speed on each link type travelled). Trip distance, number of kilometres travelled per time period, number of starts can also be deduced from the input and output of the mobility models. The main matching problems between emission calculation and mobility models remain in the calculation of kilometres driven per vehicle category and of kilometres driven per road type.

In particular, concerning cold start emissions, the number of starting operations is unknown. To find it, we can make the restrictive assumption that each trip leaving a zone is considered as a start. Concerning parking duration distribution before the trip, further information has been requested from mobility model developers in order to establish if this parameter can be provided one way or another. Cold start and evaporative emissions also depend on the outside temperature which can be different following the parking location of the vehicles (indoor, outdoor). This aspect is not considered in the models and requires additional data concerning the share of vehicles parked in an indoor heated parking. Up to now, neither mobility models nor emission models consider this aspect. New developments in cold start emission modelling [Sérié & Joumard, 1997] consider the driving pattern at the beginning of the trip using the average speed as additional data. This last parameter is available from the mobility models.

Concerning evaporative emissions, the fraction of trips finished with hot engines and the fraction of trips finished with cold engines, or with the catalyst below its light-off temperature, can be determined once the trip length distribution and the ambient temperature are known. The number of trips per vehicle and per day, and the total annual mileage of the vehicle category, can also be determined by processing the output data from mobility models. The number of times the engine is turned off can be roughly estimated by assuming that it is equal to the number of trips arriving at a zone.

As mentioned previously, similar problems arise when linking emission and mobility models. Firstly, mobility models can only distinguish the share of kilometres driven by car, bus/coach and by truck. In order to reconcile them with emission models, two solutions are envisaged:

- to refine modal choice models by splitting existing modes into sub-categories, for instance, by splitting the O/D matrices for cars into sub-matrices differentiating car sub-categories (fuel types and technological concepts). This should be assessed to see the possible level of dis-aggregation that can be achieved and the cost involved;
- to use statistical data on the car fleet, and to weight the number of vehicles on each O/D pair by the share of the different vehicle categories, including annual variations. This alternative could easily be made operational but the accuracy of the method needs to be assessed.

Secondly, differences are observed in the road typologies used for mobility and emission models. A homogenisation and a standardisation will make the link easier between both models. For instance :

- The COPERT II emission model only differentiates three road types (urban, rural and highway);
- The German/Swiss emission model differentiates for three basic road types about 20 standard traffic situations for the different vehicle categories;
- Mobility models like STREAMS differentiate 9 road type links.

Attention must be paid to the fact that mobility models represent an idealised version of reality, and the accuracy of the output data is uncertain. It is perhaps negligible for the objectives for which mobility models have been initially built (analysis of congestion, economic inefficiencies, alternative development patterns, etc.) but for linking with emission models the degree of certainty needed for input data (average speed, trip distances, etc.) must also be assessed if acceptable results are to be obtained. Finally, the transportation network area studied with mobility models only partly covers the actual transport network. Therefore, no validation with fuel consumption statistics is possible at a national level.

3.3. Inventorying tools for road transport

By Zissis Samaras, Emanuele Negrenti, Mario Keller and Robert Joumard

The initial objectives of the working group included the following main research topics:

- Harmonisation of the input categories with respect to emission factors, driving behaviour, the necessary segmentation of the mobility segments.
- Harmonisation of common tools that can be used by several users; are two models (one micro and one macroscale) sufficient? How should these models be related to each other in order to produce consistent results?
- Adoption of a common methodology and a common model to forecast motor vehicle emissions at each level.
- As regards regional and local inventories, the output of the adopted models should be compared to the results of simple approaches (e.g. spatial allocation of emissions based on local fuel consumption or traffic loads) in order to investigate whether such simple models can estimate emissions with reasonable accuracy.
- Validation of the adopted methodologies at local level.

Many of the these objectives have been met. In particular [Hickman *et al.*, 1999] provided a harmonised methodology, including emission factors and driving and usage data as well future forecasts for the estimation of emissions from all modes of transport. This was achieved through an iterative process in which all subgroups were involved. This MEET model was already used, either for calculating aggregated models [Cox and Hickman, 1998] using a first version of the model [Samaras *et al.*, 1998a], or to compare transport modes as regards their pollutant emissions [Keller and de Haan, 1998].

However, many important objectives still remain unanswered, particularly in relation to the harmonisation of micro-scale and macro-scale emission models and the validation of the emission estimates. In this section a number of emission models are compared, a review of the available emission models is presented, a discussion on the classification of the models is conducted, and finally methodological aspects are discussed, in view of their application.

3.3.1. Comparison of emission models

3.3.1.1. European models

This section provides a comparison of a number of emission estimation tools that are used in Europe. The main aim was to carry out an overall comparison of the models with particular emphasis on passenger car emissions, and to provide an appraisal of their applicability and accuracy. The following models were compared:

- The ‘Workbook of Emission Factors’, in short HBEFA [Infras, 1995], which is the result of a Swiss/German project that was carried out from the late 80s until 1995. A main feature of the model is that hot emission factors of passenger cars are expressed as a function of instantaneous vehicle speed and acceleration, and then calculated for driving patterns which represent different distributions of speed and acceleration.

- The model derived from emission measurements conducted in the framework of the DRIVE-MODEM project, in which emission factors are again expressed as a function of instantaneous speed and acceleration [Joumard *et al.*, 1995a].
- The 'Digitised Graz Method' (DGV) [Sturm *et al.*, 1994]. As with the previous two models, this model calculates emissions from passenger cars with the aid of instantaneous emission maps, albeit based on a rather limited database.
- The COPERT 90 model [Eggleston *et al.*, 1993], developed by the European CORINAIR working group.

The emissions factors were calculated for different vehicle categories with recorded driving sequences - see [Zachariadis, 1995 and 1996; Zachariadis and Samaras, 1996] for detailed results; Figure 12 present an example. One can observe the most significant differences in CO and HC emissions of catalyst cars, in NOx emissions of catalyst and diesel cars and in HC emissions of diesel cars. At medium and high speeds, though, all four models produce fairly similar results, with NOx being sometimes an exception. However, despite these significant differences in estimates of emission factors for individual vehicle categories, the overall results of the models for a real-world vehicle mix are in most cases much less pronounced, particularly between HBEFA and COPERT, with DRIVE-MODEM generally being an exception.

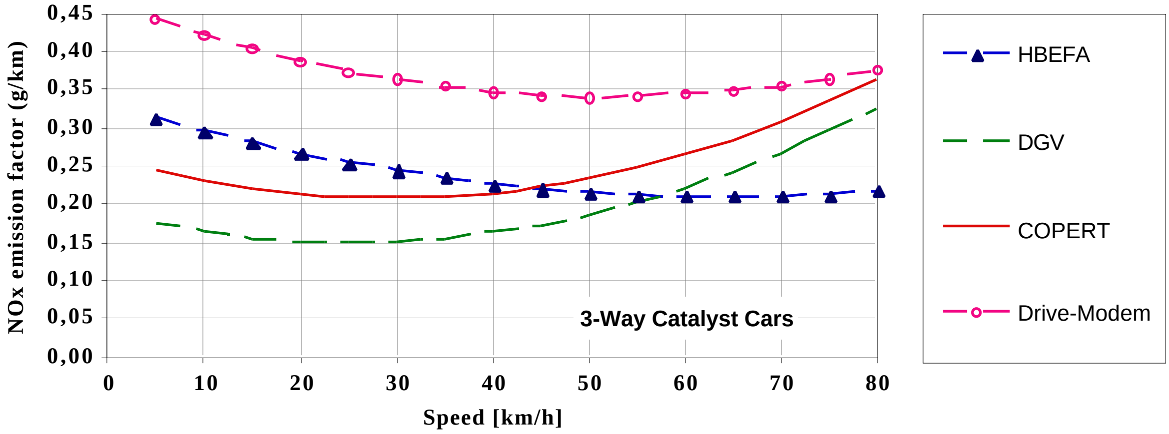

Figure 12: Comparison of hot NOx emission factors of pre-1991 3-way catalyst cars, as calculated for recorded driving sequences of Thessaloniki with the four models.

3.3.1.2. Comparison with MOBILE 5a

The structure, assumptions, and estimates of COPERT 90 were compared with those of MOBILE 5a, the latest version (at the time) of the United States Environmental Protection Agency's mobile source emission factor model [USEPA, 1992 and 1995]. The major results of this comparative analysis [Samaras & Zachariadis, 1994] are summarised below.

Federal Test Procedure (FTP) emission data provide the major background information for MOBILE's basic emission rates, deterioration rates, tampering rates and correction factors. In contrast to that, COPERT emission factors of passenger cars and light duty trucks are the product of a synthesis of emission data over various driving cycles.

MOBILE distinguishes between the three FTP operating modes: cold start, hot stabilised, and hot start, and derives the corresponding correction. COPERT assumes two operating modes: hot and cold start. A comparative assessment of the effect of ambient temperature on emissions of light-duty gasoline vehicles was performed (see an example in Figure 13). From this comparison it became clear that, with the exception of NOx emissions, there are significant differences between the two models: COPERT assumes a greater impact of low temperatures and cold start operation on non-catalyst vehicles than MOBILE, while MOBILE estimates higher emissions for catalyst vehicles in cold start operation than COPERT.

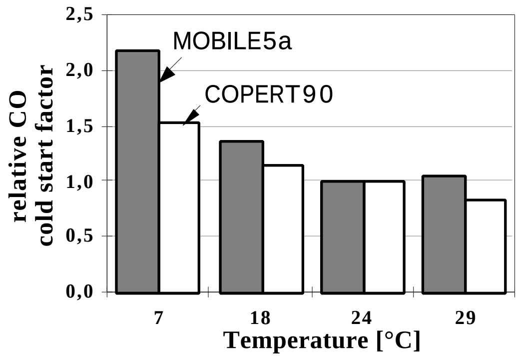

Figure 13: Extra cold start emissions of CO, as calculated by MOBILE 5a and COPERT 90 for pre-1991 3-way catalyst cars. Reference temperature is 24°C (75°F).

COPERT bases its estimates of evaporative emissions on limited information from just a few tests, whilst MOBILE has a more detailed evaporative emissions methodology. Major differences include the following:

- COPERT does not include resting losses as a separate category, and it does not estimate refuelling emissions;
- COPERT assumes zero hot soak losses for fuel injected vehicles with evaporative emission control, which is entirely different from the respective assumptions of MOBILE;
- COPERT uses average evaporative emission factors for gasoline vehicles of all types and ages, whereas the MOBILE methodology is more refined since it differentiates between vehicle types and vehicles with different emission control technology

In addition, MOBILE accounts for the influence of parameters that had not been investigated in Europe before 1990 and were therefore not included in COPERT 90. Such factors include the effects on emissions of gasoline volatility, air conditioner use, extra load, trailer towing, and altitude.

Both MOBILE 5a and COPERT 90 were used to calculation road traffic exhaust emissions in Greece in the year 1990, based on the same vehicle usage parameters. Average fuel-related emission factors were examined (Figure 14): COPERT 90 estimated higher emissions per unit of fuel consumed than MOBILE 5a. However, the total results of the calculations showed that only estimates of NOx emissions in Mobile were significantly higher (about 65%) than in COPERT. This was largely due to the higher emission factors for heavy-duty diesel vehicles in MOBILE. Exhaust NMVOC and CO emission estimates were essentially the same using both methodologies, which led to the conclusion that, even if considerable differences existed, they were almost eliminated at the level of aggregation that was investigated.

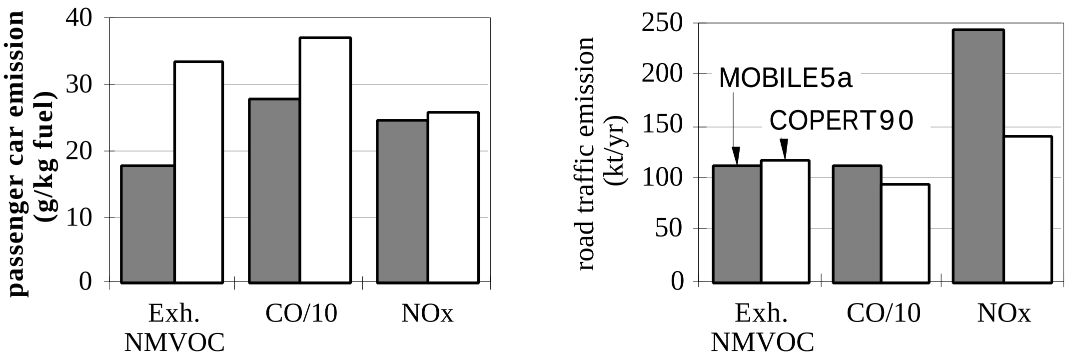

Figure 14: Average passenger car emission factors and road traffic emissions in Greece in the year 1990, as calculated by MOBILE 5a and COPERT 90.

The comparative analysis revealed that, although MOBILE 5a and COPERT 90 have the same basic structure, they also differ considerably, the differences reflecting the different stage of development of each model. MOBILE is suitable for the estimation of motor vehicle emissions in countries with an extensive FTP database and with vehicle fleet characteristics that are similar to North American ones.

3.3.2. Review of the available emission models

The level of complexity of all available models depends basically on the availability of input data. Generally three types of input data are needed: an activity or mobility indicator (e.g. vehicle-kilometres), an emission factor (e.g. g/veh-km), and a definition of the differentiation needed or desired. In general it is this latter element which determines the characteristics and the complexity of the model. This concerns in particular the pollutants covered, the categories of vehicles through their size, their technology, or their fuel, the driving conditions (average speed, or dynamics of the driving patterns), the additional factors of influence (e.g. altitude, slope, inspection/maintenance), and finally the segmentation of the activity (i.e. veh-km) according to the purpose of the model.

All models are intended to be used for a given current situation, and for future forecasts. In the latter case, the aim is usually to analyse how certain objectives can be met, or to evaluate particular measures and policies.

Thirty nine emission models have been considered. The models employ a variety of different approaches and have a number of different applications [Negrenti, 1998]. Their main parameters are presented in Annex 10.

The reported emission models belong to different families: some of them can be classified as macroscopic (city or country related models), whilst others have a more local (street level) character. Some models deal with the behaviour of a single vehicle (vehicle simulators), whilst others take into account only specific aspects (e.g. the cold start effect) of the pollutant emission process. In principle, it should therefore be possible to define a classification system for the models based on such features. In reality, the sectors of application of different types of models do not have closed boundaries, but often show a remarkable degree of overlap. To account for these limitations, we agreed to attempt a rough classification of models based on the most relevant characteristics. Two complementary ways of classifying emission models were identified. These related to either to the level of aggregation of emission factors, or to the type of application.

3.3.2.1. Classification according to the level of aggregation of emission factors

It is important to note that the differentiation of emission models according to the level of aggregation of the emission factors does not depend at all on the detail of the software, and consequently on the intended application. It is only related to the experimental data which supports the emission calculations. According to the emission factor characteristics, the emission models can generally be divided into three categories:

- The average speed based models or base models. These are the most commonly used models and account for vehicle dynamics using the concept of average speed. They work on the basis of specific emission/consumption factors for vehicle/engine technologies for particular traffic conditions. They usually form the basis of local air quality calculations, and work characteristically on the scale of a town.
- The disaggregated emission models. These take into account vehicle kinematics through detailed parameters such as speed and acceleration. They allow calculations on a local scale (down to traffic intersections), but can also be integrated for regional or national inventories. They allow vehicle characteristics to be altered individually and thereby to calculate expected future trends. They have been discussed in detail in Section 3.1.2.
- The aggregated models consist the third type of emission estimation tools. These are based on vehicle usage statistics such as annual mileage, share of road types, characteristic average speeds, etc. They calculate overall emissions/consumption, including cold-start effects, evaporation etc., and are used for regional or national emission/consumption inventories. These too make use of empirical average emission/consumption factors, usually produced on the basis of integrated values resulting from average speed models. An approach of this type was used by [Cox & Hickman, 1998] to develop the MEET model, in which emission factors were defined according to road type, country, and the whole European Union.

Table 11 provides an overview of the necessary and commonly used input data for these three types of model. It should also be noted that the above classification is in accordance with the distinction between the macroscale or top-down models (in practice this is just another name for average speed models) and microscale or bottom-up models (disaggregated models).

Table 11: Input data of the three categories of emission models.

	Disaggregated	Base	Aggregated
traffic volume	xxx	xxx	xxx
fleet composition	xx	xxx	xx°
average speed		xx	xx°
kinematics	xxx		
gradient	xx°	xx	x°
loading	xx°	xx	x°
ambient conditions (temp., humid.,etc.)	x°	x	x°
altitude	x°	x	x°
maintenance	x°	x	x°

x = relevant ... xxx = essential, ° = depends on the model

3.3.2.2. Classification according to the type of application

In order to classify the emission models according to the application, the following approach was followed:

- Systematic but aggregated definition of the expected application areas of the emission models, with the objective of defining how many types of models are needed (see Table 12). The 6 application areas were obtained by combining the 3 typical scales of calculation with the 2 usual types of calculation (absolute estimate and comparison of two situations).
- Identification of the sensitivities needed in each target model, with the objective of checking the capability of target models to take into account the relevant affecting parameters (see Table 13). The parameters have been scored in terms of relative importance for each of the 6 application areas so identified.
- Identification of the sensitivity required in each target model, with the objective of checking the ability of the models to take into account the important parameters (see Table 13). The parameters have been rated in terms of relative importance for each of the 6 application areas identified.

Table 12: Identification of the expected fundamental application areas for the emission models

	spatial scale		
type of calculation	street, route, cycle, urban area	urban network	regional, national, European
impact analysis (differential estimates)	**A**:e.g. transport telematic assess.	**C**: e.g. urban policies assessment	**E**: e.g. European network assessment
inventories (absolute estimates)	**B**:e.g. street, road, highway pollution dispersion analysis	**D**: e.g. urban inventories	**F**: e.g. national and European inventories

The following comments summarise the findings of Table 12 and Table 13:

- the split between absolute and differential analyses allowed us to determine which parameters are relevant in one case and not (or lower) in the other one.
- the defined boundaries between local, urban, and large-scale models were not absolute, but reflected the current best practice in emission modelling.
- The scheme presented in Table 12 would have apparently required 6 types of model, but in practice we can expect that the same models are used for absolute and differential calculations on the same time-space scale. Therefore, only 3 models would actually be required - one for each typical spatial (and temporal) scale.

3.3.2.3. Discussion of the two classification approaches

It is clear from the above explanation that the issue of emission inventorying has been approached from two different directions: firstly from the emissions data and secondly from the application point of view. It is evident, however, that the detail of the experimental data defines to a large extent the applicability of the emission calculations which are based on this particular data. It was made clear also (see Negrenti, 1998) that there is a great deal of overlap between the different emission models as regards the possible applications proposed by the developers. An important example here is: can average speed based emission factors support detailed calculations at very low (i.e. street) level ?

Table 13: Applications versus parameters affecting emissions

	application areas (see Table 12)						x = relevant, xx = essential
Parameters	A	B	C	D	E	F	notes
traffic volume (flow or mileage)	xx	xx	xx	xx	xx	xx	always essential
average speed	x (1)	x (1)	x	xx	xx	xx	1) less relevant than speed vs time
speed cycle	xx	xx	xx (2)	xx	-	-	2) policies impacting speed cycle (e.g. transport telematics)
gradient	x (3)	xx	-	xx	x (3)	x (4)	3) infrastructure impacts at street or corridor level 4) in very hilly countries
fleet composition	xx (5)	xx	xx (5)	xx	xx (5)	xx	5) policies changing fleet composition
Age	-	-	x (6)	-	x (6)	-	6) assess. of fleet renewal policies
maintenance	-	-	x (7)	-	x (7)	-	7) assess. of inspection maintenance policies
temperature (and trip length)	x	xx	x (8)	xx	x (8)	xx	8) policies impacting trip length
loading	-	x	x (9)	x	xx (9)	x	9) public transport or freight management
altitude	-	x (10)	-	x (10)	-	x (10)	10) relevant for CO, VOC, NOx
parking flows	xx(11)	xx	xx(11)	x	-	-	11) to assess parking policies

In view of the above, it is necessary to identify the uncertainties relating to the use of each type of model and how much can be expected from vehicle emission models.

What degree of detailed analysis is necessary for different applications?

As already mentioned, vehicle emission estimates are used for various purposes. Each one of them requires different detail and accuracy.

Emission forecasts: These are applications where fine spatial and temporal resolution is not required, and trends are generally more important than absolute emission levels. Thus, speed-dependent emission factors can adequately simulate reality. In order to come up with reliable emission factors, for each driving mode (e.g. for urban driving) the corresponding average speed should be derived using appropriate measurements and assumptions.

Air quality models: Applications for an urban region, which are comparatively detailed, require emission inventories with a spatial resolution of 500 x 500 m or 1 x 1 km. On such a scale, emissions in individual streets are not of great interest since emissions are averaged over a number of similar streets. Hence, speed-dependent emission factors seem to be sufficient. What is of particular importance in such simulations is an accurate knowledge of the distance travelled with cold engines in each part of the simulated area and for each hour of the day, as well as the impact of these cold starts on emissions. Attention should therefore focus on these issues in addition to the effect of the altitude of the region and the gradient of streets in specific parts of the area.

Small-scale applications: The calculation of emissions on the level of a single street is associated with a high degree of uncertainty. The representativity of all input data (driving profile, emissions, etc) is crucial, and the outcome for some individual streets may be considerably different from the average estimated emissions in streets of the same type. In such cases, in addition to the average speed, the vehicle kinematics on that street may have a significant influence, and simple speed-dependent emission factors may therefore be inadequate. Where driving behaviour and dynamics are of major interest (e.g. the impacts of changes in the driving behaviour have to be assessed) disaggregated approaches are recommended, as stated in chapter 3.1.2.5. However, instantaneous models do not predict consistent trends. Furthermore, the following should be noted:

- With the exception of NOx emissions, models based on modal emission measurements indicate that speed fluctuation is indeed relevant, but average speed itself is still an important influencing factor.
- The dispersion of emission results should not be overlooked. If applied to a particular case there is a wide variation of different driving profiles - even in the same individual street, creating a wide dispersion of emission results.

Table 14: Comparison of hot CO, HC and NOx emission patterns from passenger cars according to the different models in major streets of Thessaloniki.

Model	CO	HC	NOx
HBEFA built-in	118	107	71
HBEFA Thessaloniki	98	110	80
COPERT (reference point)	100	100	100
DGV	117	101	67
DRIVE-MODEM	184	141	133

The overall effect of different models on emission estimates

Hot emissions from passenger cars were studied using the 5 models presented in section 3.3.1.1 for the five streets of Thessaloniki in Greece which were used as an example earlier in this review. Two sets of HBEFA's functions were used: one derived on the basis of the Thessaloniki traffic recordings, and one based on the default traffic situations built into the model. Traffic load patterns for these streets were taken from official counts made by local authorities. A fleet composition close to that of the current Greek car fleet was assumed. Table 14 provides in relative terms the total emission estimates for all five streets. As expected, DRIVE-MODEM clearly produced higher results, particularly for some streets. The other models, in spite of considerable differences in individual vehicle categories, differed by up to ±15%. These differences were lower for CO and HC. This meant that for overall emission estimates for a country or a city, or even at street level, the differences observed, particularly between HBEFA and COPERT, were quite small.

3.3.3. Methodological aspects of emission factor application

Classical emission inventories are not the only applications for which emissions and emission factors are of relevance. In fact, many policy questions can be addressed using indicators, in particular *environmental indicators*. These are generally defined as the amount of a given pollutant released from a given process (with associated pollution control processes), normalised for a given factor (e.g. number of inhabitants, gross domestic product, etc.). Since in transport the causality between the environmental loads or pressures and the normalisation factor is not necessarily straightforward, it is more common to use *transport activity* as normalisation factor. The environmental indicators are then a measure for the "eco-efficiency" of a particular transport mode, or of a transport mode in a particular situation. These indicators can then be used to perform comparisons between different transport modes, between regions or countries, or between different points in time.

Calculation of these indicators requires quantification of the emissions as a specific term [g/veh-km], or in absolute terms [e.g. total emissions of mode m in year y]. Since environmental indicators generally only make sense in a comparative context, it is a prerequisite to consider carefully how emission factors are applied and what aspects should be considered when doing so. In the following paragraphs, several methodological aspects and important factors are addressed which have been described in studies of intermodal comparisons using the MEET methodology [Keller & de Haan, 1998].

3.3.3.1. Units of transport

In order to perform comparisons, a common unit of the transport activity has to be defined. A well established unit is the ”passenger kilometer” (p-km) or ”tonne kilometer” (t-km), resulting in indicators like ”g/p-km” or ”g/t-km”. These indicators, easy to use and to communicate, are the most commonly used. However, there are shortcomings:

- Additional information or assumptions are required, in particular about load factors (passengers or tonnes transported per vehicle) since the emissions in general are calculated per veh-km. Since the information about load factors often is scarce, this introduces a substantial source of additional uncertainty into the calculation.
- What is conceptually more relevant is that these indicators are independent of the distance over which the persons travel or the goods are transported. Often transport distances vary inherently between modes. For instance, air trips are longer than car trips. In these cases, the indicator g/p-km or g/t-km does not reflect the typical usage of the mode, and hence the behavioural dimension is ignored. Therefore, it would sometimes be more meaningful to base the comparison on the activity or the product connected with a transport activity rather than the underlying activity itself. Examples: If we compare the ecological impact of wine from Europe with wine from e.g. California, the most adequate comparison is not per tonne kilometre, but on a product basis (total transport related emissions per bottle of wine).

Despite these shortcomings, the indicators g/p-km or g/t-km are well established and can be used, in general, as an indication of the (specific) environmental loads.

3.3.3.2. Operational emissions versus life cycle analysis

In COST 319 / MEET the exhaust and evaporative emissions arising during the operation of vehicles are emphasised. In addition, the production of energy is taken into account.

However, if long term policy decisions are to be discussed, these areas form only part of a complete life cycle assessment, which roughly covers the following processes and activities:

- *Construction of vehicles*: Use of materials and energy, together with the corresponding emissions, used to build the vehicles
- *Maintenance of vehicles*: Use of materials (e.g. paint) and energy for maintenance
- *Operation of vehicles*: Direct emissions from the vehicle
- *Energy production*: Emissions due to the production and the delivery of the energy
- *Disposal and recycling of vehicles*
- *Construction of infrastructure*: Materials, energy and related emissions from the construction of the road, rail track or airport
- *Maintenance* (i. e. operation) *of the infrastructure*: Lightning of roads, tunnels and airports, use of salt in winter, etc.
- *Disposal of infrastructure.*

If comparisons (e.g. between different transport modes) are made on a *long term* basis, all the components should actually be taken into account, since it is likely that the additional demand will require new infrastructure, new vehicles will be constructed (and the old ones disposed), etc. Strictly speaking, restricting the assessment to the operational emissions is adequate only if *short term* decisions are being considered. In this case, the underlying assumption is that the present infrastructure is able to handle the (additional) demand. However, due to the lack of knowledge and data, and since the operational emissions are likely to cover the biggest part of the environmental load, most applications have to restrict themselves to the types of emissions which are treated in this report.

3.3.3.3. Average versus marginal approach

The *average* approach is based on emission factors which are representative for the entire fleet of vehicles (with varying construction years, and hence varying technologies). In general, emission inventories represent this situation. The total emissions divided by the total transport activity gives an indication of the average ecological performance in a particular year. This indicator therefore represents the average technology mix.

The *marginal* approach asks how much additional environmental load is created by one additional unit of transport. This requires, in general, a data set containing average emission factors. The use of average values is acceptable as long as future emissions will not differ substantially from the present ones. However, newer technologies generally have a better "eco performance", therefore the marginal approach looks particularly at the newest type of technology. For instance, a local public transport authority evaluating the engine type of new buses will use the marginal approach: Since new buses will be purchased, fleet emission factors do not apply.

3.3.3.4. Other influencing factors

Considering the influences on emissions and environmental indicators, a wide range of additional influencing factors have to be taken into account:

- *Time delay:* the time between the introduction of a new technology (modifying the emission rates), and the time where it generally affects the average emission level.
- *Differences per link type:* The fleet composition mix of various technologies may vary per route. This holds for road as well as rail and aircrafts.

- *Regional differences:* The composition of the fleet obviously differs from one country to another, mainly due to local behaviour, economic strength and financial incentives.
- *The structure of the energy production:* this holds for the fuel production (different refinery types), but in particular for the generation of electricity (see section 3.1.10).
- *Time of day:* The diurnal cycle of human activities and, hence, traffic, leads to a strong variation of features such as emission factors and load factors, which are important for the deduction of environmental indicators, particularly in the marginal approach. E.g. peak hour emission factors are likely to be different from average emissions factors (different fleet compositions, different shares of cold start effects etc.). Similarly the structure of the electricity production might vary during the day which makes precombustion factors for electricity a function of the time of the day.

3.4. Rail emissions

by Spencer C. Sorenson

This section discusses methods that can be used to estimate emissions from rail traffic. It is based on the methodology described in greater detail in [Jørgensen & Sorenson, 1997]. Emissions must be estimated on the basis of activity and unit emissions factors for that activity.

$$\dot{E} = \dot{A}\, E' \qquad \text{(eq. 3.4.1)}$$

Where:

$\dot{E}$ is the Emission

$\dot{A}$ is the activity

E' is the emission factor for that activity

3.4.1. Total fuel / energy consumption known

The activity is represented by the consumption of primary fuel or energy. For diesel locomotives, fuel consumed can be estimated by multiplying the fuel consumption by an energy specific emissions factor, as shown in Equation 3.4.2.

$$E_i = F \;\; FSEF_i \qquad \text{(eq. 3.4.2)}$$

Where:

E_i = total emission of pollutant, i in the time frame under consideration

F = the total fuel consumption in the time frame under consideration

$FSEF_i$ = the fuel specific emission factor, typically in gram pollutant per kg fuel

Typical factors and fuel consumption for diesel locomotive engines are given in Table 15.

Table 15: Typical emissions and fuel consumption factors for diesel railway locomotives.

Emission	Power Specific (g/kW-h)	Fuel Specific (g/kg)
CO	1 - 10	5 - 40
HC	0.5 - 4.0	3 - 25
NOx	6 - 16	30 - 70
Particulates	0.2 - 1.2	1 - 6
SO_2	0.2 - 2	1 - 10
Fuel Consumption	190- 220	-

For electric locomotives, emissions estimates can be made from of electrical power consumption. If the power consumed by trains is known the emissions must be calculated on the basis of the emissions factors for the electrical power generated in the geographical area under consideration. In this case, the calculation is as shown in Equation 3.4.3.

$$E_i = El \;\; ElSEF_i \qquad \text{(eq. 3.4.3)}$$

Where:

E_i = total emission of pollutant, i in the time frame under consideration

El = the total electricity consumption of the trains in the time frame

$ElSEF_i$ = the electrical specific emission factor, typically in gram pollutant per kWh of electricity consumed

For emissions based on electrical energy consumption, one must be careful to determine whether the electrical specific emission factors for the electrical power generation net are given on the basis of primary power plant energy consumption, or the amount of electrical energy sent out over the electrical net. The ratio between the emissions factors on these different bases is typically in the vicinity of 40 %. Since the energy consumption modelled is for train usage, it would also be appropriate to apply a suitable transmission loss in the estimation of emissions from electrical powered trains. A summary of European emissions factors for power generation can be found in [Lewis, 1997].

The emissions derived using the above approach will typically be valid for the entire mix of trains. One is not normally able to distinguish between a kWh electricity used for a passenger train or that for a freight train on the same line at the same time. Similarly, if all diesel locomotives use common fuelling facilities, it is difficult to attribute a fuel consumption to a given type of traffic.

3.4.2. Total fuel / electrical consumption not known

If the energy or fuel consumption data required for emission calculations is not known, it is then necessary to use other methods to estimate the energy consumption and, hence, emissions from this type of traffic.

The basis of the calculation procedure is the estimation of the energy consumption of a given type of train in kJ per tonne-km. This is the energy required to move the train and is essentially independent of the type of locomotion used. This enables the same methodology to be used for trains driven by either engine type. The differences in emissions arise primarily through the difference in emissions factors for diesel engines and for electrical power generation. The use of energy consumption on a mass specific basis allows for estimates in future technology based on mass reduction of trains.

Activities are in terms of passenger-km of person transport, and tonne-km of freight transport.

For **Passenger Trains**, emissions can be estimated in the following manner:

$$E_i = WSEC \ \frac{Pkm}{Pps} \ W' \ \ BSEF_i \ \ 0.0036 \qquad \text{(eq. 3.4.4)}$$

Where:

E_i is the total emission of air pollutant i in the time frame under consideration, tonnes

WSEC = weight specific energy consumption of the train in kJ/tonne-km

Pkm = the amount of passenger-km transported by the train type in the time frame

Pps = the load factor of the train, in passengers/seat

W’ = train weight in tonne per seat

BSEFi = the brake specific emission factor in g/kWh of energy produced.

For **Freight Trains**, the estimation be done in the following way.

$$E_i = WSEC \ \frac{Tkm}{Tpt} \ BSEF_i \ \ 0.0036 \qquad \text{(eq. 3.4.5)}$$

Where:

E_i = total emission of air pollutant i in the time frame under consideration in tonnes

WSEC = weight specific energy consumption of the train in kJ/tonne-km

Tkm = amount of freight transported by the train type in the time frame

Tpt = tonne-freight/total train tonne or “degree of utilisation”.
BSEFi = brake specific emission factor in g/kWh of energy produced.

The activity is represented by traffic data. In [Jørgensen & Sorenson, 1997], typical values are given for representative European railway traffic. These data give an indication occupancy rates, so that it is possible to convert typical national transport statistics in units such as passenger km to actual train km. Fleet data are also given in [Jørgensen & Sorenson, 1997] for several countries, including number of power units of different types. Weight data are given for typical diesel and electric locomotives, and for different passenger cars and train sets. Train weight is important, since the train weight is the most significant parameter in the determination of the energy consumption and subsequent emission of air pollutants. The methods recommended for estimating train energy consumption are based on train work per unit mass, and therefore it is important to be able to determine the mass of a train.

3.4.2.1. Empirical energy consumption equations

Average speed also plays a major role in the determination of energy consumption and air pollutant emissions from rail traffic, typical speeds are presented for a variety of rail traffic, including high speed trains, inter city trains, interregional trains and local trains. Empirical correlations are given in [Jørgensen & Sorenson, 1997] for train energy consumption in kJ per tonne-km, as a function of average train speed and distance between stops and gives a reasonable estimate.

The correlation for trains where information was available are given in the following equations. The distances for which the equations are valid are approximate:

ICE trains:

$$\frac{kJ}{tonne\ \ km} = 0{,}0070\,\frac{v_{average}^2}{\ln(x)} + 74 \qquad \text{(eq. 3.4.6)}$$

$$80\ km \le x \le 200\ km$$

Where:

$v_{average}$ is the average train speed over the section of the route in question
x is the distance between stops in km

TGV train:

$$\frac{kJ}{tonne\ \ km} = 0{,}0097\,\frac{v_{average}^2}{\ln(x)} + 70 \qquad \text{(eq. 3.4.7)}$$

$$150\ km \le x \le 300\ km$$

British HST Passenger train, Danish IC3:

$$\frac{kJ}{tonne\ \ km} = 0{,}012\,\frac{v_{average}^2}{\ln(x)} + 70 \qquad \text{(eq. 3.4.8)}$$

$$40\ km \le x \le 100\ km$$

Large freight train (600 tonne empty mass):

$$\frac{kJ}{tonne\ \ km} = 0{,}019\,\frac{v_{average}^2}{\ln(x)} + 63 \qquad \text{(eq. 3.4.9)}$$

$$80\ km \le x \le 200\ km$$

Swedish RC train:

$$\frac{kJ}{tonne\ \ km} = 0{,}015\frac{v^2}{\ln(x)} + 81 \qquad \text{(eq. 3.4.10)}$$

$$30\ km \le x \le 800\ km$$

Urban Trains:

Urban Train Energy consumption is estimated to lie between 200 and 270 kJ/tonne-km

3.4.2.2. Steady state train resistance

An alternative method for determining the energy consumption is based on the steady-state loading of the train. Steady-state train loads in kN have been converted to kJ/tonne-km for several types of trains, and have a second order dependence on train speed because of aerodynamic loading.

$$F' = B_o + B_1 v + B_2 v^2 \qquad \text{(eq. 3.4.11)}$$

Where F' is the train force in kN/tonne, and B_o, B_1, and B_2 are constants, and v is the train velocity in m/s.

Figure 15 shows the steady state loads for a variety of train types. The parameters for these equations are given in Table 16.

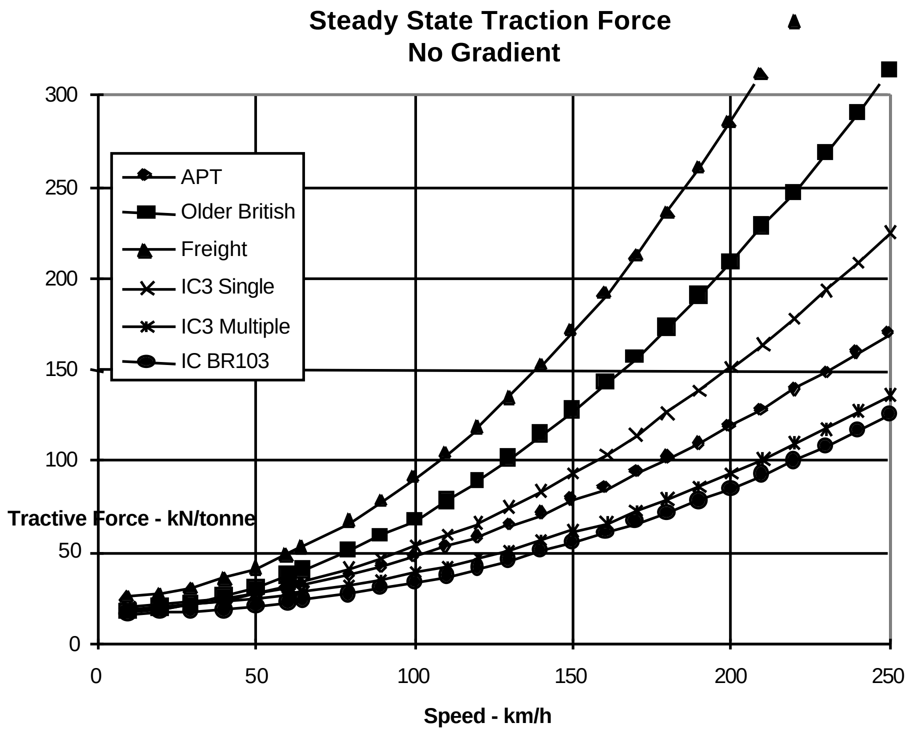

Figure 15: Traction force in kN/tonne for different types of railway trains as a function of train speed.

Table 16: Coefficients for Equation 3.4.11 for the steady state train force in kN/tonne for velocity in m/s for different train types.

Train Type	B_0	B_1	B_2
British APT	16.6	36.6×10^{-2}	26.0×10^{-3}
Older British Trains	15.5	29.2×10^{-2}	57.4×10^{-3}
Freight Trains	24.7	0	84.5×10^{-3}
Danish IC3 - Single set	19.7	0	42.5×10^{-3}
Danish IC3 - Multiple set	19.7	0	24.0×10^{-3}
German IC - BR103 Loco	16	0	22.5×10^{-3}

The steady-state load can be combined with the acceleration energy for a train, and the energy needed to move up or down a gradient, to estimate the instantaneous energy consumption of a train and therefore emissions for a more detailed route description. For emission estimations from traffic, this energy consumption must be integrated over a trip length with a representative value for the average speed. If the steady-state load is given by a second order polynomial, the integrated energy consumption for a train over a given route is given by:

$$E' \quad \frac{\left(N_{stops}+1\right)}{L}\frac{v_{\max}{}^{2}}{2} + B_0 + B_1 \quad v_{ave} + B_2 \quad v_{ave}{}^{2} + g\frac{\Delta h}{L} \qquad \text{(eq. 3.4.12)}$$

Where:

B_o, B_1, and B_2	are empirical coefficients for the steady state load
N_{stops}	is the number of time the train stops along the route
Δh	is the change in elevation between the start and end of the route in m
v_{ave}	is the average train speed on the route in m/s
v_{max}	is the maximum speed to which the train accelerates in m/s

Equation 3.4.12 applies to the situation where the maximum speed of the train is approximately constant along the route. For situations on a longer route where the are significant changes in these variables, it would be best to apply equation 3.4.12 to the separate sections of the route. This method is also based on a mass specific energy consumption, and is general since most trains of a given type have very similar loading characteristics when expressed in these units. The method should be more reliable than the empirical relationships for small distances between stops. A major difficulty is determining the true number of accelerations, since road traffic limitations give rise to accelerations which are not station related, and the first term in Equation 3.4.12 underestimates acceleration energy consumption. The appropriate average velocity is also uncertain.

3.4.3. Passenger train occupancy

Occupancy of trains is dependent of the attractiveness of a route, the time of day, and the time of year. As a first approximation, one can use the following estimates for occupancy rates on a yearly average, based primarily on German and Danish data: urban: 30 %, regional: 40 %, and inter city / international trains: 50 %

3.4.4. Passenger train weight

Passenger train weights vary considerably for different types and within a given type, depending on the specific train and configuration for a special route. [Jørgensen & Sorenson, 1997] illustrates weights for several types of passenger trains. Some representative values for common train types are:

High speed:	1.1 tonnes / seat.
Inter city:	1.0 tonnes / seat for conventional trains
	0.7 tonnes / seat for modern light weight
Regional traffic:	0.8 tonnes / seat for conventional trains
	0.4 tonnes / seat for modern light weight electric
Urban transport:	0.7 tonnes / seat for conventional trains
	0.4 tonnes / seat for modern trains

3.4.5. Freight trains

For freight traffic, an input parameter is often the amount of freight shipped in ton-kilometre. In addition to the weight of the freight, one must also consider the weight of the cars used to carry the freight. The load capacity of freight cars depends to a large extent on the allowable loading per axle. Modern trains in international traffic permit axles loads of about 22.5 tons per axle. Older trains, and trains in some countries allow loading of 20 tons per axle or lower. If a larger loading per axle is permissible without significantly increasing the weight of a given freight car, then the effectiveness of the traffic is higher. This assumes, of course, that cars are fully loaded.

Typical European freight car weights are shown in Table 17, where they are given as the ratio of the tare weight of the car, to the total capacity of the car when fully loaded.

Table 17: Typical tare weight as a function of gross vehicle weight for freight cars.

Axle rating - maximum tons per axle	WR = Tare weight/Total Weight
20.0	0.33
22.5	0.27

The total weight of the train required to transport a given quantity of goods is also a function of the degree of loading of the train. Then for a given fraction of loading, X, the ratio of the total car weight to the weight of the freight carried, FR is given as:

$$FR = 1 + \frac{WR}{[1 - WR]\ X} \qquad \text{(eq. 3.4.13)}$$

The loading fraction is that for the entire train.

3.4.6. Locomotive weight

In addition to the weight of the cars, the locomotive must also be included in the total train weight. The following correlations may be used to estimate the weight of the locomotives:

Diesel Locomotives $\ln(M) = -0.255 + 0.658\ln(P)$ (eq. 3.4.14)

Electric Locomotives and Power Units $\ln(M) = 1.29 + 0.395\ln(P)$ (eq. 3.4.15)

Where:

M is the locomotive mass in tonnes

P is the locomotive power in kW

3.4.7. Future railway emissions

For passenger traffic in person-km, it is estimated that there will be the following annual growth rates in Europe: high speed: 8-10%, regional: 1%, and urban trains: 2%. It is estimated that freight traffic in terms of tonne-km will increase at a rate of 1% annually.

Furthermore, it is anticipated that there will be an increase in the average train speed, and that up to the year 2020 the average train speeds will have in the following annual increase: high-speeds: 1.0%, inter city and regional: 0.2%, urban: 0.1%, and freight trains: 0.5%.

Electrification of the rail net is expected to increase in countries where it is now at a low level. On a European basis, the share of traffic powered by electricity is expected to increase from its current level of 65-70% to 80% in the year 2020. Maximum values in individual countries with current high levels of electrification are expected to exceed 90% in the year 2020. Note that this is the amount of traffic and not the amount of electrified track.

Train weight plays a significant role in energy consumption and emissions from railway traffic. It is anticipated the specific weight for passenger trains in the year 2020 will be, in t/seat: high-speed and inter city: 0.4, regional and urban trains: 0.3. For freight trains it is expected that the ratio of the tare weight of the cars to the maximum total loaded weight will decrease from the current level of about 0.27 to a value of about 0.22 in the year 2020.

Improvements in the emissions from electrical power generation are expected to be significant in future years. Average European emissions levels on the basis on the amount of electrical power produced in the year 2020 are expected to be as presented in Table 18. In the same table future exhaust emissions of diesel locomotives are given: they do not include the effects of production and distribution of the fuel.

Table 18: European emissions levels in the year 2020, in g/kWh.

type of locomotive	electric	diesel
type of emission	energy production	exhaust
CO	0.04	0.5
HC	0.55	0.5
NOx	0.35	3.5
Particulates	0.07	0.08
SO_2	0.80	0.03

3.4.8. Conclusion

Methods have been presented to estimate emissions from railway traffic. Three basic methods are suggested. The first is using energy or fuel specific emissions factors in combination with known energy and/or fuel consumption. The second uses empirical correlations of weight specific energy consumption for a variety of train types as a function of speed and distance between stops. The third method is based on train rolling and aerodynamic resistance integrated over a given route. The first method should be the most accurate if consumption data are available. The second method requires a minimum of information, but is approximate and based on typical traffic. The third method is the most general, and can be applied to any type of operating condition. Estimates are presented of the changes expected to occur in the future for the factors which are used in the estimation of emissions from rail traffic. These factors can be used for any of the methods presented.

3.5 Air transport emissions

By Manfred T. Kalivoda

Air traffic contributes less than 3% to total global anthropogenic emissions of carbon dioxide and nitric oxides [Brasseur *et al.*, 1997]. However, increasing numbers of flights, and the fact that the atmospheric impact varies in a most non-linear way with altitude, have drawn more and more attention to this transport sector. In Europe many institutions are working in this area, collecting traffic and emission data, generating emission inventories, and assessing effects.

Figure 16 tries to create a rough image of who is doing what and why on the European level. It is clear that there is a lot of parallel, sometimes overlapping work done using different databases and methodologies often leading to results which cannot be matched or compared. An outline of the most important European activities is given here.

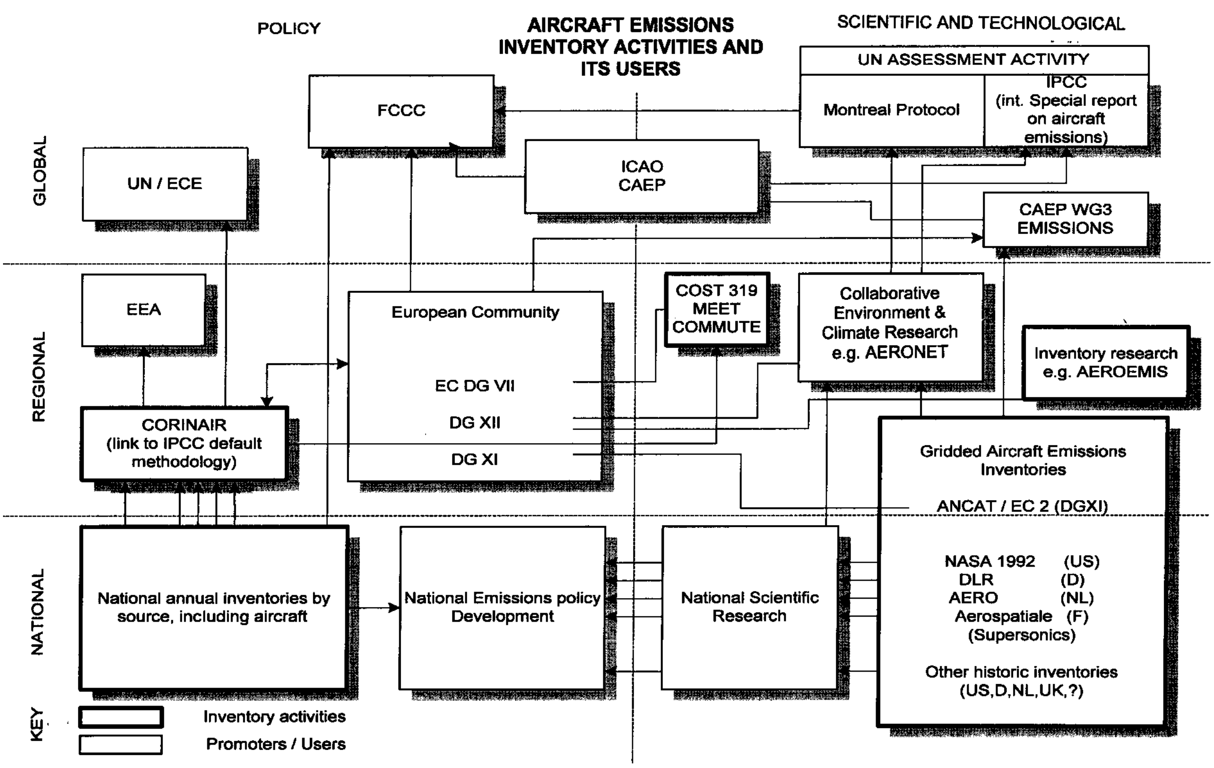

Figure 16: Rough outline of air traffic emissions related activities in Europe.

3.5.1. AERO

In 1993 the Netherlands's Department of Civil Aviation (RLD) started the national project AERO (Aviation emissions and Evaluation of Reduction Options). A consortium of four partners, RLD, Resource Analysis (RA, Delft), MVA consultancy (London, UK) and the National Aerospace Laboratory (NLR, Amsterdam) aims to determine the scope of the environmental problems related to air traffic and to find the 'best' strategy to reduce the impact on the atmosphere. A comprehensive model is being developed which makes it possible to investigate possible policy measures and to assess their impacts on the environment as well as on economies [DG of Civil Aviation, 1998].

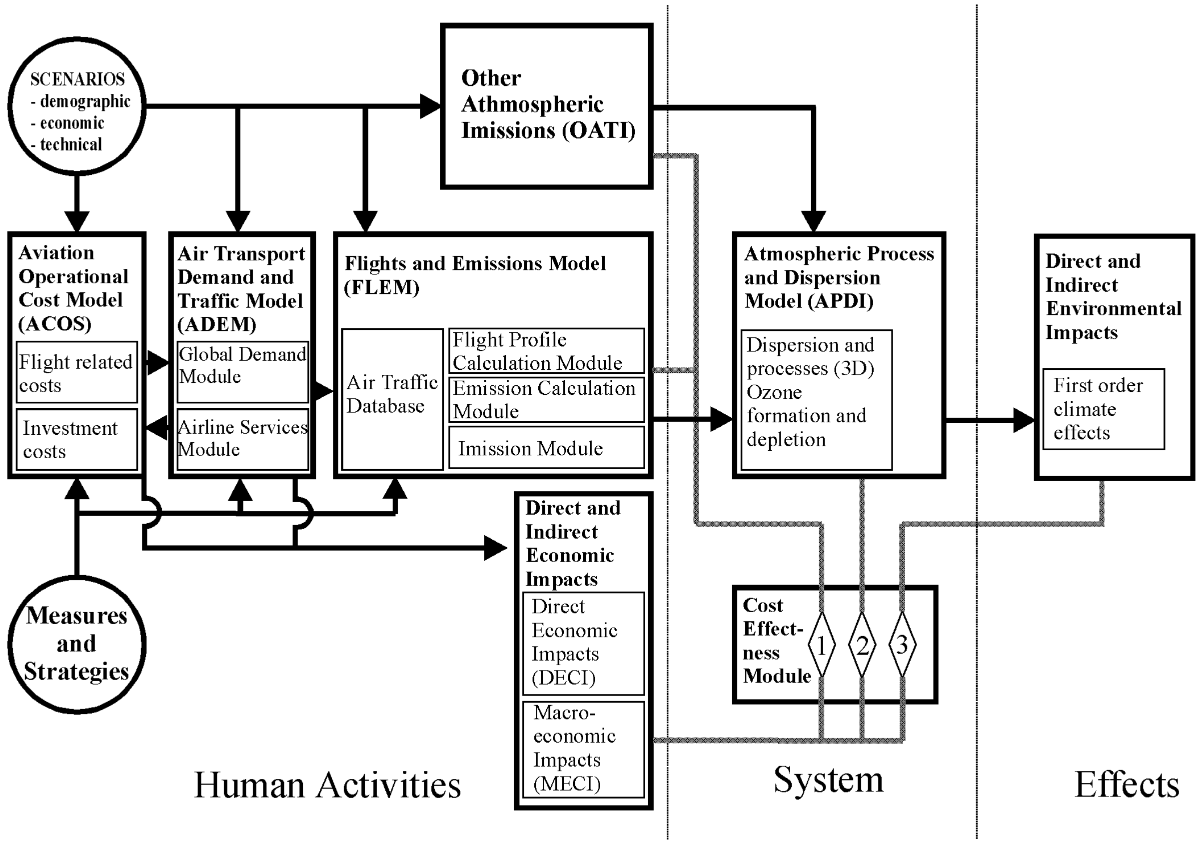

Figure 17: The AERO model [NLR, 1996].

FLEM *(Co-ordination: Paul Brok, NLR, NL)*

As an essential part of the Aero model NLR is developing the Flights and Emissions Model (FLEM). It consists of five modules:

- Flight operation modelling,
- Flight mapping,
- Emission modelling,
- Emission/immission conversion,
- Military emissions [ten Have & de Witte, 1997].

3.5.2. AERONET

AERONET is a thematic network sponsored by CEC DG XII/C Aeronautics. It started in 1997 and aims at creating an European platform

- to improve data and experience exchange,
- to establish a common view of open questions and potentials,
- to identify scientific and technological gaps,
- to specify relevant research and development projects,
- to support authorities in research and development politics,

- to support the generation of a common European position for international regulatory efforts.

No actual research work is performed within AERONET but there are five working groups focusing on the key issues.

HEIM *(Co-ordination: Richard Ramaroson, Onera, F and Roger Gardner, Dera, UK)*

HEIM stands for Harmonisation of Emission Inventories and Modelling. In its inventories part the project aims at:

- Current and forecast inventories for modelling, measurement programmes and policy support,
- Comparison of existing datasets and methodologies,
- Harmonisation of inventories,
- Scope and need to refine, species to be covered, new data sets including scenarios,
- Research planning.

The interface between emissions and atmospheric/climatic models in the near and far field of aircraft is the focus of the modelling activities in this group.

OTD *(Co-ordination: Gerard Bekebrede, NLR, NL)*

OTD stands for Operations & Forecast of Air Traffic Development and deals with:

- Expected development of air transportation system,
- Air traffic management (ATM) improvements and relation to emissions,
- Potential operational measures to reduce emissions,
- Operational measures to reduce the impact of aviation emissions.

MT *(Co-ordination: Andreas Petzold, DLR, D)*

MT stands for Measurement Techniques and deals with:

- availability,
- compatibility,
- accessibility,
- accuracy.

EAT *(Co-ordination: Roger Cottington, Dera, UK)*

EAT stands for Engine and Aircraft Technologies and deals with:

- present and future of fuel consumption and emissions,
- costs, time and risks of development.

SO *(Co-ordination: Lars-Gunnar Larson, FFA, S)*

SO stands for Systems Operations and deals with:

- system reactions and sensitivities to critical parameters,
- end-to-end analysis.

3.5.3. ANCAT

ANCAT stands for Abatement of Nuisance Caused by Air Transport and comprises a group of experts from within the European Civil Aviation Conference (ECAC). This group works on some specific topics.

AERONOX

AERONOX was a research project sponsored by the CEC which investigated the impact of NOx emissions from air traffic in the upper atmosphere (8 to 15km). There were three sub-projects in this programme:

- SP1 = Engine Exhaust Emission Data Base,
- SP2 = Physics and chemistry in the aircraft wake,
- SP3 = Global atmospheric model simulation.

ANCAT/EC2

The ANCAT/EC2 inventories are an extension of earlier work produced by the joint ANCAT/EC working group established by ECAC. A first base year inventory, known as ANCAT/EC1A, was published in 1995 and was used as an input for the global atmospheric models in the AERONOX project. In ANCAT/EC2 a new selection of representative aircraft types has been modelled using movement database from ANCAT/EC1A with only minor adjustments but a different profiling tool, being based on a parametric aircraft design model which also predicts fuel consumption throughout the flight cycle. Two global inventories have been produced for the base year 1991/92 and 2015 including fuel consumption and NOx emissions for global civil jet air traffic which have been plotted at a resolution of 1° x 1° x 1 km and an upper altitude of 17 km.

Future ANCAT work

In January 1998 the need for a proper database which included flight profiles for different stage lengths was found by the ANCAT expert group to be of major importance for the ECAC states. The work required to compile this database, including emission indices based on actual power settings and flight profiles, is on-going and is being co-ordinated by the Danish Civil Aviation Administration.

3.5.4. EEA activities

In 1994 the German Federal Environmental Agency (UBA) was appointed by the European Environmental Agency (EEA) as the project leader for the European topic centre on air emissions (ETC/AE). Their main objective is to establish the annual European inventory of air emissions, including total emissions and emissions by country and source sector. These activities are closely related and linked with EMEP (co-operative program for monitoring and evaluation of the long range transmission of air pollutants in Europe), IPCC (intergovernmental panel on climate change), and CORINAIR (core European inventory of air emissions): see Annex 1.

The EMEP/CORINAIR atmospheric emission inventory guidebook presents common guidelines for the estimation of emissions from traffic. The guidebook includes a section dealing with air transport [EEA, 1997]. The methodology presented includes three approaches (a very simple methodology, a simple methodology, and a detailed methodology), all based on fuel sales statistics. Four different classes of air traffic activities have to be taken into account:

- Domestic airport traffic (LTO-cycle < 1000 m altitude),
- International airport traffic (LTO-cycle < 1000 m altitude),
- Domestic cruise traffic (> 1000 m altitude),
- International cruise traffic (> 1000 m altitude).(Visual Flight Rules)

Emissions associated with domestic aviation are to be reported to UNFCCC using the IPCC source sector split. Emissions associated with the LTO-cycle are to be reported to the

ECE/CLRTAP. Activities include air traffic movements of scheduled and charter passengers and freight air traffic as well as taxiing, helicopter traffic and general aviation. Military air traffic are included where possible.

3.5.5. MEET

MEET stands for Methodologies for Estimating Air Pollutant Emissions from Transport. Within the MEET project a methodology for estimating air pollutant emissions from air traffic was created. Although military operational flights and VFR (Visual Flight Rules) flights are included, the main focus was on IFR (Instrument Flight Rules) flights. Emission indices for the pollutants NOx, CO, HC, CO_2, H_2O, SO_2, and for fuel consumption have been published for 30 aircraft/engine combinations [Kalivoda & Kudrna, 1997].

In a second phase of the MEET project a study on the future development of air traffic (IFR flights only), and the expected changes and improvements in specific fuel consumption and air pollutant emissions (components NOx, CO and HC), was prepared. Three aircraft emission scenarios (a baseline, a low emission and a high emission one) for 2010 and 2020 were developed, and reduction potentials were derived, for different measures, improvements in engine design, the use of alternative fuels, etc. Finally, this led to a table of reduction rates (from the base year 1995) for fuel consumption and emission indices for components NOx, CO, and HC in the years 2010 and 2020 [Kalivoda *et al.*, 1998].

3.5.6. COMMUTE

COMMUTE stands for Common Methodology for Multimodal Transport Environmental Impact Assessment and like MEET is a DG VII research and development project. Main objectives are:

- to define a methodology for strategic assessment of the environmental impacts of transport policy options to support transport policy decision making at the European level,
- to develop computer software that embodies the main aspects of the methodology and can present the results to users,
- to demonstrate the use of the main aspects of the methodology and the computer software.

This computer software includes a module for air traffic emissions which is based on the MEET methodology and data.

3.5.7. Proposal for a harmonised approach to generate emission indices

The COST 319 working group D2 – air traffic – has worked out a proposal for a harmonised approach to generate emission indices. From the working group's point of view this harmonisation is necessary to make results from different methodologies as described in international guidebooks/guidelines (in particular EMEP/CORINAIR and IPCC) comparable and exchangeable.

Figure 18 shows a table which fulfils the minimum requirements. For each aircraft/engine combination included basic information which may have a great impact on the emission indice like origin engine type used, take off weight (influenced by seat capacity, load factor and fuel reserve policy) and average cruising altitude as well as the origin of the data have to be filled in. Fuel consumption, total amount of pollutant component and/or emission indice of pollutant are displayed for LTO cycle, climb (from > 3000 ft), cruise and descent (to > 3000 ft) on one side and standard distance classes from 250 nautical miles to 8500 nautical miles or maximum range of aircraft. If available, the LTO-cycle data should be split up into these four classes: taxi out, take off and climb out to 3000 ft, approach (from 3000 ft) and landing and finally taxi in.

*) dist.: Distance flown for climb and descent in nm *) FL.: Flight level for cruise (incl. Step cruise)			*CLASS OF MISSION DISTANCE*														
			250 nm					**...**					*8500 nm*				
Origin of data:		*Component:*	*dist./ FL*)*	*fuel [kg]*	*NOx [g]*	*EINOx [g/kg]*	*other .....*	...	...	...	...	...	*dist./ FL*)*	*fuel [kg]*	*NOx [g]*	*EINOx [g/kg]*	*other .....*
aircraft type:		*LTO Taxi out*															
engine type:		*Take off & climb out (≤ 3000ft)*															
seat capacity (class):		*Approach (≤ 3000ft)*															
load factor used:		*Taxi in*															
fuel reverse policy:		*LTO TOTAL*															
cruising altitude (ft):		*CLIMB (>3000ft)*															
		CRUISE															
		DESCENT (>3000ft)															

Figure 18: Proposed data sheet to generate emission indices from air traffic in accordance with the harmonised approach (nm: nautical mile).

3.5.8. Conclusion

The approach proposed in section 3.5.6 is a first step to make results comparable. However, it must be clear that there will be differences between fuel consumption and emission indices from different inventories and laboratories. A future research need is to compare these data and to describe the reasons for differences. This will be a hard task on the way to a European set of fuel consumption and emission indices from air traffic.

At the beginning of COST 319's work, there was a large gap, and almost no link at all, between the suppliers of methodologies and data for emission inventories and the users. On one side there was the air traffic community, which has been working on engine and combustion technology for a long time, and has a detailed knowledge of emission, whilst on the other side there were those institutions monitoring the environment which needed tools that were easy to apply.

COST 319 provided the opportunity for starting a dialogue between both sides. A very important step towards a common European methodology and data set for air traffic emission inventories was achieved by introducing a data sheet for emission indices which fulfilled the requirements of the most important users.

Nevertheless, this proposal is just a starting point, and at present only the format has been agreed. There is no commonly agreed data. The next steps will be:

- to collect all relevant emission data available,

- to explain differences between the single data sources,
- to find a European set of emission indices for air traffic emission inventories.

3.6 Maritime transport and inland navigation emissions

By Carlo Trozzi and Rita Vaccaro

In the framework of MEET project two methodologies for the estimate of maritime fuel consumption and emissions have been developed [Trozzi & Vaccaro, 1998]:

- a simplified one based on present day statistics relating to maritime traffic;
- a detailed one based on present day statistics relating to maritime traffic and port operations.

In addition specific functions for fuel consumption and days in navigation have been elaborated.

3.6.1 General background

In the simplified methodology emission factors are defined for engine types. In the detailed methodology emissions factors are defined for engine types and for the different operating modes:

- cruising
- manoeuvring
- hotelling
- tanker loading and off-loading
- auxiliary generators.

Figure 19: Ship traffic representation

Maritime traffic can be represented in the way shown in Figure 19. The Figure contains two examples:

1. typical cargo, container or similar traffic in which the ship stays in harbour up to several days;
2. ferry traffic.

In shipping activity it is customary to distinguish between (a) approaching and docking in harbours; (b) hotelling in harbours; (c) departing from the harbour, (d) cruising. Phase (a) starts when the ship's deceleration begins and ends at the moment of the docking, while phase (c) starts with departure from the berth and ends when cruising speed has been reached.

From a fuel consumption and emissions point of view, there are two manoeuvring phases (a) and (c), one hotelling phase (b) and one cruising phase (d). After its arrival in harbour a ship continues to emit at dockside (while in hotelling phase). Power must be generated in order to supply the ship's lighting, heating, refrigeration, ventilation, etc. A few steam ships use auxiliary diesel engines to supply power but they generally operate one or more main boilers under reduced load. Ships powered by internal combustion engines normally use diesel powered generators to furnish auxiliary power.

For liquid-bulk ships the power requirements of the cargo pumps for tanker off-loading, and the ballast pumps for tanker loading, must also be taken into account. In smaller tankers the pumping power requirement will add to the electrical load, whereas for larger tanks steam turbine driven pumps are generally used (even on motor tankers) with a consequent boiler load. As these power requirements can be relatively high the emissions will be estimated separately.

In ferry traffic the hotelling and manoeuvring phases are not as essential as the cruising phase. However, it would be essential to take into account manoeuvring for short passages. As the passage length increases (i.e. to over a few hours) this element will become less important and could eventually be neglected.

The following detailed methodology has been developed mainly for use in example 1, whereas the simplified methodology has been developed for use in example 2 or wherever information on harbour activity is not available. The detailed methodology must also be used, where possible, for short passages ferry traffic.

The pollutants taken into account are NO_x, SO_x (sulphur oxides), CO, VOC, PM and CO_2.

The ship types taken into account are:

- Solid Bulk
- Liquid Bulk
- General Cargo
- Container
- Passenger/Ro-Ro/Cargo
- Passenger
- High speed ferries
- Inland Cargo
- Sail ships
- Tugs
- Fishing
- Other

The engine types taken into account are:

- Steam turbines
- High speed motor engines
- Medium speed motor engines

- Slow speed motor engines
- Inboard engines - pleasure craft (only for detailed methodology)
- Outboard engines (only for detailed methodology)
- Engines for tanker loading and off-loading (only for detailed methodology)

The fuel types taken into account are:

- Residual oils
- Distillate oil
- Diesel fuel
- Gasoline fuel.

3.6.2 Simplified methodology

In order to apply a simplified methodology it is necessary to estimate the number of working days for each class of ship equipped with a particular engine types and using a particular fuel.

The emissions are obtained as:

$$E_i = \Sigma_{jkl} E_{ijkl} \qquad \text{with} \qquad E_{ijkl} = S_{jk}(GT) \cdot t_{jkl} \cdot F_{ijl}$$

where:

i	pollutant
j	fuel
k	ship class for use in consumption classification
l	engine type for use in emission factors characterisation
E_i	total emissions of pollutant i
E_{ijkl}	total emissions of pollutant i from use of fuel j on ship class k with engine type l
S_{jk} (GT)	daily consumption of fuel j in ship class k as a function of gross tonnage
GT	gross tonnage
t_{jkl}	days in navigation of ships in class k with engine type l using fuel j
F_{ijl}	average emission factors of pollutant i from fuel j in engines type l (for SOx, taking into account average sulphur content of fuel)

The emission factors are selected in the framework of the MEET project. The average specific daily consumption for the different ships types is also evaluated in the framework of the MEET project. A rough estimate of pollutant emissions is possible by using this data as well as the number of navigation days of all vessels in each class.

For short-passage ferry traffic, in order to take into account hotelling and manoeuvring emissions the days in navigation must be increased, since in these modes fuel consumption is about a half of that when cruising. In this case tjkl it is equal to the sum of the days spent cruising plus half of the days spent hotelling and manoeuvring.

3.6.3 Detailed methodology

In order to apply a detailed methodology it is necessary to have:

- statistics on navigation (along a line and in ports) reporting gross and fuel use distribution of ships and average times spent in different mode;

when the previous ones are not available:

- statistics compiled directly from the register of single ship movements to obtain detailed estimate of emissions;

or

- approximate distribution of ships and general statistics of movements to obtain gross estimate of emissions.

From such information is then possible to estimate the number of working days in the different mode for each class of ships equipped with a given engine type and using a given fuel. The emissions are obtained as:

$$E_i = \Sigma_{jklm} E_{ijklm} \qquad \text{with} \qquad E_{ijklm} = S_{jkm}(GT) \cdot t_{jklm} \cdot F_{ijlm}$$

where the new parameters are:

m	mode
E_{ijklm}	total emissions of pollutant i from use of fuel j on ship class k with engine type l in mode m
$S_{jkm}(GT)$	daily consumption of fuel j in ship class k in mode m as a function of gross tonnage
t_{jklm}	days in navigation of ships in class k with engine type l using fuel j in mode m
F_{ijlm}	average emission factors of pollutant i from fuel j in engine type l in mode m (for SOx, taking into account average sulphur content of fuel)

The main difference between simplified and detailed methodology is that the latter takes into account the following aspects:

- emissions during transient phases,
- emissions during hotelling phases,
- emissions deriving from auxiliary power generators,
- emissions deriving from tanker loading and off-loading,
- emissions deriving from inboard and outboard pleasure craft engines.

3.6.4 Fuel consumption

In the framework of the MEET project [Trozzi & Vaccaro, 1998] the data on fuel consumption at full power are provided. In particular, a regression analysis has been made on fuel consumption vs. gross tonnage for each ship class with the exception of inland navigation (for which data on general cargo must be used). The data are highly correlated ($r > 0.68$ for all cases) and all regressions are significant at a confidence level greater than 99%.

When information on ship class is not available, fuel consumption regression data for all ships in the database can be used. If information on gross tonnage is not available, the average fuel consumption can be used.

In the detailed methodology the effective fuel consumption can be obtained from:

$$S_{jkm}(GT) = C_{jk}(GT) * p_m$$

where the new parameters are:

C_{jk} (GT)	daily consumption at full power of fuel j in ship class k as a function of gross tonnage
p_m	fraction of maximum fuel consumption in mode m

Default fractions are reported for the different mode in the framework of MEET project. For the simplified methodology the fraction of cruising can be used.

3.6.5 Days in navigation

If days in navigation are not known, they can be estimated by service speed and distance covered as:

$$t_{jkl} = d_{jkl} / v_{jkl}$$

where the new parameters are:

- d_{jkl} distance covered (in nautical miles) by ships in class k with engine type l using fuel j
- v_{jkl} average service speed in knots (nautical miles/hour) of ships in class k with engine type l using fuel j

For the days in navigation in the framework of the MEET project [Trozzi & Vaccaro, 1998], Lloyd's maximum service speed data are used to give average values for the ship classes. The actual service speed can be well below this figure, and values can be used only as defaults.

Future work must be finalised to analyse service speed data for ship classes using the regression method, and to correlate actual service speed to maximum service speed.

3.6.6 MEET methodology for estimating future emissions from ships

The methodology is based on the MEET simplified methodology for estimating actual emissions from ships: see [Kalivoda *et al.*, 1998] for a more detailed description. Reduction scenarios are introduced only for sulphur oxides and nitrogen oxides. For the application of the methodology estimates of the number of working days for each class of ships equipped with a given engine type and using a given fuel are required.

The emissions are obtained as:

$$E_i = S_{jkl} E_{ijkl}$$

$$\text{with } E_{ijkl} = S_{jk} (GT) \cdot t_{jkl} \cdot F^*_{ijls} = S_{jk} (GT) \cdot t_{jkl} \cdot F_{ijl} \cdot f_{is}$$

where the new parameters are:

- s reference reduction scenario (low, medium, high)
- F^*_{ijls} average reduced emission factors of pollutant i from fuel j in engine type l (for sulphur oxides, taking into account average sulphur content of fuel) in the scenario s
- f_{is} reduction factors of pollutant i in the scenario s

4. Further research needs

This chapter contains a list of future needs in areas where there are substantial gaps in knowledge.

It should be the aim of the future research activities to create better insight and empirical data, in such a way that both national and European needs are met. This will require, in particular, standardisation of the approaches, methods of measurement, and models to be applied and developed.

The list presented below gives the level of priority (◆ = lower priority; ◆◆ = higher priority), and indicates where it will only be possible to conduct the research on a European level (E). It should be noted that the word "emissions", in this context, always relates to "emissions and energy consumption".

4.1. Emission factors and functions for road transport

◆◆E **Analysis of the large differences between laboratories** (car manufacturers and research organisations) concerning emission levels. As all co-operative work has shown, large discrepancies tens to be observed between measurements conducted at different laboratories: the differences can arise from measurement accuracy (sampling accuracy, analyser accuracy), vehicle sample factors, or environmental conditions (ambient temperature, pressure, and humidity). In addition, these laboratory effects should be compared to the effects of well-known parameters such as average speed, vehicle technology, etc.

◆◆ The amount of emission data available for heavy-duty traffic is much smaller than that available for cars. Heavy-duty traffic is responsible for approximately 50 % of total NOx emissions, and therefore in this case the amount of data available should be proportional to the size of the problem in order to achieve comparable accuracy and reliability. **New emission measurements of heavy duty vehicles** must be therefore performed: either with engine emission maps and vehicle models including the driving resistance (driving resistance is probably less well understood than engine emissions), or by direct measurement of vehicle emissions either on a dynamometer or using an on-board system.

◆◆ Measurement of emissions of the numerous **non-regulated pollutants** (including particle size, heavy metals for the health effects, hydrocarbon speciation and NO/NO_2 for photochemical pollution, greenhouse gases, etc.) : knowledge of these is becoming more and more important, but the amount of data is often too low, and in some cases it is non-existent.

- ◆◆ New steps in the measurement and modelling of **evaporative emissions**. The amount of data is insufficient at present, and does not allow accurate assessments to be made; more detailed research is required.
- ◆◆ Influence of the **auxiliaries** on emissions. Air conditioning in particular is known to have a strong effect on emissions.
- ◆◆ The **cold start effect** at ambient and engine temperatures below 10 degrees, the cold start effect for the latest engines and catalysts, and the cold start effect for engine temperatures that are intermediate between the ambient temperature and the hot' temperature.
- ◆ **Producing a large number of emissions engine maps** for passenger cars, and in particular duty vehicles. Agreement on a v**ehicle model** which allows these engine emissions to be transformed into vehicle emissions.
- ◆ **Effects of driving conditions** on emissions, in order to assess the impact of small changes in driving behaviour on emissions on the urban scale.
- ◆ **Effects of fuel** quality, alternative fuels, and alternative technologies on the emissions from passenger cars and duty vehicles, including energy use.
- ◆ Emissions from **2-wheelers**, especially VOCs which are increasingly important, especially in southern countries.
- ◆ Updating the emission database for the **latest vehicles**.

4.2 Road traffic characteristics

- ◆◆ Precise modelling of the **future composition of the vehicle fleets** and usages, combining the present knowledge of the technological structure of the fleets and traffic with the socio-economic approaches to the evolution of registration and use of the vehicles based on human demographic parameters.
- ◆◆ Analysis of the **driving behaviour of heavy-duty vehicles**, with extensive measurement campaigns of all vehicle types and usages, especially engine and vehicle speed, vehicle and engine load.
- ◆◆ Analysis of the **driving behaviour according to the infrastructure** type and the traffic management strategies for the passenger cars, and then the duty vehicles: localisation of the traffic characteristics.
- ◆◆ Modelling of microscopic driving behaviour by **traffic models**.
- ◆◆E Collection and processing at the **European** level of the **traffic characteristics** necessary for the emission calculations, from existing statistics.
- ◆◆E Measurement of **driving behaviour in different countries**, especially for passenger cars - driving cycles, parking time, air conditioning use, etc., in order to have a good geographical representativity of driving behaviour.

4.3 Inventorying tools for road transport emissions

- ◆◆E **Verification of inventorying models** by independent measurements. Emission models combine different submodels dealing with emission factors and traffic characteristics, but the final model is never tested. It is nevertheless necessary for assessing the accuracy of the models. A large measurement campaign should be undertaken, for instance over a whole city, and under specific meteorological conditions.
- ◆ Building reliable vehicle or **disaggregated models** which allow us to assess the longitudinal evolution of emissions along a street, to evaluate the influence of even small changes in driving behaviour, or to produce average emission factors.
- ◆ Building of **intelligent modelling of the future emission** inventory, combining the technological knowledge of the future emission factors, the forecast of the fleets and traffic based on the human demography, the most known future parameter.

4.4 Rail transport

- ◆◆ Better and more complete **driving resistance and energy consumption** data for freight trains. The cars have varying shapes, and the trains are put together in random order, which makes it difficult to estimate aerodynamic drag. The is not the case for passenger trains, where the shapes are quite similar. This data can be obtained by better contact with technical divisions of railway companies, who should be in possession of fuel and energy consumptions statistics for freight trains. Manufacturers of railway wagons may also have data that can be used.
- ◆ Better **statistics on the driving patterns of freight trains**. Passenger train characteristics can be evaluated from publicly available timetable data. Freight train statistics and scheduling are not generally available to the public and must be obtained from railway agencies. As a last resort, studies could be made by observation, but this appears to be very difficult, time consuming, and expensive.
- ◆ A more complete **statistical compilation of the types of tracks** and power units used throughout Europe would be useful in order to split emissions between diesel and electric units. Some statistics have been collected, but this data base should be improved and expanded.

4.5. Ship transport

- ◆◆ A better **identification of inland shipping**, in terms of sizes, engine sizes and engine maps for emissions, and amount of traffic.
- ◆◆ The evaluation of **emissions arising from the activity of maritime traffic** in port, and with maintenance procedures. In port the emissions come from all land-based activity (fuel tanks, load and unload of oil product, loading and unloading of road vehicles, electric power generation, etc.). The emissions arising from maintenance procedures, such as paint application and other repair operations, must be taken into account. All these emissions must be taken into account to evaluate the impact of inter-modal networks in the different countries.

4.6. Air transport

- ◆◆E **Comparison and verification of the emission factors** from different inventories/models. The COST 319 D2 subgroup has agreed on a scheme to make emission factors and emission simulation results comparable. This scheme has to filled in with individual results and differences which are likely to exist have to be explained (hidden model assumptions).
- ◆◆ Influence of the **in-flight situation** on emissions: at the moment all the calculations and emission simulations are also based on the ICAO certification data (for standard ground environmental conditions) using correction factors for the in-flight situation.
- ◆◆ Emissions from **ground operation**: evaporative emissions, refuelling emissions, operation of auxiliary power units, engine start up: these emissions are not covered at the moment but have a great influence on local VOC emissions.
- ◆ **Influence of maintenance and ageing** on the emissions: at the moment only ICAO certification data from new engines are used.
- ◆ Improvement of **database for VFR** (general aviation) and military: ANCAT has carried out a substantial amount of work in this area, but this work only covers NOx and fuel consumption (and then CO_2 and H_2O). No information on HC and CO emissions is available.

5. Conclusion

The results of the COST 319 Action "Estimation of pollutant emissions from transport" are threefold: the determination of the state of the art, identification of gaps in the scientific knowledge gaps, and the implementation of a European network of co-operation.

An understanding of the current state of the art has enabled us to structure the scientific field, to organise it clearly, and to improve its presentation. Secondly, the current state of the art - which is the subject of Section 3 in this report - corresponds to a substantial qualitative progression from the previous state of the art defined at European level (CORINAIR). At the time this was based on the knowledge acquired by just five or six specialists from various laboratories. The active participation of many more specialised researchers in the COST 319 action ensured that the most of the recorded data and acquired knowledge at the European level were taken into account, and that a consensus was reached. However, this was only achieved after lengthy and complex discussion, especially where the views of the various experts involved differed significantly. The widespread participation of users of inventory methods, and the determination of their needs through surveys, enabled us to consider and develop methods corresponding to actual user needs, even if in some circumstances such needs could not immediately be satisfied owing to a lack of knowledge.

By considering the user needs, the opinions of experts in the pollutant emissions field, and further developments in vehicle and transport systems, we were able to establish future research needs. These include, in particular, the development of tools which integrate the COST / MEET methods for different applications, measurement methods for emission factors, heavy vehicles, unregulated pollutants, evaporative emissions and the effects of using auxiliaries, the further development of vehicle fleets, the geographical analysis of the driving patterns throughout Europe, the features of goods trains and river transport, aircraft emission factors under real-world condition and, eventually, the checking of inventory models. This list may seem very long, but only a comparatively small number of items have been mentioned. The lack of relevant data contributes to the significant inaccuracies in current emission evaluations. Although predictions have improved since the first CORINAIR/COPERT project, the inaccuracies remain significant. Emission inventories developed for use on the micro scale, air quality models set up on the city scale, or national emission factors (which are the subject of specific measures on the international scale) need to be more accurate.

The data which has been synthesised during this action has been acquired mainly through national research programmes, including large measurement campaigns. This synthesis, even if very important from a scientific standpoint, only corresponds to a small part of the global effort being made. In addition, further research into transport-related emissions should be based mainly on costly measurement campaigns involving heavy-duty test equipment (amounting to several million Euros). But synthesising the recorded data, determining a new state of the art, and developing software programmes, although very important aspects, can only be performed in a second step.

The third action resulted in the setting up of an extensive network of European researchers and users in the field of transport-related emission inventory methods. This multi-disciplinary, pluri-modal field includes the majority of European specialists (over 200 members) from various laboratories and engineering departments. The long-term research work carried out jointly by several tens of experts, and the information supplied to less active members, provides this network with a real efficiency. The results presented here are a first product of it, and future co-operation will undoubtedly produce more.

What is the future for the COST 319 action?

Mutual knowledge, and the contacts developed between specialists, should lead to the setting up of consortia or working groups studying specific research items. The objective is to draw up the 5th framework programme for Research and Development in Europe, to develop multinational initiatives linking the most involved researchers and in some circumstances their national sponsors, and to launch co-ordinated national programmes and even European projects.

These consortia and co-operation groups will be, in a way, the secondary fruit of the COST 319 network. Nevertheless, we would like to maintain the whole network since various points of view must be presented, to co-ordinate various research projects, and to improve the state of the art step by step. The structure and the means required for such a network are not well defined at present.

The network should open up to traffic engineers who are increasingly concerned about environmental issues, to transport economists and their models, and to specialists of non-road transport modes since the inter-modal issue is of prime interest. The balanced appraisal of all the scientific fields involved in calculating transport-related emissions, and coverage of highly diversified applications, will guarantee action efficiency.

From a geographical standpoint the network covers nearly the whole of Europe. Specific attention should nevertheless be paid to the active participation of our colleagues from Eastern Europe, who are under-represented in the present network for a number of reasons. The acute problems generated by transport-related pollutant emissions in these countries, the specificity of the vehicle fleets and transport systems, and the likely developments in the transport field clearly justify such attention.

Finally, most of the European method to be used for calculating transport-related emissions is based on the state of the art presented in this report. This method will be used by most of the European users, but also by a great number of developing countries. This can be explained by their specific relations with Europe, their vehicle fleets and transport systems coming from Europe, or by the very interest of the method. If the method itself is to be easily exported, the associated database must be adapted to local conditions where they differ significantly from European ones. Such a situation will involve the opening of the network to developing countries, and may require specific measures to be taken, as is usually the case for such co-operation programmes.

Annex 1: International activities on reporting of national air emission inventories

The main objective of the European Environment Agency (EEA) and it's European topic centre on air emissions (ETC/AE) is to establish the annual European inventory of air emissions, based on the official national inventories, including total emissions and emissions by source sector, that have to be submitted to the European Commission (Monitoring mechanism for CO_2 and other greenhouse gas emissions), the UNECE convention on long range transboundary air pollution (CLRTAP), assisted by EMEP (the co-operative programme for monitoring and evaluation of the long range transmission of air pollutants in Europe) and the United Nations framework convention on climate change (UNFCCC), assisted by the intergovernmental panel on climate change (IPCC). This European inventory is the core European inventory of air emissions (CORINAIR).

ETC/AE assists participating countries to report their national emission inventories to the various international obligations in a consistent, transparent, complete and timely way. For this purpose it makes available a software package. In addition specifically for road transport it continued the further development of COPERT, resulting in COPERT 2 that was made available to participating countries in 1997. COPERT 2 makes use of intermediate results from COST 319 and MEET.

In the work programme of ETC/AE is included the updating of COPERT 2 based on the main results of this report for road transport. It is intended to exchange further information between different projects and to improve the understanding of user needs. Therefore COPERT 3 is expected to be finalised in 1999.

UNECE/CLRTAP and encourages and recommends countries to report by using the joint atmospheric emission inventory guidebook, according to the IPCC source sector split. After a first edition [EEA, 1996], a revised edition [EEA, 1998], the second edition of the guidebook will be published by the European Environment Agency in 1998, including the latest COST 319 and MEET results.

UNFCCC encourages parties to report their national emission inventories using the IPCC guidelines for national greenhouse gas inventories [IPCC/OECD/IEA, 1997]. In these guidelines experiences from several European experts and organisations have been included. Possibly these guidelines will be revised in the future and might then include results from COST 319 and MEET.

It should be noted that for both conventions countries can report also using their own more detailed methods, provided these methods, as well as the differences with the "standard/reference" approaches in the guidebook and/or guidelines, are well documented.

More information is provided in EEA and OECD internet sites: http://www.eea.eu.int and http://www.oecd.org/env/cc/tocinv.htm.

Annex 2: Memorandum of understanding (M.O.U.)

The Signatories to this Memorandum of Understanding, declaring their common intention to participate in a European project in the field of estimation of pollutant emissions from transport, have reached the following understanding:

Section 1

1. The Signatories intend to co-operate in a project to promote research in the field of estimation of pollutant emissions from transport (hereinafter **referred to** as the "project").
2. The main objective of the project is to develop harmonised methods and models to be applied in different estimation cases of pollutant emissions.
3. The Signatories hereby declare their intention of carrying out the project jointly, in accordance with the general description given in Annex II, adhering as far as possible to a timetable to be decided by the Management Committee referred to in Annex I.
4. The project will be carried out through concerted action, in accordance with the provisions of Annex I.
5. The overall value of the activities of the Signatories under the Project is estimated at ECU 1 000 000 at 1992 prices.
6. The Signatories will make every effort to ensure that the necessary funds are made available under their internal financing procedures.

Section 2

The Signatories intend to take part in the Project in one or several of the following ways:

(a) by carrying out studies and research in their technical services or public research establishments (hereinafter referred to as "public research establishments");

(b) by concluding contracts for studies and research with other organisations (hereinafter referred to as "research contractors?");

(c) **by contributing** to the provision of a Secretariat and/or other co-ordinatory services or activities necessary for the aims of the project to be achieved;

(d) by making information on existing relevant research, including all necessary basic data, available to other Signatories;

(e) by arranging for inter-laboratory visits and by co-operating in a small-scale exchange of staff in the later stages.

Section 3

1. This Memorandum of Understanding will take effect for four years upon signature by at least five Signatories. This Memorandum of Understanding may expire on the entry into force of an agreement between the European **Communities** and the non-Community COST member countries having the same aim as that of the present Memorandum of Understanding. This change in the rules governing the project is subject to the prior agreement of the Management Committee referred **to in Annex I.**

2. This Memorandum of Understanding may be amended in writing at any time by arrangement between the Signatories.

3. A Signatory which intends, for any reason whatsoever, to terminate its participation in the Project will notify the Secretary-General of the Council of the European Communities of its intention as soon as possible, preferably not later than three months beforehand.

4. If at any time the number of Signatories falls below four. the Management Committee referred to in Annex I will examine the situation which has arisen and consider whether or not this Memorandum of Understanding should be terminated by decision of the Signatories.

Section 4

1. This Memorandum of Understanding will, for a period of six months from the date of the first signing, remain open for signing, by the Governments of the countries which are members of the COST framework and also by the European Communities.

2. The Governments referred to in the first subparagraph and the European Communities may take part in the Project on a provisional basis during the abovementioned period, even though they may not have signed this Memorandum of Understanding.

3. After this period of six months has elapsed, application to sign this Memorandum of Understanding from the Governments referred to in paragraph 1 or **from the European** Communities will be decided upon by the Management Committee referred to in Annex I, which may attach special conditions thereto.

4. Any Signatory may designate one or more competent public authorities or bodies to act on its behalf, in respect of the implementation of the Project.

Section 5

This Memorandum of Understanding is of an exclusively recommendatory nature. It will not create any binding legal effect in public international law.

Section 6

1. The Secretary-General of the Council of the European Communities will inform all Signatories of the signing dates and the date of entry into effect of this Memorandum of Understanding, and will forward to them all notices which he has received under this Memorandum of Understanding.
2. This Memorandum of Understanding will be deposited with the General Secretariat of the Council of the European Communities. The Secretary-General will transmit a certified copy to each of the Signatories.

Geschehen zu Brüssel am neunundzwanzigsten April neunzehnhundertdreiundneunzig.

Done at Brussels on the twenty-ninth day of April in the year one thousand nine hundred and ninety-three.

Fait à Bruxelles, le vingt-neul avril mil neuf cent quatre-vingt-treize.

For the Government of the Republic of Greece

For the Government of the Republic of Finland

Für die Regierung der Schweizerischen Eidgenossenschaft
Pour le Gouvemement de la Confédération suisse
Per il Governo della Confederazione svizzera

For the Government of the Slovak Republic

For the Government of the United Kingdom of Great Britain and Northern Ireland

Annex 1 of the M.O.U.: Co-ordination of the project

Chapter I

1. A **Management Committee (hereinafter** referred to as "the Committee") will be set up, composed of not more than two representatives of each Signatory. Each representative may be accompanied by such experts or advisers as he or she may need.

   The Governments of the countries which are members of the COST framework and the European Communities may, in accordance with the second subparagraph of Section 4(1) of the Memorandum of Understanding, participate in the work of the Committee before becoming Signatories to the Memorandum, without, however, having the right to vote.

   When the European Communities are not a Signatory to the Memorandum of Understanding, a representative of the Commission of the European Communities may attend Committee meetings as an observer.

2. The Committee will be responsible for co-ordinating the Project and in particular for making the necessary arrangements for:
   (a) the choice of research topics on the basis of those provided for in Annex II including any modifications submitted to Signatories by the competent public authorities or bodies; any proposed changes to the Project framework will be referred for an opinion to the COST Technical Committee on Transport;
   (b) advising on the direction which work should take;
   (c) drawing up detailed plans and defining methods for the different phases of execution of the Project;
   (d) co-ordinating the contributions referred on in subparagraph (c) of Section 2 of the Memorandum of Understanding;
   (e) keeping abreast of the research being done in the territory of the Signatories and in other countries;
   (f) liasing with appropriate international bodies;
   (g) exchanging research results amongst the Signatories to the extent compatible with adequate safeguards for the interests of Signatories, **their competent public authorities** or bodies and research contractors in respect of industrial property rights and commercially confidential material;
   (h) drawing up the annual interim reports and the final report to be submitted to the Signatories and circulated as appropriate;
   (i) dealing with any problem which may arise out of the execution of the Project, including those relating to possible special conditions to be attached to accession to the Memorandum of Understanding in the case of applications submitted more than six months after the date of the first signing.

3. The Committee will establish its rules of procedure.

4. The Secretariat of the Committee will be provided at the invitation of the Signatories by either the Commission of the European Communities or one of the Signatory States.

Chapter II

1. Signatories will invite public research establishments or research **contractors in their** territories to submit proposals for research work to their respective competent public

authorities or bodies. Proposals accepted under this procedure will be submitted to the Committee.

2. Signatories will request public research establishments or research contractors, before the Committee takes any decision on a proposal. to submit to the public authorities or bodies referred to in paragraph 1 notification of previous commitments and industrial property rights which they consider might preclude or hinder the execution of the Projects of the Signatories.

Chapter III

1. Signatories will request their public research establishments or research contractors to submit periodical progress reports and a final report.
2. The progress reports will be distributed to the Signatories only, through their representatives on the Committee. The Signatories will treat these progress reports as **confidential and will not use them for purposes other** than research work. In order to assess better the final data on the action, the Signatory States are invited, for the preparation of the final report. to state the approximate level of spending at national level arising from their involvement in the said action. The final report on the results obtained will have much wider circulation, covering at least the Signatories' public research establishments or research contractors concerned.

Chapter IV

1. In order to facilitate the exchange of results referred to in Chapter I, paragraph 2(g), and subject to **national law, Signatories intend to** ensure, through the inclusion of appropriate terms in research contracts, that the owners of industrial property rights and technical information resulting from work carried out in implementation of that part of the Action assigned to them under Annex II (hereinafter referred to as "the research results") will be under an obligation. if so requested by another Signatory (hereinafter referred to as the "applicant Signatory"), to supply the research results and to grant to the applicant Signatory or to a third party nominated by the applicant Signatory a licence to use the research results and such technical know-how incorporated therein as is necessary for such use if the applicant Signatory requires the granting of a licence for the execution of work in respect of the Action.

   Such licences will be granted on fair and reasonable terms, having regard to commercial usage.

2. Signatories will, by including appropriate clauses in contracts placed with research contractors, provide for the licence referred to in paragraph 1 to be extended on fair and reasonable terms, having regard to commercial usage, to previous industrial property rights and to prior technical know-how acquired by the research contractor insofar as the research results could not otherwise be used for the purpose referred to in paragraph 1.

   Where a research contractor is unable or unwilling to agree to such extension, the Signatory will submit the case to the Committee. before the contract is concluded; thereafter the Committee will state its position on the case, if possible after having consulted the interested parties.

3. Signatories will take any steps necessary to ensure that the fulfilment of the conditions laid down in this Chapter will not be affected by any subsequent transfer of rights to ownership of the research results. Any **such transfer will be notified** to the Committee.

4. If a Signatory terminates its participation in the Project, any rights of use which it has granted, or is obliged to grant to, or has obtained from. other Signatories in application of the Memorandum of Understanding and **concerning work** carried out up to the date on which the said Signatory terminates its participation will continue thereafter.
5. The provisions of paragraphs 1 to 4 will continue to apply after the period of operation of the Memorandum of Understanding has expired and will apply to industrial property rights as long as these remain valid, and to unprotected inventions and technical know-how until such time as they pass into the public domain other than through disclosure by the licensee.

Annex II of the M.O.U.: General description of the project

1. Background

It has long been recognised that transport, and in particular road traffic, is an important source of pollution in Europe. As an example, the recently published results of the CORINAIR programme show that the contribution of road traffic to total man-made NOx emissions was estimated to be about 55%. while the contribution to total VOC emissions was about 54% in 1985 in the European Community. Additionally, transport has also been identified as the third important source of greenhouse gas emissions, emitting approximately 25% of total $C0_2$ emissions in the EC, more than three quarters of which are allocated to road traffic. Obviously, the **contribution of these emissions** varies significantly from one country to another (according to particular vehicle fleet and fuel characteristics) and between urban agglomerations and rural areas (due to the different vehicle usage patterns and actual vehicle density). Moreover, seasonal variations and geographical features strongly influence the local patterns of the emissions.

At present, the research carried out in Europe in the field of transport emissions is aimed mainly at improving the knowledge on the actual emissions (through measurements of unit vehicle emissions and driving behaviour, as well as assessment of vehicle fleet characteristics), but it is also directed towards studying the potential solutions of air pollution related to transport (via both technological and socio-economic measures).

The main part of these research activities is conducted at local or national level, while an increasing number of research teams is producing an equally increasing number of different approaches. The actual co-ordination of these activities is very limited: it is allocated either to exchange of ideas and information in conferences or to first level evaluations in **working groups (e.g. the** CORINAIR working group on emissions from road **traffic).**

Moreover, common research projects are as yet very rare in this field (e.g. DRIVE-MODEM or German-Swiss-Austrian co-operation) and mainly aimed at improving knowledge on vehicle unit emissions. The considerable amount of partial solutions tested at local level needs to be co-ordinated and analysed on a commonly accepted base; knowledge accumulated on emissions throughout Europe has to be pooled to form a basis for common tools.

It should be mentioned that the estimation of emissions from transport might be, more than in the case of other source categories. a permanent task. This is due to the relatively great changes in this sector e.g. the turnover of the fleets is rather short, legislation requirements change quickly, the number of vehicles and mobility increase steadily. These changes require not only continuation of the work but also a constant adaptation and up-dating of the methods applied.

The scientists and research laboratories in the field of transport emissions and the economy of this sector express in this context the need for a wider collaboration and co-ordination of the related research activities.

2. Objectives

It should be recalled that various approaches have been developed so far **for the** estimation of transport emissions, based on the available statistical and laboratory data. A characteristic basic to all these approaches is the formula:

d(Emissions) [g] = Unit Emission [g/activity unit] Mactivity) [activity unit]

where activity unit = distance [m] or quantity of fuel fkg] or time of operation [h].

Depending on the available data and on the level of detail imposed by the aim of the calculations, the application of the above equation is in principle possible either in a differentiated or an integrated form. e.g.

- using yearly averages of emission factors for a broad calculation of annual emissions over a large territorial unit,
- introducing statistical dependencies for the emission factors (e.g. speed, age, cylinder capacity) for a first level split of the emissions,
- combining emission maps with vehicle characteristics and driving patterns, for the detailed calculation of the emissions on a local (e.g. street) level.

COST Project 319, the main objectives of which are:

1) to assess the current situation and

2) to propose and evaluate solutions for the future

is designed to:

(a) analyse the methods and the results of research,

(b) carry out synthesis of the available data and develop appropriate tools,

(c) co-ordinate research

on direct or indirect emissions of regulated and unregulated pollutants as well as fuel consumption or energy use by transport.

As regards aim (a), it has to be stressed that due to the differences in the applied methods, as well as in the statistical but - predominantly -experimental data, major inconsistencies in the calculated emission levels have been identified so far among the research results reported by different institutions. The need for harmonisation, transparency and comparability of data has already been identified and requested by all investigators in the field.

In this context, the first major task of COST Project 319 should be data collection on :

- emission factors and functions of the different vehicle and engine categories and transport modes. Data collected should cover not only existing vehicles, but also future ones. Moreover, an effort has to be made in order to collect emission data covering all possible detail of expression, i.e. from surrogate emission factors to engine emission maps;
- driving behaviour. This is of particular interest for road traffic , as it has a major effect on emission levels, specifically in urban areas;

- passenger and freight transport vehicle use. Vehicle usage (e.g. annual mileage, split into different road categories, occupancy rates, actual carrying capacity, etc) is of high importance, as it influences total emissions via the second term of the basic equation. At this point it should be recalled that technical policy plans and socio-economic measures are already underway to influence the general usage of the vehicles, in order to comply with targets such as CO_2 stabilisation and reduction;

- statistics of different vehicle fleets, referring both to road traffic (e.g. number of passenger cars - gasoline and diesel -, light duty vehicles, heavy goods vehicles, two-wheeled vehicles. lifetime functions. age - capacity -weight distribution etc.), as well as to other modes of transport (trains, aircraft etc).

Knowledge already collated on the abovementioned topics, together **with that to be acquired in the** future, will facilitate the analysis of the methods developed and applied so far, in order to determine the extent of application, **to identify the** limitations and to produce recommendations as to how these methods should be applied.

As regards aim (b), a synthesis of the baseline data will be conducted (both in terms of raw data and of available methodologies), in order initially to evaluate existing procedures and subsequently to produce and propose harmonised methodological approaches to be applied in different estimation cases. Such methods have to take into account the peculiarities of each specific application, in an attempt to develop also the necessary interfaces between applications of different local and temporal resolution. Nevertheless, it is necessary to categorise the different application levels, in order to optimise in terms of efforts and accuracy.

In this context, it is envisaged that work will focus on the development of a number of tools, in particular:

- Creation and maintenance of a data base on vehicle unit emissions. This may be envisaged as a priority task, as it will attempt to incorporate in an intelligent way the major portion of existing knowledge on vehicle unit emissions and to afford the possibility of usage for different purposes and by different users;

- simulation of the emissions, e.g. from steady-state and transient emission **maps, coupled** to vehicle characteristics and fed with traffic conditions. In this activity it is planned to take advantage of the experience gained with existing models for traffic engineering applications;

- emission inventorying methodologies, taking into account different **approaches for the** local, national and international scale;

- emission trends analysis and forecast models for the evaluation of transport policies. traffic management and efficiency of technological developments. Economic research techniques for studying the evolution of mobility and its determinants are highly important in this context.

As far as aim (c) is concerned, the identification of the gaps in the knowledge of the emission behaviour of the different transport sub-groups will be a major outcome of the previous activities. COST project 319 should also be aimed at co-ordinating and supporting the research activities in the identified fields. Engineering topics such as emissions of heavy duty vehicles. emissions of two-wheeled vehicles. emissions from two-stroke engines, evaporation losses, cold start emissions, unregulated pollutants, emissions of aircraft, trains and ships can already be mentioned as examples which will require particular attention. Additionally, factors that influence vehicle operation, such as traffic management techniques, and social and economic policies that influence transport activity should be given attention.

3. Work method and group management

Clearly, the objectives stated above relate both to scientific fields (e.g. unit emissions, vehicle usage patterns) and to fundamental synthetical requirements, such as the knowledge of actual emission situations (e.g. inventories) and the evaluation of potential solutions (e.g. traffic **management, vehicle** use etc.). In this respect the researchers potentially interested in these activities are of different specialities (engine specialists, economists, planners etc): it is therefore necessary to envisage both inter-disciplinarity and exchange of expertise.

COST Project 319 will thus have to operate fundamentally as one group. in order to ensure its cohesion, and in sub-groups in order to ensure its scientific efficiency. Hence the following scheme may be envisaged:

- in the beginning: plenary sessions in order precisely to define the objectives of the group, more enlarged than its initial composition. With this in mind, wide publicity is required in order to attract the interest of experts in the field.
- as a second stage: definition of sub-groups
- finally: work in subgroups and periodic plenary meetings.

As a first approach, the proposal is to form three main sub-groups. in order to deal with three different levels of emission estimation from transport:

- Sub-group A: Emission Factors and Functions

  It is proposed that Sub-Group A concentrate mainly on the field of emission factors, dealing with actual emissions. technology (engine and **fuel) related alternatives, driving** patterns dependencies, covering both **regulated and unregulated emissions.**

- Sub-group B: Traffic Characteristics

  The tasks of Sub-group B will include traffic management, driving behaviour, fleet statistics, mobility analysis, cost-price impacts etc.

- Sub-group C: Tool Harmonisation and Development

  The tasks that could be envisaged by Sub-Group C may include development of methods and techniques for the estimation of transport emissions (to be used in inventories, forecasts etc), preparation of relevant guidelines (with, possibly, appropriate publications) and development of relevant software tools (e.g. engine and vehicle models). In this framework, the creation and maintenance of a database on emission factors from the different transport modes could, for example, be contemplated.

It is evident that each group will have to take into account the existing methodologies developed so far in different countries and that the different sub-group activities and targets will have to be clearly linked to the main objectives of the work.

Collaboration and co-ordination of COST Project 319 with ongoing activities at international level are absolutely necessary. Thus, for example, CORINAIR (European Environmental Agency - Task Force), UN ECE inventory work, as well as other relevant COST activities (in particular CITAIR) will have to be closely followed. In this respect COST Project 319 may play an **important** role in linking the research on transport emissions.

Finally, the dissemination of the information produced within the framework of the project is also of importance, as it may provide a significant feedback to both the quality of the data and the methodologies developed.

4. Duration

The duration of the project is four years (1993-1996).

As a first step, it is anticipated that periodic meetings (one every six months) of each working sub-group and one seminar (geared to a meeting of the technical committee) will be necessary.

5. Participants

Initially the working group will consist of scientists from Austria. Belgium, Finland, France, Germany, Greece, Italy, Sweden and the United Kingdom. However, the project still needs to be widely advertised in order to attract the interest of scientists in all European countries, as well as from industry.

6. Estimated cost

The cost of direct participation in this activity by the nine initial members is estimated to be ECU 1 000 000.

In addition there is extensive research in progress nationally, which is estimated to be in the order of ECU 70 000 000.

Annex 3: Structure of the action: working groups

Chairman: R. Joumard (F)

Vice-chairmen: J. Hickman (UK), O.H. Koskinen (FIN), Z. Samaras (GR)

Secretary: R. Mayet (CEC)

A : Emission Factors and Functions O.H. Koskinen (FIN)												B : Traffic Characteristics J. Hickman (UK)					C : Inventorying Tools Z. Samaras (GR)		D : Non-Road Transport S. Sorenson (DK)		
A1	A2	A3							A4			B1	B2		B3	B4	C1	C2	D1	D2	D3
Engine Maps	Instant Veh. Emis.	Average Vehicle Emissions							Future Vehicle & Life Cycle Emissions			Traffic Management	Driving Behaviour		Traffic Composition	Mobility	Bottom-up Appr.	Top-down Appr.	Rail Transport	Air Transport	Waterborne Transp
O.H. Koskinen (FIN)	P. Sturm (A)	R.C. Rijkeboer (NL)							L. Donovan (IRL)			J. Perez-Cerezo (E)	U. Hammarström (S)		N. Kyriakis (GR)	W. Hecq (B)	E. Negrenti (I)	M. Keller (CH)	S. Sorenson (DK)	M. Kalivoda (A)	C. Trozzi (I)
		A3A	A3B	A3C	A3D	A3E	A3F	A3G	A4A	A4B	A4C		B2A	B2B							
		Hot Emis. Fact. / PC	Cold Start Emis.	Evaporative Emis.	Gradient Infl.	Light Duty Veh.	Heavy Duty Veh.	Motor-cycles	Alternative Fuels	New Vehic. Tech.	Life Cycle Emis.		Simulation Models	Measures & Meas. Meth.							
		Z. Samaras (GR)	R. Joumard (F)	R.C. Rijkeboer (NL)	D. Hassel (D)	Z. Samaras (GR)	J. Hickman (UK)	R.C. Rijkeboer (NL)	L. Donovan (IRL)	S. Sorenson (DK)	A. Lewis (UK)		U. Hammarström (S)	M. André (F)							

Annex 4: Working group meetings

Sub-group (see annex 3)	date	location	participants
A+B+C+D	8-9 Nov. 1994	Brussels	30
D	30 Jan. 1995	Vienna	6
A2	2 Feb. 1995	Graz (A)	14
A4	11 Feb. 1995	Birmingham (UK)	5
A3	27 March 1995	Delft (NL)	8
A1	16 May 1995	Helsinki	12
B	June 1995	Madrid	8
A+B+C+D	27-28 Nov. 1995	Brussels	35
A3F	7 May 1996	Cologne (D)	8
A+B+C+D	30 May 1996	Bron (F)	25
A2 + C	10 June 1996	Thessaloniki (GR)	15
B2	19-20 Sept. 1996	Linköping (S)	16
A1 + A4	21 Oct. 1996	Nuneaton (UK)	6
A1 + A3F	29 Oct. 1996	Graz (A)	11
B2 + B3	25 April 1997	Zürich (CH)	6
A4 + COST 616	12-13 May 97	Naples (I)	125
A1 + A3F	6 June 1997	Delft (NL)	9
D2	29 August 1997	Vienna	5
French participants	4 Sept. 1997	Arcueil (F)	17
C	29 Sept. 1997	Prague	26
A4	14 Nov. 1997	Paris	10
D2	9 Dec. 1997	Brussels	6
A2	4 Feb. 1998	Thessaloniki (GR)	9
A3A + A3E	5 Feb. 1998	Thessaloniki (GR)	14
D2	20 April 1998	Copenhagen	7
C	4 May 1998	Rome	18
French participants	11 June 1998	Paris	24
A2	18 June 1998	Graz (A)	8

In addition 12 management committee meetings were held every 6 months with 20 to 30 participants each, where technical discussions took place also: In Brussels (EC, May and October 1993, 28 November 1994, 7 April 1997), Avignon (F, INRETS, 10 June 1994), Helsinki (Min. Transport, 15 May 1995), Brussels (ULB, 28 November 1995), Bron (F, INRETS, 31 May 1996), Barcelona (E, UPC, 7 October 1996), Prague (CUAP, 30 September 1997), Rome (ENEA, 5-6 May 1997) and finally Budapest (KTI, 1-2 October 1998).

Annex 5: List of the active members per domain

See annex 3 for the meaning of the working group numbers (A1, A2 ... D3).

w : **member** of the working group

* : specialist

			Emission Factors				Traffic				Tools		Non-Road		
			A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	D1	D2	D3
Faiz Asif	World Bank	Argentina			*		*		*	*					
Hausberger Stefan	Technical Univ. Graz	Austria		w	w										
Kalivoda Manfred	Consultant	Austria											w	w	
Medinger Walter	Municipality Linz	Austria									*	*			
Pischinger Rudolf	Technical Univ. Graz	Austria	*	w	*	*		*			*	*			
Reiter Christoph	Technical Univ. Graz	Austria		w	*						*	*			
Sammer Gerd	Univ. Bodenkultur Vienna	Austria					*			*					
Schinagl Gerhid	Technical Univ. Graz	Austria		w											
Sturm Peter	Technical Univ. Graz	Austria	w	w	w			w	w		w	w			
De Vlieger Ina	VITO	Belgium	w	w	*										
Dunker Reiner	CEC-DG XII.C.3.	Belgium				*								*	
Favrel Vincent	CEESE	Belgium								w					
Gilson Benoit	CEESE	Belgium								w					
Hecq Walter	CEESE - ULB	Belgium			*	*			*	w		*	*	*	*
Mahieu Vincent	ULB	Belgium			w										
Toussaint Yves	Univ. Liège	Belgium	*	*	*			*							
Vandenberghe Christian	Eurocontrol	Belgium												w	
Barzev Kiril	Technical Univ. Rousse	Bulgaria	w		w										
Otto Karel	Czech Univ. Agric. Prague	Czech Rep.		*	*										
Volák Vladimir	Motor Vehicle Research Institute	Czech Rep.	*	*	*	*							*		
Bendtsen Hans	Road Directorate	Denmark					*	*	*	*	*				
Coffey Robert	Denmarks Tech. Univ.	Denmark			*	w									
Fenger Jes	Nat. Environmental Research Inst.	Denmark		*							*	*			
Jol André	European Environment Agency	Denmark									w	w			
Michelsen Nic	Civil Aviation Administration SLV	Denmark												w	
Sorenson Spencer C.	Technical Univ. Denmark	Denmark	*	*	w	*						*	w		
Winther Morten	Nat. Environmental Research Inst.	Denmark			*									w	
Juva Ari	Neste Oy	Finland	*		*										
Karhula Mervi	Finnish National Road Adm.	Finland						*	*		*	*			
Koskinen Olavi H.	Ministry Transport & Communication	Finland	w	w	w			*	*		w	w			
Laurikko Juhani	VTT Energia	Finland			w										
Mäkelä Kari	VTT	Finland			w		*	w	*	*	*	*	*		
Otterström Tomas	Ekono Energy Ltd	Finland								*					
André Michel	INRETS	France					w	w	w						
Badin François	INRETS	France				w									
Casalé Eric	Scetauroute - DTTS	France			*			*							

w : **member** of the working group * : specialist			Emission Factors				Traffic				Tools		Non-Road		
			A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	D1	D2	D3
Charbonnier Marc-André	Lucas Varity Diesel Syst.	France	*	*	*	*									
Cotte Hélène	PSA Peugeot-Citroën	France		*	*	w	*	*	*		*	*			
Faudry Daniel	IEPE	France								*					
Fontelle Jean-Pierre	CITEPA	France									*	*			*
Gallet Michel	Eres Transport-Ingetrans	France					*	*	*	*	*		*		
Guillermo René	École des Mines de Douai	France			*						*				
Jaecker Anne	IFP	France									*	*		*	
Joumard Robert	INRETS	France	w	w	w			*	w		w	w			
Nicolas Jean-Pierre	LET	France								*					
Nollet Valérie	Univ. S. T. Lille	France	*	*	*	*					*	*			
Noppe Jane	Ademe	France		*	*	w					w	w			
Parfait Christine	RATP	France		*	*										
Paturel Laurent	Univ. Savoie	France			*										
Pereira Alice	LCPC	France				*									
Pillot Didier	INRETS	France						*	*						
Roumégoux Jean-Pierre	INRETS	France	*	*	*										
Thibaut Gérard	Ville de Paris	France					*	*							
Vantelon Alain	BCEOM	France						*							
Villanova A.	RATP	France	*	*	*	*	*	*	*	*	*	*			
Benz Thomas	Benz Consult Gmbh	Germany	*	*	*			*	*		*	*			
Brannolte Ulrich	PTV Consult Gmbh	Germany					*	*	*	*					
Geier Martin	BMW AG	Germany									w	w			
Gruden Dusan	Porsche AG	Germany	*	*	*	*	*		*						
Hassel Dieter	TÜV Rheinland	Germany	w	w	w						w	w			
Heland Jörg	FhG-IFU	Germany	*	*		*								*	
Hellebrandt Pia	Heusch-Boesefeldt GmbH	Germany					*	*				*			
Höpfner Ulrich	IFEU	Germany			*	*					w	w			
Hotes Andreas	Techn. Univ. Berlin, ILR	Germany												*	
Metz Norbert	BMW AG	Germany		*	*	*			*	*					
Niederau Arnold	Heusch-Boesefeldt Gmbh	Germany					*				*		*	*	
Niederle Werner	Umweltbundesamt	Germany		w	w	*					w	w			
Wacker Manfred	Inst. f. Strassen- & Verkehrswesen	Germany	*	*	*		*	*	*						
Weber Franz-Josef	TÜV Rheinland	Germany		*	w										
Kyriakis Nikos	Aristotle Univ. Thessaloniki	Greece	*		*	*		w	w		*	*			
Ntziachristos Leonidas	Lab. Applied Thermodynamics	Greece		w	w						*				
Samaras Zissis	Lab. Applied Thermodynamics	Greece	*	w	w	*			w		w	w	*		*
Michelberger Pál	Budapesti Múszaki Egyetem	Hungary							*	*		*	*	*	
Pollák Iván	Institute for Transport Sciences (KTI)	Hungary	*	*	*				*	*	w	w			
Donovan Liam	Univ. Limerick	Ireland				w									
Cernuschi Stefano	Politecnico di Milano	Italy		*	w						w	w			
d'Elia Sergio	Univ. della Calabria	Italy			*					*					
Danieli Guido	Univ. della Calabria	Italy	*	*	*	*		*	*						
Negrenti Emanuele	ENEA	Italy		w		*	*	w		*	w	*			
Police Giuseppe	Istituto Motori CNR	Italy		*	*										
Rapone Mario	Istituto Motori CNR	Italy						w			w	w			

w : **member** of the working group * : specialist			Emission Factors				Traffic				Tool s		Non-Road		
			A 1	A 2	A 3	A 4	B 1	B 2	B 3	B 4	C 1	C 2	D 1	D 2	D 3
Skouloudis Andreas	CCR/ISPRA	Italy									*	*			
Trozzi Carlo	Techne SRL	Italy									*	*		*	w
Vaccaro Rita	Techne SRL	Italy													w
Milukaite Androné	Institute of Physics	Lithuania			*										
Wane Hamdou Rabby	CERPOD	Mali						*	*		*				
Gong Rose	Industrial Res. Ltd	New Zealand		*											
Larssen Steinar	Norwegian Inst. Air Research	Norway			*						*	*			
Rypdal Kristin	Statistics Norway	Norway									*	*		w	*
Adamski Andrzej	Univ. Mining & Metallurgy	Poland		*	*		*			*					
Bukowy Elzbieta		Poland		*	*	*	*	*	*	*	*	*	*		*
Lukanin Valentin	MADI-TU	Russia		*	w	*		*	*	*					
Nemtchinov Michail	Moscow State Auto. Road Inst.	Russia		*	*		*		*						
Sinyavski Vladimir V.	MADI-TU	Russia		*	*	*									
Krakovsky Pavol		Slovakia	*	*	*			*	*			*	w		
Baldasano José	Univ. Politèc. Catalunya	Spain									w	w			
Laguna J.Pablo	INTA	Spain		*	w										
Pérez-Cerezo Julia	Environment, Transport & Planning	Spain			*	*	w	*		*	*	*	*	*	
Dahlstedt Sven	VTI	Sweden						*							
Egnell Rolf	Aspen Utvecklings AB	Sweden	w		w										
Ericsson Eva	Lund Inst. Traffic Planning Eng.	Sweden						w			w	w			
Erlandsson Lennart	Motortestcenter	Sweden	w		w										
Flodström Eje	MariTerm AB	Sweden													*
Hammarström Ulf	Swedish Road Traffic Res. Inst.	Sweden	w		w		*	w		*	w	w			
Höglund Paul G.	Royal Institute of Technology	Sweden		w	*		*	w	w		w	w			
Johansson Lars	Swedish State Railways	Sweden			*	*									
Larson Lars-Gunnar	FFA	Sweden		*	*						*			w	
Sjöbris Anders	MariTerm AB	Sweden													*
Sjödin Äke	Swedish Environ. Res. Inst.	Sweden		*	*								*	*	*
Wallin Mats	AB Svensk Bilprovning	Sweden	*	*	w										
de Haan Peter	Infras AG	Switzerland		w											
Evéquoz Roger	OFEFP	Switzerland	*	*	*			*	*		w	w	*	*	*
Keller Mario	Infras AG	Switzerland		w	w			w	w		w	w			
Schweizer Thomas	EMPA	Switzerland		w	*										
Brok Paul	National Aerospace Lab. NLR	The Netherlands												w	
Riemersma Iddo	TNO-WT	The Netherlands		*	*						*				
Rijkeboer Rudolf C.	TNO-IW	The Netherlands	w		w	*					w	w			
Göktan Ali	Techn. Univ. Istanbul	Turkey	*		*			*							
Uyumaz Ali	Istanbul Tech. Univ.	Turkey						*							

w : **member** of the working group * : specialist			Emission Factors				Traffic				Tools		Non-Road		
			A 1	A 2	A 3	A 4	B 1	B 2	B 3	B 4	C 1	C 2	D 1	D 2	D 3
Boulter Paul G.	TRL	U.K.		w	w										
Charters Derek	MIRA	U.K.			*	w		*			*				
Chiquetto Sergio	TTR	U.K.			*										
Davison Paul	AEA Technology Environment	U.K.				*									
Falk Robert S.	DTI - Dept Trade Industry	U.K.												w	
Hickman John	TRL	U.K.	w	w	w	*	w	w	w		w	w			
Mc Crae Ian	TRL	U.K.		*	*		*		*				*		
Moon David	AEA Technology Environment	U.K.				*									
Namdeo A.K.	Univ. Nottingham	U.K.			*				*						
Newton Peter J.	DTI	U.K.												*	
Noons Richard	MIRA	U.K.				w					w	w			
Swann Jaimie	MIRA	U.K.				w									
Williams Ian	Middlesex Univ.	U.K.		*	*		*				*	*			

Annex 6: Coordinates of the network members

Name : specialist (see annex 5) **Name** : only interested by results	address	phone number *fax number* e.mail	scientific fields
Pr **Adamski** Andrzej	**Univ. Mining & Metallurgy** - Inst. Automatics - - 30-059 Cracow - Poland	+48 12 34 15 68 or 17 28 51 *+48 12 34 15 68* aad@earth.ia.agh.edu.pl	traffic management and control (individual and public transport), transport environmental impacts measurements, modelling and estimation, multicriteria networks optimisation problems (optimal algorithms, tools etc.), applied mathematics (stochastic, AI-tools, rough sets, optimisation)
Mr **Alary** René	**LCPPP** - 39 bis, rue de Dantzig - - 75015 Paris - France	+33 (0)145 31 14 80 *+33 (0)145 31 27 81*	measurement of urban air pollution
Mme **Allemand** Nadine	**CITEPA** - 10, rue du Faubourg Poissonnière - - 75010 Paris - France	+33 (0)144 83 68 83 *+33 (0)140 22 04 83* citepa@compuserve.com	
Mr **Anders** Peter	**Deutsche Automobilgesellschaft mbh** - Julius-Konegen-str. 24 - - 38114 Braunschweig - Germany	+49 531 59 09 363 *+49 531 59 09 310* anders@daug.de	traffic engineering, exhausts, man-machine interaction
Mr **André** Michel	**INRETS** - case 24 - - 69675 Bron cedex - France	+33 (0)472 14 24 73 *+33 (0)472 37 68 37* andre@inrets.fr	driving behaviour, methods of emission and consumption measurements
Mr **Badin** François	**INRETS** - case 24 - - 69675 Bron cedex - France	+33 (0)472 14 24 74 *+33 (0)472 37 68 37* badin@inrets.fr	electric and hybrid vehicle modelling (cars and bus), energy consumption and emissions of passenger cars and buses, fuel consumption and emissions of internal combustion engines
Mr **Baldasano** José	**Univ. Politèc. Catalunya** - ITEMA - Ap. Correus 508 - 08220 Terrassa - Spain	+34 3 739 83 91 *+34 3 739 83 81* baldasano@pe.upc.es	environmental modelling, air pollution modelling, waste management and pollution prevention
Dr **Barzev** Kiril	**Technical Univ. Rousse** - Lab. on Ecological Problems of Engines - 8, Studentska str. - Rousse 7017 - Bulgaria	+359 82 44 47 16 *+359 82 45 10 92*	reduction of emissions of internal combustion engines by means of additional devices and alternative fuels
Ms **Beckestad** Tone	**Norwegian Inst. Air Research** - PB 100 - - 2007 Kjeller - Norway	+47 63 89 80 87 *+47 63 89 80 50* tone@zardoz.nilu.no	air pollution from vehicles, emissions rather dispersion, effects of air pollution
Dr **Beckroege** Wolfgang	**Kommunalverband Ruhrgebiet** - Kronprinzstr. 35 - - 45128 Essen - Germany	+49 201 2069 614 *+49 201 2069 500 to 502*	transport emissions and immissions, climate, air pollution control, air pollution simulation models
Mr **Bendtsen** Hans	**Road Directorate** - Niels Juels Gade 13 - - 1059 Copenhagen - Denmark	+45 33 93 33 38 *+45 33 93 07 12* hbe@tmvd.dk	road noise, traffic characteristics, road traffic and air pollution, alternative transportation systems, traffic calming
Mr **Benkhelifa** F.	**Explicit** - 69 rue de Rochechouart - - 75009 Paris - France	+33 (0)148 74 36 20 *+33 (0)148 74 36 25* explicit@worldnet.fr	energy, environment

<u>Name</u> : specialist (see annex 5) **Name** : only interested by results	address	phone number *fax number* e.mail	scientific fields
Dr **<u>Benz</u>** Thomas	**Benz Consult Gmbh** - Kaiserstr. 23 - - 76131 Karlsruhe - Germany	+49 721 3 45 80 *+49 721 3 34 81* benzconsult@t-online.de	emission, dispersion, air quality, traffic flow, software development
Pr **Bernhardt** Maciej	**Univ. Technique Varsovie** - faculté SIMR - rue Narbutta 84 - 02-524 Varsovie - Poland	+48 22 49 03 03 or 14 *+48 22 49 03 06*	air pollution from motor vehicles
Mr **Blaison** Jean Claude	**Ministère de l'Environnement** - DPPR - 20, av. de Ségur - 75302 Paris 07SP - France	+33 (0)142 19 14 96 *+33 (0)142 19 14 71*	
Mr **Boch** Wolfgang	**CEC-DGXIII** - Beaulieu 29 - 200, rue de la Loi - 1049 Brussels - Belgium	+32 2 296 35 91 *+32 2 296 23 91*	co-ordination of the environment telematics research activities
Dr **Boschetti** Paola	**IPLA** - Corso Casale 476 - - 101 Torino - Italy	+39 011 899 89 33 *+39 011 898 93 33*	bioenergy (composting, use of organic wastes in agriculture, etc.), road traffic pollution and its environmental impact (on air, soil, vegetation, surface water and man)
Mr **Boughedaoui** Menouer	**Univ. Blida** - BP 270 - - 09000 Blida - Algeria	+213 349 09 13 *+213 349 09 13* boughedaoui@ist.cerist.dz	air pollution, car pollution
Mr **<u>Boulter</u>** Paul G.	**TRL** - Old Wokingham road - - RG45 6AU Crowthorne - United Kingdom	*+44 1344 77 00 28*	
Mr **Bowsher** Jason	**Consultants Environmental Sciences Ltd** - Maunsell House, 160 Croydon rd - Beckenham Kent - BR3 4DE London - United Kingdom	+44 181 663 6730 *+44 181 663 6731* jpb@beck-ces.demon.co.uk	air pollution, noise, water pollution
Dr **<u>Brannolte</u>** Ulrich	**PTV Consult Gmbh** - Beratende Verkehrsingenieure - Gerwigstr. 53 - 76131 Karlsruhe - Germany	+49 721 62 88 80 *+49 721 62 88 88*	traffic management, transport operations, transport economics, emissions, air quality, simulation, modelling, traffic safety
Mr **Breziansky** Ivan	**Transport Research Institute** - Velky Diel - P.P. B-49 - 01139 Zilina - Slovakia	+42 89 41 756 *+42 89 65 28 83* breziansky@vud.sk	evaluation methods of transport impacts upon the environment, emission factors
Mr **<u>Brok</u>** Paul	**National Aerospace Lab. NLR** - Anthony Fokkerweg 2 - - 1059 CM Amsterdam - The Netherlands	+31 20 511 34 79 *+31 20 511 32 10* brok@nlr.nl	aircraft emissions tools, aircraft noise tools, air transport policy analysis, aircraft operational procedures
Mme **<u>Bukowy</u>** Elzbieta	- ul. Zubrzyckiego 42/4 - - 41-606 Swietochlowice - Poland	+48 32 455 483 *+48 32 455 483*	sustainable development, environmental impact assessment for transport and industry, industry and transport emission factors, transport studies and projects
Mrs **Canale** Sascia	- Viale B. Buozzi 47 - - 00197 Roma - Italy	+39 06 808 46 20 *+39 06 807 68 06*	air pollution from transport
Dr **Casado** H.	**Univ. del Pais Vasco** - Faculdad de Farmacia - - 01007 Vitoria - Spain	+34 945 13 16 66 *+34 945 13 07 56 ?* wdpcahoh@vc.ehu.es	acid deposition : dry, wet and total

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Dr **Casalé** Eric	**Scetauroute - DTTS** - Les Pleïades n°35 - Parc nord Annecy - La Bouvarde - 74373 Pringy - France	+33 (0)450 27 39 76 *+33 (0)450 27 39 40* e.casale@scetauroute.fr	pollution control in tunnels, environment, fires in tunnels
Mr **Cecchi** Maurizio	**Italtel / Tecnitel** - - via Abruzzi 3 - Roma - Italy	+39 06 47 80 82 12 *+39 06 47 80 82 44*	dispersion, emissions models, especially in urban areas
Mr **Cernuschi** Stefano	**Politecnico di Milano** - DIIAR - Sez. Ambientale - P.za L. da Vinci, 32 - 20133 Milano - Italy	+39 02 23 99 64 11 *+39 02 23 99 64 99* cernushi@amb1.amb.polimi.it	air pollution, emissions treatment
Dr **Charbonnier** Marc-André	**Lucas Varity Diesel Syst.** - Direction Technique - 9, Bd de l'Industrie - 41000 Blois - France	+33 (0)254 55 59 51 *+33 (0)254 55 39 90*	vehicle emissions, car pollution, exhaust emission reduction, emission measurements, driving cycles, emission database, energy saving
Mr **Charters** Derek	**MIRA** - Watling street - Warks - CV10 0TU Nuneaton - United Kingdom	+44 (0)12 03 35 53 57 *+44 (0)12 03 35 53 55* derek.charters@mira.co.uk	
Mme **Chene** Anne	**Ademe** - 27 rue Vicat - - 75015 Paris - France	+33 (0)147 65 24 35 *+33 (0)147 36 48 83* chene@ademe.fr	
Dr **Chiquetto** Sergio	**TTR** - 16 Bore Street - Lichfield - Staffordshire WS13 6LL - United Kingdom	+44 15 43 41 64 16 *+44 15 43 41 66 81* 100664.427@compuserve.com	emission and dispersion of pollutants, effects of transport policies on air quality, global emissions
Mr **Coffey** Robert	**Denmarks Tech. Univ.** - Department of Energy Technology - Building 403 - 2800 Lyngby - Denmark	+45 45 25 41 66 *+45 45 93 06 63* robert@et.dtu.dk	road vehicle emissions, transport, air pollution and emission factors
Mme **Cotte** Hélène	**PSA Peugeot-Citroën** - DETA/MXT/CED - 18 rue des Fauvelles - 92250 La Garenne-Colombes - France	+33 (0)147 69 39 73 *+33 (0)147 69 87 70*	automobile pollution, emission inventories, emission factors, traffic influence, chemistry of the atmospheric pollution, anthropogenic emissions
Mr **d'Elia** Sergio	**Univ. della Calabria** - Dip.Pianificazione Territoriale - - 87030 Rende (CS) - Italy	+39 09 84 44 68 06 *+39 09 84 44 68 07*	traffic characteristics, pollutant production in traffic
Mr **Dahlstedt** Sven	**VTI** - - - 58195 Linköping - Sweden	+46 13 20 40 66 *+46 13 14 14 36*	road user behaviour
Mr **Danieli** Guido	**Univ. della Calabria** - Dip. di Meccanica - - 87030 Rende (CS) - Italy	+39 09 84 49 48 24 *+39 09 84 83 71 55* g.danieli@unical.it	combustion in engines, biomechanics, pollutant production in urban traffic, electronic measuring equipment
Mr **Darbéra** Richard	**CNRS - LATTS** - ENPC - Cité Descartes - 77455 Marne la Vallée cedex 2 - France	+33 (0)1 64 15 38 34 *+33 (0)1 64 15 38 47* darbera@enpc.fr	
Mr **Davison** Paul	**AEA Technology Environment** - D5 Culham - - Abingdon OX14 3DB - United Kingdom	+44 12 35 46 39 10 *+44 12 35 46 35 74* paul.davison@aeat.co.uk	alternative transport technologies and fuels
Mr **de Haan** Peter	**Infras AG** - Mühlemattstrasse 45 - - 3007 Bern - Switzerland	+41 31 370 19 19 *+41 31 370 19 10* pdehaan@infras.ch	emission factors, air pollution modelling, particulates

Name : specialist (see annex 5) Name : only interested by results	address	phone number *fax number* e.mail	scientific fields
Ms **De Vlieger** Ina	**VITO** - Boeretang 200 - - 2400 Mol - Belgium	+32 14 33 58 31 *+32 14 32 11 85* dvliegeri@vito.be	inventory of Belgian road transport (e.g. activities), technical-scientific support to the Flemish demonstration programs on alternative motor fuels, determination of emission values in real traffic situations based on "on-the-road" emission measurements
Mr **de Winne** Etienne	**Min. Flemish Community** - WTC 3 - Simon Bolivarlaan, 30 - 1210 Brussel - Belgium	+32 2 208 48 25 *+32 2 208 48 00*	traffic engineering, planning for traffic road safety
Mr **Deroyer** Sylvain	**OPET-CS** - - Av. r. Vandendrisshe, 18 - 1150 Bruxelles - Belgium	+32 2 771 53 70 *+32 2 771 56 11*	
Mr **Diebold** François	**INRS** - BP 27 - - 54501 Vandoeuvre cedex - France	+33 (0)383 50 20 00 *+33 (0)383 50 20 60* boulet@inrs.fr	industrial hygiene, pollutant measurements (gas, particulates)
Mr **Donovan** Liam	**Univ. Limerick** - National Technological Park - Plassey - Limerick - Ireland	+353 61 20 28 83 *+353 61 20 29 44* liam.donovan@ul.ie	evaluation and optimisation of performance characteristics of natural gas fuelled vehicles, with special emphasis on exhaust emissions / pollutants, reduction etc.
Mr **Dunker** Reiner	**CEC-DG XII.C.3.** - MO75 3/59 - 200 rue de la Loi - 1049 Bruxelles - Belgium	+32 2 296 16 08 *+32 2 296 67 57*	
Mr **Egnell** Rolf	**Aspen Utvecklings AB** - Hyllegränd 5 - - 22359 Lund - Sweden	+46 46 18 96 20 *+46 46 18 96 25* rolf.egnell@netor.se	emission factors and functions, driving behaviour, inventorying tools
Dr **Ekert** Karol	**Aviation Institute** - Al. Krakowska 110/114 - - 02-256 Warszawa - Poland	+48 22 46 08 01 ext 618 *+48 22 46 44 32*	pollution generated by I.C. engines, combustion processes
Ms **Ericsson** Eva	**Lund Inst. Traffic Planning Eng.** - Lund Univ. - Box 118 - 22100 Lund - Sweden	+46 46 222 91 38 *+46 46 12 32 72* eva.ericsson@tft.lth.se	driving behaviour, traffic modelling
Mr **Erlandsson** Lennart	**Motortestcenter** - Box 223 - - 13623 Haninge - Sweden	+46 8 5006 5612 *+46 8 5002 83 28* lennarte@mtc.se	
Mr **Evéquoz** Roger	**OFEFP** - - - 3003 Berne - Switzerland	+41 31 322 93 40 *+41 31 324 01 37* roger.evequoz@buwal.admin.ch	air pollution due to transport
Dr **Faiz** Asif	**World Bank** - Bouchard 547- Piso 3 - Capital Federal - 1106, Buenos Aires - Argentina	+54 11 43 16 97 00 or 59 *+54 11 43 13 12 33 or 45 86* afaiz@worldbank.org	air pollution control
Mr **Falk** Robert S.	**DTI - Dept Trade Industry** - 151 Buckingham Palace Road - - SW1 W922 London - United Kingdom	+44 171 215 13 92 *+44 171 215 11 80*	
Dr **Faudry** Daniel	**IEPE** - BP 47X - - 38040 Grenoble cedex 09 - France	+33 (0)476 63 57 72 *+33 (0)476 51 45 27*	urban utilities management, environment economics
Mr **Favrel** Vincent	**CEESE** - ULB - 44, av. Jeanne C.P. 124 - 1050 Brussels - Belgium	+32 2 650 33 65 *+32 2 650 46 91* vfavrel@ulb.ac.be	air quality, urban traffic, external costs, air pollution modelling, economic impacts, sustainable mobility

<u>Name</u> : specialist (see annex 5) **Name** : only interested by results	address	phone number *fax number* e.mail	scientific fields
Dr **<u>Fenger</u>** Jes	**Nat. Environmental Research Inst.** - Frederiksborgvej 399 - P.O. Box 358 - 4000 Roskilde - Denmark	+45 46 30 11 25 *+45 46 30 11 14*	climate change, policy analysis, material damage
Mr **Festa** Demetrio	**Univ. della Calabria** - Dipart. di Pianificazione Territoriale - C. da Santo Stefano - 87030 Rende (CS) - Italy	+39 09 84 44 68 06 *+39 09 84 44 68 07*	Traffic flow analysis, transport demand modelling, evaluation of traffic pollution
Mr **<u>Flodström</u>** Eje	**MariTerm AB** - Box 12037 - - 401 42 Gothenburg - Sweden	+46 31 12 20 30 *+46 31 24 58 56* mariterm@algonet.se	emissions from sea (and rail) transportation
Mr **Fontana** Marco	**Lab. Sanità Pubblica - USL 5** - via Leonardo da Vinci 44 - - 10095 Grugliasco (TO) - Italy	+39 011 401 76 21 *+39 011 411 08 37*	air pollution, industrial hygiene, estimation of transport emissions, strategies of monitoring
Mr **<u>Fontelle</u>** Jean-Pierre	**CITEPA** - 10, rue du Faubourg Poissonnière - - 75010 Paris - France	+33 (0)144 83 68 83 *+33 (0)140 22 04 83* 100706.407@compuserve.com	air pollution emission inventories (all sectors), measurements
Mr **Foray** Jean-Pierre	**Ministère de l'Environnement** - DPPR - 20, av. de Ségur - 75302 Paris 07SP - France	+33 (0)142 19 14 33 *+33 (0)142 19 14 67*	elaboration of national and community standards
Mr **Froelich** Daniel	**ENSAM** - Savoie Technolac - BP 295 - 73375 le Bourget du Lac - France	+33 (0)4 79 25 36 55 *+33 (0)4 79 25 36 70*	eco-conception, environmental management
Dr **Frondaroli** Alberto	**Centro Studi sui Sistemi di Trasporto** - via Sallustiana, 26 - - 00187 Roma - Italy	+39 06 488 17 71 *+39 06 481 83 61* csstrm@mclink.it	traffic and transport planning and management
Mr **<u>Gallet</u>** Michel	**Eres Transport-Ingetrans** - 8, crs Général Giraud - - 69001 Lyon - France	+33 (0)4 78 28 89 12 *+33 (0)4 78 39 28 04* 1013612721@compuserve.com	inter-modal transportation, traffic engineering
Mme **Gallez** Caroline	**INRETS** - 2, av du Général Malleret Joinville - - 94114 Arcueil cedex - France	+33 (0)1 47 40 72 73 *+33 (0)1 45 47 56 06* gallez@inrets.fr	mobility, energy and emissions inventories, long term forecasting, policy assessment
Dr **Gambino** Michele	**Istituto Motori CNR** - via Marconi, 8 - - 80125 Napoli - Italy	+39 081 717 71 40 *+39 081 239 60 97* gambino@motori.im.na.cnr.it	CNG and LPG duty engines, oxygenated additives for fuels, regulated and unregulated emissions, after-treatment of emissions
Mr **Gardner** Roger	**UK DERA** - 170 Bldg, Pyestock - Farnborough - Hants, GU14 OLS - United Kingdom	+44 (0) 1252 37 44 26 *+44 (0) 1252 37 24 77* dhlister@dra.hmg.gb	aircraft emissions certification, international regulation controls, aircraft emissions inventories
Mr **Gaudioso** Domenico	**ENEA - Environment Dpt** - CRE Casaccia - Via Anguillarese 301 - 00060 S. Maria di Galeria - Italy	+39 06 3048 3571 or 3894 *+39 06 3048 4925* gaudioso@casaccia.enea.it	emission inventories, air pollution problems at local and global scale
Mr **<u>Geier</u>** Martin	**BMW AG** - Abt. W-2 - Petuelring 130 - Postfach 40 02 40 - 80788 Munich 40 - Germany	+49 89 38 24 67 87 *+49 89 38 24 57 60* martin.geier@bmw.de	
Dr **Giavazzi** Fulvio	**Euron Spa** - Via Maritano, 26 - - 20097 S. Donato Mil. - Italy	+39 02 520 56 421 *+39 02 520 56 612*	fuel quality and emissions

Name : specialist (see annex 5) **Name** : only interested by results	address	phone number *fax number* e.mail	scientific fields
Mr **Gilson** Benoit	**CEESE** - ULB - 44, av. Jeanne C.P. 124 - 1050 Brussels - Belgium	+32 2 650 33 65 *+32 2 650 46 91* gilsonb@ulb.ac.be	mobility models, mobility determinants, sustainable mobility
Pr **Göktan** Ali	**Techn. Univ. Istanbul** - I.T.U. Makina Fakültesi - Gümüssuyu - 80191 Istanbul - Turkey	+90 212 285 34 58 *+90 212 285 34 43* goktan@sariyer.cc.itu.edu.tr	vehicle technology, internal combustion engines, combustion and emissions
Ms **Gong** Rose	**Industrial Res. Ltd** - Gracefield rd - P.O. Box 31-310 - Lower Hutt - New Zealand	+64 4 569 05 34 *+64 4 569 04 31* r.gong@irl.cri.nz	vehicle emission technology, remote sensing for diesel and petrol vehicles, energy applications, combustion efficiency, mathematical modelling, coal pile spontaneous combustion
Dr **Gotsias** Apostolos	**Dept Business Administration** - Univ. of the Aegean - Michalon 8 - 82100 Chios - Greece	+30 1 684 73 23 *+30 271 436 40* agotsia@posidon.servicenet.ariadne-t.gr	air transport, efficiency issues in all transport modes, energy models (statistical, econometric), energy management
Mr **Grimaud** Laurent	**Scetauroute - DTTS** - Les Pleéiades n°35 - Parc Nord Annecy - La Bouvarde - 74373 Pringy cedex - France	+33 (0)4 50 27 39 61 *+33 (0)4 50 27 39 40* l.grimaud@scetauroute.fr	ventilation of road and rail tunnels, atmospheric pollution from tunnels, treatment methods of air pollution in tunnels
Dr **Gruden** Dusan	**Porsche AG** - Poeschestr. 42 - - 70435 Stuttgart - Germany	+49 711 827 56 62 *+49 711 827 52 16*	automotive industry and environment exhaust emission
Dr **Guerrassi** Noureddine	**Lucas** - BP 849 - - 41008 Blois cedex - France	+33 (0)254 55 59 52 *+33 (0)254 55 39 07*	diesel engines research and development
Mme **Guieu-Renzi** Patricia	**Airmaraix** - 67/69 av. du Prado - - 13286 Marseille cedex 6 - France	+33 (0)491 83 63 90 *+33 (0)491 83 64 43* p-guieu@airmaraix.com	traffic and NO, NO2, NOx air pollution
Pr **Guillermo** René	**École des Mines de Douai** - 941, rue C. Bourseul - - 59508 Douai - France	+33 (0)327 71 26 00 *+33 (0)327 71 25 25* guillermo@ensm-douai.fr	atmospheric environment measurements (SO2, NOx, O3, VOC, particles), study of photochemical reactions in the troposphere, emission factor determination for VOC
Mr **Güller** Peter	**Synergo** - Fraumünsterstr. 23 - C.P. 4925 - 8022 Zurich - Switzerland	+41 1 211 40 12 *+41 1 212 39 07*	regional development, transport policy (urban, national, European), ecology, urbanism
Dr **Hahn** Jürgen	**Fraunhofer Inst. Atm. Umweltforsch.** - Kreuzeckbahnstr. 19 - - 82467 Garmisch-Partenkirchen - Germany	+49 88 21 183 210 *+49 88 21 735 73* hahn@ifu.fhg.de	air pollution chemistry, anthropogenic emissions, temporal trends of trace components in the atmosphere
Mr **Hammarström** Ulf	**Swedish Road Traffic Res. Inst.** - Olaus Magnus väg 37 - - 581 93 Linköping - Sweden	+46 13 20 41 72 *+46 13 20 40 30* ulf.hammarstrom@vti.se	traffic signals, model of vehicle costs, mechanistic and empirical models of exhaust emissions for transport sector,
Mr **Hassel** Dieter	**TUV Rheinland** - - - 51105 Köln 1 - Germany	+49 221 806 24 79 *+49 221 806 17 56* d-hassel@compuserve.com	emissions and air pollution caused by traffic

Name : specialist (see annex 5) **Name** : only interested by results	address	phone number *fax number* e.mail	scientific fields
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Pr **Hecq** Walter	**CEESE - ULB** - av. Jeanne, 44 - CP 124 - 1050 Bruxelles - Belgium	+32 2 650 33 77 & 78 *+32 2 650 46 91* whecq@ulb.ac.be	cost assessment of pollution control, externalities, environmental impact, emission inventories, economic optimisation of pollution control
Mr **Heich** Hermann-Joseph	**TÜV Rheinland Sicherheit und Umwelschentz GmbH** - - Konstantin-Wille Strasse, 1 - 51108 Köln - Germany	+49 221 806 20 18 *+49 221 806 17 56*	
Mr **Heland** Jörg	**FhG-IFU** - Kreuzeckbahnstr. 19 - - 82467 Garmisch-Partenkirchen - Germany	+49 88 21 1 83 0 *+49 88 21 7 35 73* schaefer@ifu.fhg.de	remote sensing measurements, FTIR-absorption and emission spectroscopy, combustion chemistry, atmospheric chemistry, aircraft engine emissions
Mrs **Hellebrandt** Pia	**Heusch-Boesefeldt GmbH** - Liebigstr. 20 - - 52070 Aachen - Germany	+49 241 96 69 126 *+49 241 96 69 155*	traffic related environmental planning, emission / immission calculation, environmental impact studies
Mr **Henriet** Alain	**PSA Peugeot Citroën** - DRAS - route de Gisy - 78140 Vélizy - France	+33 (0)141 36 29 30 *+33 (0)141 36 33 78*	automobile pollution, traffic
Mr **Hickman** John	**TRL** - Old Wokingham road - - RG45 6AU Crowthorne - United Kingdom	+44 1344 770 351 *+44 1344 77 00 28* ahickman@trl.co.uk	exhaust emissions, air pollution, energy consumption
Dr **Hitchcock** Guy	**ETSU** - B156 Harwell Didcot - - OX11 0RA - United Kingdom	+44 12 35 43 68 35 *+44 12 35 43 26 62* guy.hitchcock@aeat.co.uk	
Mr **Hivert** Laurent	**INRETS** - 2, av du Général Malleret Joinville - - 94114 Arcueil cedex - France	+33 (0)1 47 40 72 66 *+33 (0)1 45 47 56 06* hivert@inrets.fr	
Dr **Höglund** Paul G.	**Royal Institute of Technology** - Dept Traffic and Transport Planning - - 10044 Stockholm - Sweden	+46 8-790 79 36 or 91 20 or 80 11 *+46 8 21 28 99* phoglund@ce.kth.se	traffic : field measurements, analysis and systems' development, control and intersection design, flow and environment; micro analysis of traffic flow, emission models, traffic behaviour, driving patterns
Dr **Höpfner** Ulrich	**IFEU** - Wilckenstr. 3 - - 69120 Heidelberg - Germany	+49 62 21 47 670 *+49 62 21 47 67 19* 100564.632@compuserve.com	estimation models
Mr **Hotes** Andreas	**Techn. Univ. Berlin, ILR** - Sekr. F3 - Marchstr. 14 - 10587 Berlin - Germany	+49 30 314 26 569 *+49 30 315 90 414* hotti@ilrserv.fb12.tu-berlin.de	air pollution from civil aircraft in the direct vicinity of airports, optimisation of flight routing (North-Atlantic), "ecological" flight routing, usage of APU during ground handling of aircraft
Mr **Hvid** Erling	**Cowi** - Parallelvej 15 - - 2800 Lyngby - Denmark	+45 45 97 22 11 *+45 45 97 22 12*	relations between emission and traffic management, traffic management as a tool for reducing the total environmental load in urban areas (air pollution, noise, traffic accidents ...), specific emissions from vehicles

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Dr **Jaecker** Anne	**IFP** - 1 & 4 av. de Bois Préau - - 92852 Rueil malmaison - France	33-1 47 52 73 25 *33-1 47 52 66 85* anne.jaecker@ifp.fr	air quality modelling, tropospheric chemistry, mission factors, emission inventory
Mr **Janssen van de Laak** Willem H.	**RWS - DWW** - Postbox 5044 - - 2600 GA Delft - The Netherlands	+31 15 699 465 *+31 15 611 361*	soil and air pollution
Dr **Jez** Marian	**Aviation Institute** - Al. Krakowska 110/114 - - 02-256 Warszawa - Poland	+48 22 46 08 01 ext 616 *+48 22 46 44 32*	aviation-generated pollution, dynamics of internal combustion engines, diesel engine pollution
Mr **Jimenez** Jose-Luis	**M.I.T.** - 66-060 - - 02139 Cambridge, MA - USA	+1 617 253 5973 *+1 617 258 0546* jljimene@mit.edu	combustion-generated air pollution, atmospheric chemistry and dispersion, measurement techniques, uncertainty analysis
Dr **Johansson** Lars	**Swedish State Railways** - SJ-HK - Stab Information - 10 550 Stockholm - Sweden	+46 8 762 31 91 *+46 8 411 12 16*	transport & ecology, & health effects, & society planning
Mr **Jol** André	**European Environment Agency** - Kongens Nytorv 6 - - 1050 Copenhagen K - Denmark	+45 33 36 71 44 *+45 33 36 71 99* andre.jol@eea.eu.int	atmospheric emissions (all modes), national inventories and projections, emission reduction measures, air quality, ozone, acidification
Dr **Joumard** Robert	**INRETS** - case 24 - - 69675 Bron cedex - France	+33 (0)472 14 24 77 *+33 (0)472 37 68 37* joumard@inrets.fr	transport and air pollution, emission factors, emission inventory, control and reduction of air pollution
Dr **Jung** Hans Josef	**IABGmbH** - TAF - Einsteinstr. 20 - 85521 Ottobrunn - Germany	+49 89 60 88 34 78 *+49 89 60 88 33 99* jung@iabg.de	atmospheric dispersion of pollutants, photochemical reactions, climate modelling
Mr **Juva** Ari	**Neste Oy** - - Box 310 - 06101 Porvoo - Finland	+358 15 187 3469 *+358 15 187 7636*	low emission traffic fuels, traffic emissions
Dr **Kalivoda** Manfred	**Consultant** - - Aspettengasse 24 - 2380 Perchtoldsdorf - Austria	+43 1 865 67 55 *+43 1 865 67 55* psia-consult@eunet.at	noise control, psycho-acoustics, traffic emissions, traffic planning
Mrs **Karhula** Mervi	**Finnish National Road Adm.** - Traffic and Road Engineering - P.O.B 33 - 00521 Helsinki - Finland	+358 20 444 2342 *358 20 444 2395* mervi.karhula@fieh.fi	driving cycles, emission models
Mr **Keen** Keith	**European Commission-DGVII E2** - Beaulieu 31 5/40 - 200, rue de la Loi - 1049 Brussels - Belgium	+32 2 296 34 69 *+32 2 295 43 49*	transport strategies
Mr **Keller** Mario	**Infras AG** - Mühlemattstrasse 45 - - 3007 Bern - Switzerland	+41 31 370 19 19 *+41 31 370 19 10* mario.keller@infras.ch	economy, environment, transport
Mr **Kerbachi** Rabah	**École Nationale Polytechnique** - 10 av. Hacène Badi - El-Harrach - 16200 Alger - Algeria	+213 2 76 53 01 *+213 2 76 09 66* kerbachi@ist.cerist.dz	atmospheric pollution
Dr **Kettrup** Antonius	**GSF** - Inst. Okologische Chemie - Ingolstädter Landstr.1 - 91465 Neuherberg - Germany	+49 89 3187 4048 *+49 89 3187 3371*	indoor pollution, outdoor pollution, aerosol analysis, PCDD/PIDF, PAH, hydrocarbons
Mr **Kölar** Drahoslav	**Centrum dopravniho vyzkume Parno** - - Botanickà 68a - 66312 Brno - Czech Rep.	+42 5 41 21 32 95 *+42 5 41 21 15 26*	
Mr **Koskentalo** Tarja	**Helsinki Metropolitan Area Council** - Opastinsilta 6 A - - 00520 Helsinki - Finland	+358 9 156 13 58 *+358 9 156 13 34*	Air quality, especially the impact of traffic on air quality

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Mr **Koskinen** Olavi H.	**Ministry Transport & Communication -** Road Administration - Box 33 - 00521 Helsinki - Finland	+358 20 444 25 02 *+358 20 444 23 95* olavi.koskinen@tieh.fi	engine maps of fuel consumption and emissions, driving cycles
Mr **Krakovsky** Pavol	- Osikovà 17/54 - - 010 01 Zilina - Slovakia		car and engine diagnostic methods without dismantling, service life, reliability, fuel consumption, exhaust gas emissions
Mr **Kröbl** Ladislav	**Ustav pro vyzkum motorovych vozidel -** - Lihovarskà 12 - 180 68 Prague 9 - Czech Rep.	+42 2 684 51 28 *+42 2 66 31 03 43*	
Dr **Kyriakis** Nikos	**Aristotle Univ. Thessaloniki -** Lab. Applied Thermodynamics - - 54006 Thessaloniki - Greece	+30 31 99 60 83 *+30 31 99 60 19* nkyr@eng.auth.gr	internal combustion engines, engine emissions, emission modelling, driving pattern development, fleet statistics
Mr **Labrousse** Michel	**Explicit** - 69 rue de Rochechouart - - 75009 Paris - France	+33 (0)148 74 36 20 *+33 (0)148 74 36 25* explicit@worldnet.fr	energy, environment
Mr **Laguna** J.Pablo	**INTA** - Centro Experimentación Homologación Vehículos - Carretera de Ajalvir km. 4 - 28850 Torrejón de Ardoz - Madrid - Spain	+34 1 520 17 23 *+34 1 520 13 19*	motor vehicle emissions
Mrs **Lahtinen** Tarja	**Min. Environment -** Environment Protection Dept - PO Box 399 - 00121 Helsinki - Finland	+358 9 1991 97 04 *+358 9 1991 97 16*	air pollution abatement and traffic
Mr **Lamberts** F.	**CEC-DGXI** - T174 - 1/54c - 200 rue de la Loi - 1049 Bruxelles - Belgium	+32 2 236 87 10 *+32 2 296 95 54* Frank.Lamberts@dg11.cec.be	emissions from all mobile sources
Mr **Larson** Lars-Gunnar	**FFA** - Aeronautical Res. Inst. Sweden - - 161 11 Bromma - Sweden	+46 8 634 13 40 *+46 8 25 34 81* lgl@ffa.se	environmental impacts of air traffic, flight and air traffic simulation
Mr **Larssen** Steinar	**Norwegian Inst. Air Research -** P.O. Box 130 - - 2001 Lilleström - Norway	+47 6 381 41 70 *+47 6 381 92 47*	air pollution problems relating to car exhaust in general, dispersion modelling of car exhaust emissions, emission factors
Mr **Laurikko** Juhani	**VTT Energia -** Moottoritekniikka - PL 1601 - 02044 VTT - Finland	+358 9 456 54 63 *+358 9 460 493* juhani.laurikko@vtt.fi	
Dr **Lehnhart** Lutz	**IER -** Stuttgart University - Hessbrühlstr. 49a - 70565 Stuttgart - Germany	+49 711 780 61 37 *+49 711 780 39 53* ll@iersv1.energietechnik.uni-stuttgart.de	calculation of emission data in Europe with high spatial and temporal resolution
Mrs **Loran** Gisela	**Taller d'Enginyeries SA -** c/ Frederic Mompou, 6, 1er - - 08005 Barcelona - Spain	+34 3 221 10 63 *+34 3 221 62 99* taller_enginyeries@bcn.servicom.es	environmental impact assessment
Pr **Lukanin** Valentin	**MADI-TU** - 64, Leningradskyi prospect - - 125829 Moscow - Russia	+7 095 151 64 12 or 155 03 70 *+7 095 151 03 31 or 151 89 65* lukanin@madi.msk.su	motor vehicle internal combustion engines, ecological problems of engines, design of ecologically sound engines

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Mr **Mahalec** Ivan	**Fac. Mechanical Eng. Naval Arch.** - Univ. Zagreb - Ivana Lucica 5 - 41000 Zagreb - Croatia	+38 1 61 68 159 or 444 *+38 1 61 56 940* ivan.mahalec@fsb.hr	internal combustion engines
Mr **Mahieu** Vincent	**ULB** - SMA CP165 - 50 av. Roosevelt - 1050 Brussels - Belgium	+32 2 650 26 71 *+32 2 650 27 10*	engines : air and fuel management systems
Mr **Mäkelä** Kari	**VTT** - Communities & Infrastructure - P.O. Box 1902 - 02044 VTT - Finland	+358 9 456 45 86 *+358 9 464 850* kari.s.makela@vtt.fi	air pollution emissions (all sectors), modelling, road noise, fuel consumption, traffic characteristics
Mr **Mayet** Rémi	**CEC-DG VII** - BU31-5/34 - 200 rue de la Loi - 1049 Bruxelles - Belgium	+32 2 296 46 77 *+32 2 295 43 49* remi.mayet@dg7.cec.be	COST secretary, projects MEET and COMMUTE, environmental impact assessment, emissions from new transport technologies, external costs from transport
Mr **Mc Crae** Ian	**TRL** - Old Wokingham road - - RG45 6AU Crowthorne - United Kingdom	+44 1344 77 02 71 *+44 1344 77 00 28* imccrae@trl.co.uk	emission modelling, air pollution modelling
Dr **Medinger** Walter	**Municipality Linz** - Env. Dept - Neues Rathaus - Hauptstr. 1-5 - 4041 Linz - Austria	+43 732 70 70 26 90 *+43 732 70 70 26 99*	air quality management, environmental assessment
Dr **Merétei** Tamás	**Institute for Transport Sciences (KTI)** - XI. Thán Károly u. 3-5 - - 1119 Budapest - Hungary	+36 1 1666 945 *+36 1 1666 945*	exhaust emission technology, control of exhaust emissions by catalytic converters, emission inventory, emission factors for several traffic circumstances
Dr **Metz** Norbert	**BMW AG** - Abt. W-2 - Petuelring 130 - Postfach 40 02 40 - 80788 Munich 40 - Germany	+49 89 38 24 65 40 *+49 89 38 24 57 60* norbert.metz@bmw.de	estimation of exhaust emissions including forecast, development of catalyst in the European fleet, CO2 and greenhouse gases, carcinogenic substances, ozone, forest decline, fuel consumption
Mr **Mezghani** Mohamed	**BCEOM** - Place des Frères Mongolfier - - 78286 Guyancourt cedex - France	+33 (0)130 12 48 01 *+33 (0)130 12 10 95* bceom10@calvanet.calvacom.fr	energy saving and environmental impact in the transport sector, traffic management, urban public transport, transport policies
Pr **Michelberger** Pál	**Budapesti Múszaki Egyetem** - Technical Univ. Budapest - Budapest Múegyetem rkp. 3 - Pf 91.1521 Budapest - Hungary	+361 463 17 28 *+361 463 17 83*	vehicles dynamics
Mr **Michelsen** Nic	**Civil Aviation Administration SLV** - Box 744 - 50 Ellebjergvej - 2450 Copenhagen SV - Denmark	+45 36 44 48 48 *+45 36 44 03 03* nimi@slv.dk	aviation
Mme **Mietlicki** Fanny	**Airparif** - 10, rue Crillon - - 75100 Paris cedex 04 - France	+33 (0)1 44 59 40 92 *+33 (0)1 44 59 47 67* fmietlicki@airparif.asso.fr	air quality monitoring and modelling
Dr **Milukaite** Androné	**Institute of Physics** - Gostauto 12 - - 2001 Vilnius - Lithuania	+370 2 64 18 54 *+370 2 61 70 70*	investigation of exhaust emissions, impact of emission on environment, modelling of dispersion from vehicle exhaust

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Ms **Miranda** Ana	**Univ. Aveiro** - Dept of Environment - - 3800 Aveiro - Portugal	+351 34 250 85 *+351 34 292 90* aicm@ci.ua.pt	air quality, air pollution modelling, local scale environmental impact assessment, mesoscale photochemical phenomena and sea-breeze circulations, environmental impact of forest fires
Dr **Moon** David	**AEA Technology Environment** - D5 Culham - - Abingdon OX14 3DB - United Kingdom	+44 12 35 46 35 39 *+44 12 35 46 35 74* david.moon@aeat.co.uk	energy, environment & transport, modelling, environmental impact assessment, emission assessment
Pr **Moussiopoulos** Nicolas	**Aristotle Univ. Thessaloniki** - Box 483 - University Campus - 54006 Thessaloniki - Greece	+30 31 99 60 11 *+30 31 99 60 12* moussio@vergina.eng.auth.gr	environmental engineering, air pollution modelling
Dr **Namdeo** A.K.	**Univ. Nottingham** - Sutton Bonnington Campus - Loughborough - LE12 5RD Loughborough - United Kingdom	+44 115 951 51 51 ext 8719 *+44 115 951 62 61* Anil.Namdeo@nottingham.ac.uk	air pollution monitoring and modelling, vehicle emission rates, airborne particulate pollution, traffic composition
Dr **Negrenti** Emanuele	**ENEA** - ERG-SIRE - C.R.E. Casaccia - 00060 Roma - Italy	+39 06 30 48 41 12 *+39 06 30 48 66 11* negrenti@casaccia.enea.it	modelling of consumptions, emissions and pollutants diffusion from vehicular traffic
Pr **Nemtchinov** Michail	**Moscow State Auto. Road Inst.** - Leningradsky prospect, 64 - - 125829 Moscow - Russia	+7 095 155 07 45 *+7 095 151 03 31 or 89 65* info@madi.msk.su	emission, toxicity, traffic and road characteristics, air, soil, water pollution from roads and streets
Mr **Newton** Peter J.	**DTI** - 151 Buckingham Palace rd - - London SW1W 9SS - United Kingdom	+44 171 215 11 17 *+44 171 215 29 09* peter.newton@air.dti.gov.uk	emissions inventories, aircraft emissions, long term trends, forecasting
Dr **Nicolas** Jean-Pierre	**LET** - ENTPE - rue Maurice Audin - 69518 Vaulx en Velin cedex - France	+33 (0)4 72 04 85 17 *+33 (0)4 72 04 70 92* jean-pierre.nicolas@entpe.fr	socio-economic evaluation of transport policies
Mr **Niederau** Arnold	**Heusch-Boesefeldt Gmbh** - Liebigstr. 20 - - 52070 Aachen - Germany	+49 241 16 805 17 *+49 241 16 805 55*	traffic and environment planning
Mr **Niederle** Werner	**Umweltbundesamt** - Bismarckplatz 1 - - 14191 Berlin - Germany	+49 30 89 03 25 13 *+49 30 89 03 22 85* werner.niederle@uba.de	reduction of impact of traffic by means of traffic calming, traffic management and technical means
Mme **Nollet** Valérie	**Univ. S. T. Lille** - LC3 - bat. C11 - 59655 Villeneuve d'Ascq - France	+33 (0)320 43 67 22 *+33 (0)320 43 69 77* valerie.nollet@univ-lille1.fr	measurement and modelling of photochemical oxidants formation in the troposphere
Mr **Noons** Richard	**MIRA** - Watling street - Nuneaton - Warwickhire CV10 OTU - United Kingdom	+44 (0) 1203 355 000 & 170 *+44 (0) 1203 355 355* richard.noons@mira.co.uk	advanced powertrains, vehicle modelling and simulation
Mme **Noppe** Jane	**Ademe** - 27 rue Vicat - - 75015 Paris - France	+33 (0)147 65 24 77 *+33 (0)147 36 48 83* noppe@ademe.fr	road transport emissions, evaluation methodology and unit emissions, dispersion models

Name : specialist (see annex 5) **Name** : only interested by results	address	phone number *fax number* e.mail	scientific fields
Dr **Nowak** Barbara	**Silesian Univ. Medicine -** Dept Toxicology - ul. Jagiellonska 4 - 41-200 Sosnowiec - Poland	48-22 66 96 11 p164 *48-22 66 89 68* tokswi@informed.slam.katowice.pl	heavy metal emission along roads, trace element content in environment, emission sources, metal concentration function of traffic and road distance
Mr **Ntziachristos** Leonidas	**Lab. Applied Thermodynamics** - Aristotle Univ. Thessaloniki - - 54006 Thessaloniki - Greece	+30 31 99 60 61 *+30 31 99 60 19* leon@eng.auth.gr	average emission functions, particle measurement in exhaust emissions, inventories software development
Mr **O'Grady** Rory	**Bord Gais** - D'Olier Street - - Dublin 2 - Ireland	+353 1602 12 84 *+353 1 602 11 10*	impact of emissions from road transport in urban fleet applications, potential emission reductions with alternative transport fuels e.g. natural gas
Dr **Orfeuil** Jean Pierre	**INRETS** - - - 94114 Arcueil cedex - France	+33 (0)147 40 72 57 *+33 (0)145 47 56 06* orfeuil@inrets.fr	mobility analysis, energy environment assessment
Mr **Otterström** Tomas	**Ekono Energy Ltd** - Tekniiknantie 4A, Otaniemi - P.O. Box 27 - 00131 Helsinki - Finland	+358 9 469 13 29 *+358 9 469 19 81 or 12 75* nto@poyry.fi	energy and environmental economics, environmental impacts of transport and energy systems, life-cycle analysis
Mr **Otto** Karel	**Czech Univ. Agric. Prague -** Suchdol - - 165 21 Praha 6 - Czech Rep.	+420 224 38 21 86 or 87 *+420 220 92 13 63* otto@itsz.czu.cz	
Dr **Pagowski** Zbigniew	**Institute of Aviation -** Al. Krakowska 110/114 - - 02 256 Warszawa - Poland	+48 22 46 44 95 *+48 22 46 44 32*	emission, toxicity, fuel equipment, diesel engines, biofuels
Dr **Pankrath** Jürgen	**Umweltbundesamt -** Postfach 33 00 22 - - 14191 Berlin - Germany	+49 30 23 145 782 *+49 30 23 15 638*	dispersion and chemical reactions of air pollutants, international environmental affairs
Mme **Parfait** Christine	**RATP** - 13 rue Jules Vallès - - 75011 Paris - France	+33 (0)144 36 38 80 *+33 (0)148 04 16 26*	pollution and air quality for public transportation network
Mr **Paturel** Laurent	**Univ. Savoie** - ESIGEC - - 73376 Le Bourget du Lac - France	+33 (0)479 75 88 40 *+33 (0)479 75 88 43*	analyse, metrology in the environment (PAH)
Dr **Pereira** Alice	**LCPC** - 58, bd Lefebvre - - 75732 Paris cedex 15 - France	+33 (0)1 40 43 53 11 *+33 (0)1 40 43 54 94* pereira@lcpc.fr	life cycle analysis of transport infrastructures, environmental impact, assessment methodologies, global emission inventory, air pollution effects on environment
Ms **Pérez-Cerezo** Julia	**Environment, Transport & Planning -** General Pardiñas 112 bis, 1°A - - 28006 Madrid - Spain	+34 1 411 23 11 *+34 1 563 27 99* environment@servicom.es	environment, transport and environment
Mr **Person** Alain	**LHVP** - 11, rue G. Eastman - - 75013 Paris - France	+33 (0)144 97 87 87 *+33 (0)144 97 87 55*	air quality, urban environment, indoor / outdoor air
Mr **Petit** Alain	**Renault** - Direction de la Mécanique - 1, allée Cornuel - 91510 Lardy - France	+33 (0)1 69 27 85 33 *+33 (0)1 69 27 81 40*	
Dr **Pilat** Günter	**Steyr-Daimler-Puch AG -** Technologie Zentrum - Schönauerstr. 5 - 4400 Steyr - Austria	+43 72 52 580 23 34 *+43 72 52 45 112*	engine, transmission and vehicle engineering, fatigue analysis, driving simulation of vehicles for fuel consumption and emissions prediction

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Mr **Pillot** Didier	**INRETS** - case 24 - - 69675 Bron cedex - France	+33 (0)472 14 24 86 *+33 (0)472 37 68 37* pillot@inrets.fr	pollutant emissions of commercial vehicles
Pr **Pischinger** Rudolf	**Technical Univ. Graz** - Inst. Internal Combustion Engines & Thermodynamics - Kopernikusgasse 24 - 8010 Graz - Austria	+43 316 873 72 00 *+43 316 82 14 90* baumann@vkma.tu.graz.ac.at	emission factors (cold start, gradient,...), road resistance of vehicles, traffic emissions
Mr **Police** Giuseppe	**Istituto Motori CNR** - Viale Marconi 8 - - 80125 Napoli - Italy	+39 081 71 77 112 and 111 *+39 081 239 60 97*	Engine optimisation for emissions control
Mr **Pollák** Iván	**Institute for Transport Sciences (KTI)** - Thán K. u. 3-5 - - 1119 Budapest - Hungary	+36 1 205 58 75 or 97 *+36 1 205 58 97 or 59 51*	exhaust emission technology, control of exhaust emissions by catalytic converters, emission inventory, emission factors for several traffic circumstances
Dr **Rapone** Mario	**Istituto Motori CNR** - Viale Marconi 8 - - 80125 Napoli - Italy	+39 081 71 77 114 *+39 081 239 60 97* mrap@ motori.im.na.cnr.it	reliability and standards development, emission modelling
Mr **Reiter** Christoph	**Technical Univ. Graz** - Inst. Intern. Comb. Eng. & Thermod. - Inffeldgasse 25 - 8010 Graz - Austria	+43 316 873 75 84 *+43 316 46 21 75* reiter@vkmb.tu-graz.ac.at	emission modelling
Mr **Riemersma** Iddo	**TNO-WT** - Schoemakerstraat 97 - PO Box 6033 - 2600 JA Delft - The Netherlands	+31 15 269 67 45 *+31 15 269 68 74* riemersma@wt.tno.nl	hybrid- and electrical vehicles, heavy duty emissions
Mr **Rijkeboer** Rudolf C.	**TNO-IW** - P.O. Box 6033 - - 2600 JA Delft - The Netherlands	+31 15 269 63 60 *+31 15 269 68 74* rijkeboer@wt.tno.nl	emissions and fuel consumption of road vehicles
Dr **Rombout** Peter	**RIVM** - Lab. for Toxicology - PO Box 1 - 3720 BA Bilthoven - The Netherlands	+31 30 274 29 36 or 22 38 *+31 30 274 44 48* toxpr@rivm.nl	health risk assessment of air pollution (urban smog, traffic related air pollution, emission, air quality, exposure)
Dr **Roumégoux** Jean-Pierre	**INRETS** - Lab. Energie Nuisances - case 24 - 69675 Bron cedex - France	+33 (0)472 14 23 00 *+33 (0)472 37 68 37* roumegoux@inrets.fr	vehicle modelling, pollutant emissions, fuel consumption, computer simulation
Ms **Rypdal** Kristin	**Statistics Norway** - P.O.B. 8131 Dep - - 0033 Oslo - Norway	+47 22 86 49 49 *+47 22 86 49 98* krr@ssb.no	emission inventories, substance flow analysis
Ms **Sakellariadou** Fani	**Univ. Piraeus** - Dept Maritime studies - 40 Karaoli and Dimitriou st. - 185 32 Piraeus - Greece	+30 1 41 73 742, 41 20 751 ext 217, or 89 53 397 *+30 1 41 25 808* fsakelar@unipi.gr	maritime geochemistry, oceanography, air pollution and sea pollution
Dr **Samaras** Zissis	**Lab. Applied Thermodynamics** - Aristotle Univ. Thessaloniki - - 54006 Thessaloniki - Greece	+30 31 99 60 14 *+30 31 99 60 19* zisis@eng.auth.gr	internal combustion engines, applied thermodynamics, air pollution from road & non-road transportation
Pr **Sammer** Gerd	**Univ. Bodenkultur Vienna** - Inst. Transportation Studies - Gregor Mendel Str. 33 - 1180 Vienna - Austria	+43 1 476 54 53 01 *+43 1 476 54 53 44* verkehr@mail.boku.ac.at	transportation planning

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Ms **Schinagl** Gerhid	**Technical Univ. Graz** - Inst. Intern. Comb. Eng. & Thermod. - Inffeldgasse 25 - 8010 Graz - Austria	+43 316 873 75 84 *+43 316 46 21 75*	emission modelling
Mr. **Schweizer** Thomas	**EMPA** - - †berlandstrasse 129 - 8600 Dübendorf - Switzerland	+41 1 823 46 79 *+41 1 823 40 12* thomas.schweizer@empa.ch	emission factors, measuring technologies, driving cycles, special emission examination
Mr **Sieminski** Andrzej	**Min. Environment** - Dept of Air Land Protection - - 00-922 Warsaw - Poland	+48 22 258 973 *+48 22 25 20 03*	environmental pollution from vehicle and engines, with roads and fuel aspect
Pr **Silyanov** Valentin	**MADI-TU** - 64, Leningradski prospekt - - 125829 Moscow - Russia	+7 095 151 05 81 *+7 095 151 03 31* vvs@madi.msk.su	traffic simulation and control
Dr **Sinyavski** Vladimir V.	**MADI-TU** - Leningradskiy prospekt, 64 - - 125829 Moscow - Russia	+7 095 155 08 80 *+7 095 151 89 65 or 09 31* dvs@madi.msk.su	Sophistication of diesel engine working process, i.e. heat losses reduction, conversion of diesel engine to work on CNG, turbo-charged engines, reduction of emissions of all these engines and vehicles on which they are installed
Mr **Sjöbris** Anders	**MariTerm AB** - Box 12037 - - 401 42 Gothenburg - Sweden	+46 31 12 20 30 *+46 31 24 58 56* mariterm@algonet.se	emissions from sea and rail transportation
Mr **Sjödin** Äke	**Swedish Environ. Res. Inst.** - P.O.Box 47086 - - 40258 Göteborg - Sweden	+46 31 46 00 80 *+46 31 48 21 80* ake.sjodin@ivl.se	local air quality, atmospheric chemistry, monitoring of real-world emissions from transport, real-world emission factors for road veh., ships and aircrafts
Mr **Skouloudis** Andreas	**CCR/ISPRA** - Environment Institute - - 21020 Varenne - Italy	+39 03 32 78 91 86 *+39 03 32 78 96 76 or 78 91 86* andreas.skouloudis@cen.jrc.it	emissions from traffic and transport, air quality, scenarios impacts
Mr **Smokers** Richard T.M.	**TNO Road Vehicles Res. Inst.** - P.O. Box 6033 - - 2600 JA Delft - The Netherlands	+ 31 15 269 75 11 *+31 15 269 68 74* smokers@wt.tno.nl	electric and hybrid vehicles, emission factors, energy and environmental impact analysis
Mr **Sorenson** Spencer C.	**Technical Univ. Denmark** - Dept of Energy Engineering - Bldg 403 - 2800 Lyngby - Denmark	+45 45 25 41 70 *+45 45 93 06 63* Spencer.Sorenson@et.dtu.dk	air pollution from engines and vehicles, internal combustion engines : combustion, fuels, emissions
Dr **Stathopoulos** Antony	**National Techn. Univ. of Athens** - Civil Eng./ Transportation - 5, Iroon Polytechniou st. - 157 73 Athens - Greece	+30 1 772 12 88 *+30 1 772 13 27* 72644.1752@compuserve.com	environmental traffic control, transportation planning & management, parking management, information systems
Mr **Steinemann** Urs	**Ingenieurbüro US** - Schwalbenbodenstr. 15 - - 8832 Wollerau - Switzerland	+41 1 784 53 65 *+41 1 784 53 66*	HVAC-systems, tunnel ventilation, indoor and outdoor air quality, emissions from all the sources, air pollution analysis
Dr **Sturm** Peter	**Technical Univ. Graz** - Inst. Intern. Comb. Eng. & Thermod. - Inffeldgasse 25 - 8010 Graz - Austria	+43 316 873 75 84 *+43 316 46 21 75* sturm@vkmb.tu-graz.ac.at	emission modelling, air quality and/or dispersion modelling

Name : specialist (see annex 5) **Name** : only interested by results	address	phone number *fax number* e.mail	scientific fields
Mr **Swann** Jaimie	**MIRA** - Watling street - Warks - CV10 0TU Nuneaton - United Kingdom	+44 (0)12 03 355 329 *+44 (0)12 03 355 355* jaimie.swann@mira.co.uk	vehicle modelling and simulation, advanced powertrains, fuel cell technology
Mr **Thibaut** Gérard	**Ville de Paris** - Dir. Protection Environnement - 7, rue Maleville - 75008 Paris - France	+33 (0)145 61 54 70 *+33 (0)145 61 54 90* spaas_mairie_paris@compuserve.com	urban atmospheric pollution : emissions and air quality, policy and actions about traffic and its consequences
Ms **Torp** Charlotte	**Norwegian Soc. Conservation Nature** - PB 2113 - Grunerloekka - 0505 Oslo - Norway	+47 22 04 46 61 *+47 22 71 56 40*	air pollution from vehicles, emissions rather dispersion, effects of air pollution
Mr **Toussaint** Yves	**Univ. Liège** - Mécanique du Transport - 21, rue E. Solney - 4000 Liège - Belgium	+32 41 66 91 72 *+32 41 53 25 81*	hybrid propulsion, combustion phenomenon in internal combustion engines, cold start and transient regime, driving behaviour in urban conditions
Mr **Trozzi** Carlo	**Techne SRL** - Via Nicola Zabaglia, 3 - - 00153 Roma - Italy	+39 06 57 79 173 or 57 48 348 *+39 06 57 41 801* technerm@mclink.it	air pollutant emissions, air quality management plans
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Annex 7: Road vehicle emission data exchange: parameter list

The objective of this proposal is to facilitate the exchange of vehicle emission data, listing all the necessary parameters, and their unit. The main parameters are underlined.

In any case when a parameter is missing, please do not use a blank, but only a negative figure (-1 for instance, but -99 for temperatures and other parameters which can be negative).

At the begin of the file, or on a separate sheet, please indicate the order of the parameters (and if necessary the writing format), in order to avoid any reading error.

The format should be ASCII with a given separator, or can be a spread sheet (Microsoft Excel...), or a fixed format. It is better to separate the variables by a comma and to write the alphanumeric data (names, comments ...) between two ' (for instance a vehicle model can be written 'Golf GTX 16v').

Only measured parameters should be provided (especially for CO_2 and F.C.). If a calculated parameter is provided, indicate it in comments.

The descriptive parameters which are not basically numeric (for instance the gearbox type) should be either alphanumeric parameters (with a clear description, for instance 'manual gearbox'), or transformed into a number (for instance 1 for the manual gearbox), but in this case the correspondence, i.e. the meaning of the numeric figures, must be clearly indicated in comments.

Vehicle data

laboratory, laboratory internal identification of the vehicle, make (for instance Peugeot), model (for instance 405-GTL), national vehicle type number,

vehicle mass (empty vehicle, kg), max. power (kW), engine capacity (cm^3), number of speeds, gearbox type (manual, automatic...),

first driving day, month, year, local name of the emission standard, normal fuel type (petrol, diesel, LPG, GNV...), fuel H/C ratio,

production emission standards (g/test, or g/km only for directive 91/441 and further) for CO, HC+NOx, NOx, HC (expressed as in the standard, i.e. measured by NDIR for 1500 to 1503), particulates, certification results of the type of vehicle (for the same pollutants),

aftertreatment (without catalyst, uncontrolled or oxidation catalyst, 3-way catalyst...), engine technology (carburettor, electronic carburettor, single point injection, multi-point injection, with EGR, without or with air pump, turbo, comprex, mechanical charging system...),

mileage (km), type of vehicle provenance (private owner, rental company, company vehicle, garage...), type of the choice of the vehicle (random choice, chosen as low emitter, chosen as high emitter...),

size of tyres, tyre pressure at the test (bar),

number of cycles performed, for each pollutant: pollutant name, complete emission unit (if possible g/km, for HC precise the equivalent unit of HC emission (g equivalent $CH_{1.85}$ / km, or

CH_4, ...), for NOx precise if a humidity correction is applied or not (and give the correction formulae in comment) - pollutant order : CO, CO_2, HC, NOx, part., F.C., ...)

For each driving cycle

laboratory, laboratory internal identification of the vehicle, day, month, year, hour, minute, second of the test, maintenance (before maintenance, after maintenance), preconditioning cycle (not or yes), cold/hot cycle (cold, intermediate, hot), engine temperature at the begin of the test (°C - indicate in the comments if it is water or oil temperature), engine temperature at the end of the test (°C), catalyst temperature at the begin of the test (°C), inertia weight (kg), power setting at specific speeds,

pressure during the test (mbar or hPa), ambient temperature (°C), humidity (%), cycle name, theoretical duration (sec), theoretical driving distance (m), actual driving duration (sec), actual driving distance (m), speed standard deviation (m/s),

for each pollutant: emission

Additional comments

specification of the dynamometer setting,

description of the driving cycles, ...

Annex 8: Annual mileage of passenger cars

Figure A8-1: Annual mileage as a function of the passenger car age (1990 data).

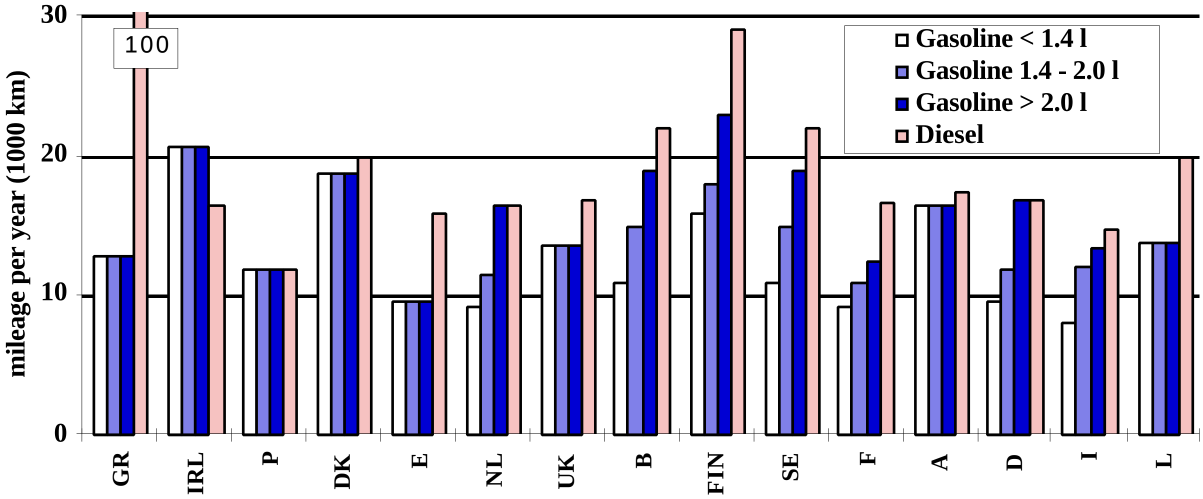
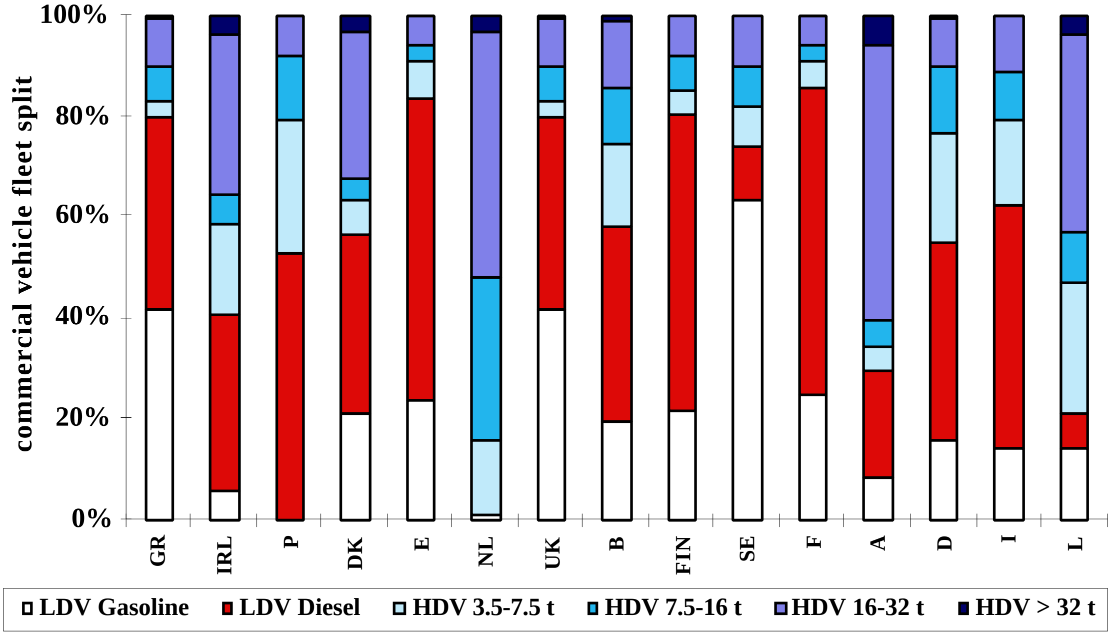


Figure A8-2: Engine type and size effect on annual mileage of passenger cars in the European Union (1995 data).

Annex 9:Commercial vehicle fleet split



Annex 10: Review of emission models

A large number of emission models have been considered by collecting information through COST 319 action partners and parallel initiatives financed by the European Commission (e.g. DRIVE II KITE project and DG VII COMMUTE project). These models allow the assembly of a real 'puzzle' of different approaches, tools, applications representing the substantial value of the review effort. The essential information about these models was put in a synthetic form by means of tables [Negrenti, 1998] which on one hand might limit the completeness of information but on the other hand certainly allow a clear comparison and an easy search of the wished details.

In this annex the detailed contents used in these summarising tables adopted for reporting the information on the 39 reviewed emission models are described (see the list of models in Table 19). The most relevant items to be looked at (for the purpose of a model classification) are the spatial and time scales (that basically differentiate micro-models from macro-models) and the fleet composition (putting into evidence the consideration of a real fleet or of a single vehicle). These pieces of information, together with many others considered relevant for an adequate model comprehension, are described below and reported in the summarising tables included in [Negrenti, 1998].

Table 19: List of reviewed emission models.

Table number in [Negrenti, 1998]	models names			
1	TEEM	MODEM	TAPEM	PREMIT
2	PREDCO	ROADAIR	AAQUIRE	AIRVIRO
3	BENZ	EMIL	KOSKINEN	COLDSTART
4	EVA	VETO	EM94	HEF
5	NETSIM	AEA	VISSIM	VISUM
6	NEMIS	EMISMOB	LIISA	CAREMIS
7	TEE	ASHDOWN	DGV	KEMIS
8	SCRAP	TEE-TURBAN	VERSIT	ROADFAC
9	VEMI	MADI-EM	EMOD	COPERT
10	TEDMAN	TREMOD	CITAIR	

The first two items in these tables concern the *Model Owners* (or developers) and the *type* of model. Two types of classifications are here proposed (see section 3.3.2): one based on the space-time scale and the other based on the aggregation level of emission factors.

Spatial Scale is a critical information for both the description of the model and the model selection process. Actions impacting transport systems often have an inherent spatial scale, so the capability of the emission model to treat that specific level of description is essential. This parameter can be regarded as a key-parameter for models classification.

Time Scale is also a relevant parameter for the selection of models for any impact evaluation. Often actions on transport systems have an inherent time resolution (either short or long) and the capability of models to treat the different possibilities of time extension is therefore a fundamental information. It must be noted that many emission models do not have a specific time dimension (i.e. their core formulas are related to traffic variables, like average speed and mileage, that can be referred to any time scale), but this is not the general case and reporting such a characteristic of the model looks appropriate.

Traffic Input is meant to identify in which way the traffic amount is described in the input to the emission model (either vehicle flow rates or miles travelled or any other quantification of traffic volume). Such information is also essential for the selection of an emission model. All transport policies and actions are generally expected to impact the amount of traffic, due to modal shift and-or improvements of flow conditions. It is therefore critical to know how the emission model takes into account the traffic quantity. Particular evidence was given in the tables to the emission parameters which belong to the area of traffic input: the vehicle*kilometers run by the vehicle, the number of vehicles (traffic volumes or densities), and the trip length.

The indication of the modelled *Pollutants* is a basic information for the description of an emission model, and for the selection process related to any environmental evaluation. The importance of the modelling of specific pollutants will be in general a function of local city or regional needs and problems.

The availability of a *Traffic Model included* in the emission software can in principle be an advantage for the building up of a complete suite of models for any inventory or impacts analysis. The analyst will anyway have to check if this integration doesn't involve any unacceptable degree of simplification in the emissions modelling. For several reasons, in the past, traffic and emission models (and dispersion models as well) were developed along different paths and with different purposes. This means that efforts on the model accuracy have been done in different directions, and it is possible that integrated packages whose development started from a traffic model show poor treatment of emission problems. In practice the availability of an integrated traffic software can have pros and cons to be carefully evaluated.

Most of current policies in the transport sector, are supposed to cause modal shift due to more favourable conditions for the use of public transport. Moreover when considering future inventories of consumption and emissions it is necessary to represent changes in national or local fleets. From the modelling point of view this means that the emission model must be capable of adequately representing changes of *Fleet Composition*, either at street, area, or city level (this will depend on the spatial resolution of the expected impacts). The presented tables give evidence to this for those models that (at least in a rough form) show capability to simulate fleet changes.

The description of the *Vehicle Kinematics* is probably one of the most crucial elements in the modelling of any environmental impact deriving from changes in the transport system. The analysis of the anticipated impacts of many policies and actions on traffic can lead to the synthetic conclusion that the kinematics impact can have two different forms :

- a change in the overall average speed of the vehicles
- a change of the more detailed speed and acceleration profile (idling, cruise, acceleration and slowing down).

The capability of emission models to treat such information is a key point in the selection of the right model for a certain transport system to be evaluated. In general it would be preferable to use models capable of using information on speed and acceleration variability, but this obviously implies to have real data on speed changes in time, and this can be very costly. Moreover instantaneous emission functions have recently shown not negligible difficulties in accurately predicting emissions over specific speed profiles. On the other hand, experimental or calculated data on average speed of vehicles are more easily available, but it is evident that the inherent approximation of the kinematics information can lead to wrong conclusions, especially in the case of pollutants which show remarkable sensitivity to speed variability around the average value.

Pollutants emission is affected by several *Other Parameters* beyond kinematics. Among these we can here mention: vehicle load, vehicle maintenance, vehicle age, and road gradient. Cities and countries implementing actions recognised to have a potential impact on these parameters should take care of emission models capabilities to treat related data. Only vehicle load and vehicles maintenance appear likely to be impacted by policies in general. Modal shift towards public transport should bring in principle to a slight increase in the average loading of buses. Similarly, improved freight management is allowing an increase in the average loading of light and heavy duty vehicles. Maintenance policies for limiting high emissions from old or poorly maintained vehicles are also in the agenda of several governments.

Details on the *Output* of the models can be of help in understanding how well the model fits the specific needs of analysis. The output data of emission models are also of importance when a dispersion model will be used. In this case calculated emissions are input data for the dispersion calculation and have to be in a format which can be used by the dispersion model.

The provided tables show also information on the activities of *Model Assessment* (assessed model sections, sources of data for the assessment, criteria of assessment). This set of data can be important in the choice of the right tool, since well assessed models generally should be more reliable as compared to models without any testing certification.

The field dedicated to the *Experimental Data Sources* covers fundamental data for the development of a model core (e. g. emissions correlations). This information is also crucial for the evaluation of model reliability and accuracy. Most emission models depend on experimental measurements of vehicle emissions under a range of operating conditions. The data available are by no means complete. Sufficiently reliable measurements of emissions are usually not available for e.g.: operation at altitude, cold starts, accelerating vehicles, effects of vehicle maintenance, and effects of vehicle loading.

In some applications, the use of "off-the-shelf" emission factor models looking at relative emission levels can be acceptable. However, in applications where absolute emission levels are important, it is recommended that the experimental emission data used as the basis for emission models are reviewed with model developers.

Information on *Computer Requirements, Language and Model Availability,* although not strictly needed from the point of view of modelling quality and evaluation capabilities, is nevertheless included in the tables in order to provide practical data in view of a potential selection. Information on *Anticipated Applications and Users* have also been included in order to give an idea on the normal scenario of use of the models, and therefore to draw conclusions (even draft) on the appropriateness of the model.

Finally, information on *References and Descriptive Papers* concludes the information summary.

Annex 11: Publication data form of the final MEET report

1. Unit of the 1st author Transport Research Laboratory		2. Project n°	3. TRL report n° SE/491/98
4. Title Methodology for calculating transport emissions and energy consumption			
5. Subtitle			6. Language: English
7. Author(s) J. Hickman, D. Hassel, R. Joumard, Z. Samaras, S. Sorenson			8. Affiliation TRL (UK) TÜV Rheinland (D) INRETS (F) LAT-AUTh (GR) DTU (DK)
9 Sponsor, co-editor, name and address European Commission/DG VII Rue de la Loi 200, 1049 Brussels, Belgium			10. Contract ST-96-SC.204 11. Publication date 1999
12. Notes			
13. Summary This report is a summary of all the individual methodologies and corresponding emission factors and functions produced in the MEET project, for use in estimating pollutant emissions and energy consumption from transport. It covers all current vehicle technologies for all different types or classes of road vehicles, as well as rail, shipping and air transport. For road transport, cold start extra emissions, evaporative losses, road gradient and vehicle load effects are addressed. In addition, guidance is given regarding the emissions behaviour of future vehicles and fuels. The methodologies and emission data are complemented with statistical input as regards the necessary transport activity data. Data are also provided on the pollutant emissions associated with energy production. Examples of the use of the methodologies are included in two ways: for road and rail transport, a variety of aggregated emission factors have been calculated, and comparisons have been made for passenger and freight journeys using different modes of transport.			
14. Key Words Emission factors and functions, energy consumption, statistical data, cold start, evaporation, air traffic emissions, road emissions, rail emissions, ship emissions		15. Distribution statement Not classified	
16. Nb of pages 350	17. Price	18. Declassification date	19. Bibliography Yes

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List of illustrations

Literature

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