Estimating Real World Emissions from Passenger Cars – Use and Limitations of Instantaneous Emission Data **(submitted to Int.J. on Vehicle Design, 1999)**

Sturm P.J., Hausberger S.

Technical University Graz, Institute for Internal Combustion Engines and Thermodynamics, Inffeldgasse 25, 8010 Graz, Austria; sturm@vkmb.tu-graz.ac.at

Keller M., de Haan P.

INFRAS Bern, Mühlemattstrasse 45, 3007 Bern, Switzerland; bern@infras.ch

Abstract

In recent years, many measurements of emissions on chassis-dynamometers have already incorporated the online measurement of emission concentrations at the exhaust as standard, alongside the usual average values. These data collected with a high time resolution (e.g. 1 second) can be combined with the likewise modal-recorded operating condition of the vehicle (engine load) and serve as a basis for methods of calculating emission. Compared to the widely used characterisation of a driving pattern by its average speed only, the explicit dependence of the emission behaviour on the engine load allows to take into account the level of dynamics of each driving situation individually. A reliable emission data set gives the possibility of calculating emissions for different real world driving conditions. For many applications, it is thereby no longer necessary to carry out costly and time-consuming chassis-dynamometer tests.

The generation of emission data sets takes place on chassis-dynamometers using different driving patterns. Systematic investigations should show the requirements necessary for the generation of instantaneous emission matrices, and how important a reliable consideration of driving kinematics is in estimating emissions for real world driving accurately.

Keywords: vehicle emissions, modal modelling, emission factors, passenger cars

1. INTRODUCTION

A correct description of the emission behaviour of a vehicle corresponding to real world driving behaviour is necessary to determine emission quantities caused by road traffic. To accurately estimate real-world emissions from traffic, special emission functions and factors must be determined. The approach used to obtain these emission functions varies.

In former years, chassis dynamometer tests were 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 roads. The emission factors derived using this procedure were then representative for those driving situations.

Nowadays the use of instantaneous emission models to estimate emission quantities or define emission factors is rapidly growing. A major advantage of such models is that emission calculations can be made which correspond to real world driving behaviour without the necessity of time consuming and expensive chassis dynamometer tests. This requires that emission data sets are capable of delivering the requisite information with sufficient accuracy.

It is a well known fact that the use of average speed to determine the emission level of vehicles is often not sufficient. Driving dynamics, which is the driving force behind emission quantities, has to be described better than through the average speed alone, because a lot of different driving patterns with more or less the same average speed, but totally different driving dynamics and therefore different emission quantities, exist.

This article is a summary and conclusion of work on instantaneous emission data and methods which is reported in full detail in Sturm et al. (1998), Schweizer (1998) aun INFRAS (1997). The work was part of the COST 319 program (estimation of emissions from transport) and the MEET project (methodology for estimating emissions from transport) financed under the 4th EC Research Framework Program on Traffic.

1.1. Instantaneous emissions approach (modal modelling)

Within the so-called Modal Modelling approach, emission estimates are based on calculations using emission functions. Within these functions the emission quantity is correlated to parameters which describe the operating conditions of a vehicle. These parameters are e.g. instantaneous values of speed (v) and acceleration (a). The emission functions are defined as two-dimensional matrices, with the rows representing a velocity interval (e.g. in km/h units), and the columns being assigned to an interval of acceleration or acceleration times velocity (e.g. in m^2/s^3 units); i. e., according to the velocity and acceleration of the measured vehicle at that time, all instantaneous emission data are put into one cell of the emission matrix. 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 is then possible to calculate emission amounts for any driving pattern – which is defined as modal value-pair for speed and acceleration.

Ideally, in order to guarantee the correct calculation of emission amounts for all driving conditions, every possible operational condition of the vehicle must be supported with emission values from real world driving cycles. This is theoretically desirable but hardly workable in practice, since this would mean that a very large number of driving patterns would have to be tested on the chassis-dynamometer whereby the advantages of numerical modelling of pollutant emissions would be lost.

1.2. 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)) , MOBILE 5, etc. This approach is based on aggregated emission information for various driving patterns, were the driving patterns are represented by their mean speeds only. All this information is put together according to vehicle technology, capacity class and model year and a speed dependent emission function is derived. That means that in addition to vehicle type the average speed of the vehicle is the only decisive parameter in estimating the emission quantities. This restricts the approach to certain applications, which are mostly found in emission estimates at a national level. The dynamics of a driving pattern - which is especially of importance in urban driving - is only taken into account implicitly.

A comprehensive application of an instantaneous emission model was performed to establish the emission factor workbook (Keller et al. (1997), Zachariadis and Samaras (1997). Real world driving behaviour was recorded on the road. From these records, representative “real world“ driving patterns were derived by statistical means. Using emission functions based on the instationary measurement data of various chassis dynamometer tests, emission factors for the real world driving patterns were derived. The decisive parameter is now a “verbal” description followed by information concerning the dynamics instead of 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, where it should be possible to calculate emissions, when even small changes of driving behaviour have to be taken into account.

The results derived on applying different calculation methods for a whole city – average speed models (Ahlvil et al. (1997)), emission factor workbook and instantaneous emissions model (Sturm et al. (1998)) – showed relatively good agreement (Zachariadis and Samaras (1997)). But at least two areas can be identified where the average speed approach is not applicable, because the mean speed is no longer the representative parameter for that specific problem at hand.

i) When performing micro-scale calculations; the assumptions used in an average speed or emission factor methodology may not be valid, e.g. because of local influences which alter vehicle kinematics considerably, while hardly affecting the mean speed.

ii) The assessment of traffic-related measures such as speed reduction or street capacity reduction; while such measures will affect the mean speed of the vehicles, the main effect may be the different

dynamics of the driving behaviour of these vehicles. Such a change in dynamics can cause changes in emission level considerably larger than a change caused by a different mean speed.
In these cases more sophisticated emission models based on emission matrices may be adequate.

2. PRESENT APPLICATIONS AND CURRENT RESEARCH ON INSTANTANEOUS EMISSION MODELS

Modal modelling is a well known approach for estimating emissions. Current on-going activities therefore mostly deal with investigations concerning the usability of modal modelling for micro-scale emission modelling.

2.1. Present Applications

One of the first applications of instantaneous emission models was the Graz model (DGV) (Pischinger and Haghofer (1984)). This model serves as a method to estimate road traffic emissions in direct combination with recordings of driving patterns and is used to evaluate traffic calming measures (e.g. Sturm et al. (1994)).
Another model was created within the Drive/Modem project (Jost et al. (1992) and Joumard et al. (1995)). This study was carried out as part of the EC DRIVE program to determine the most important parameters that influence the emissions and fuel consumption of passenger cars. In the course of the project 14 so-called modem-cycles were derived, on the basis of recorded driving patterns from several European cities. These driving cycles were then used for chassis dynamometer tests performed on 150 vehicles in three different labs. The emission data was recorded with a high time resolution (1 second) and emission matrices with the parameters velocity and acceleration times velocity were derived.
A joint emission factor work program from Germany and Switzerland (Keller et al. (1995)) used instantaneous emission data to create emission factors for passenger cars. The basis for the emission matrices were chassis dynamometer tests for some 300 vehicles using the FTP 75, NEDC, US-Highway and German Autobahnzyklus as driving patterns. The result of this work is an emission factor workbook, which is now state of the art for the determination of road traffic emissions in Germany, Switzerland and Austria.

2.2. Current research

The aim of current activities is to define the scope for presently available instantaneous emission data and to improve the models. Questions which have to be answered are: which applications can be covered with the current available emission matrices? Which requirements have to be put on driving cycles used for emission matrix generation? Are there additional parameters which have to be taken into account to describe dynamic driving behaviour?

On-going investigations in Switzerland (Schweizer (1998), INFRAS (1997)) aim to define the application range of the methodology used for the determination of emission factors (BEFU – methodology), and to define requirements for emission matrices (BEFU) when such models are used for estimating emissions based on real world driving behaviour. The on-going activities at the Technical University of Graz deal with defining the underlying conditions necessary in the measurement program in order to obtain reliable emission matrices for the estimation of real world emissions (Sturm et al. (1998)). Results of the activities from BUWAL/EMPA (Switzerland) and the Technical University Graz, Austria, are part of this report.

3. METHODOLOGICAL ASPECTS AND DISCUSSION OF THE INSTANTANEOUS EMISSION APPROACH

The use of arithmetical models based on modal-collected emission data should make the calculation of emissions for real world driving conditions possible. 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 these differing vehicle categories.

Presently it is so, that modal-collected emission data are available for a great number of private motor vehicles (e.g. Hassel et al. (1994), Andre et al. (1991) and BUWAL (1994)). These data records are mostly generated on the chassis-dynamometer using special driving cycles. Parameter studies with these data are restricted, since standardised driving patterns are used and details regarding emissions from actual driving behaviours are missing or vice-versa.

Therefore for the purpose of the present investigation, additional chassis-dynamometer measurements have been carried out which permit the desired parameter investigations. From existing data records, measurements were taken which satisfy the requirements of the planned investigation, such as the use of modal emission data based on intervals of one second as well as using standardised and real-world-driving cycles for the generation of the emission data (Sturm et al. (1998), Schweizer (1998), INFRAS (1998)).

Since noticeable restrictions are met with when creating the basis data set for emissions, it must be clarified, to what extent a universally valid application of the emission data - and that of the calculation models built up from these - is still ensured. For this purpose, systematic investigations were carried out to investigate the following influences:

Influence of the measurement set-up

Influence of the measurement program

3.1. Influence of the measurement set-up

Differences between modal data (integral values) and bag values

Modal data are collected during the on-line measurement of exhaust gases. In addition the measurements were performed according to the CVS method, where the diluted exhaust gases are sampled in bags. The analysis of the gas from the bags results in concentrations for the pollutant averaged over the whole driving cycle. The values measured from the bags should – in general – correspond to the sum of the modal values recorded for that specific driving pattern. Due to restrictions in the measurement set-up and the accuracy of the analysers differences between the bag values and the sum of the modal values are to be expected. This difference must be small if the modal data is to remain reliable.

The sample used for the investigations of gasoline cars showed the following differences between bag and modal values. The majority of the differences found between bag and sum of modal values was between 0 to 5% for CO2, +/- 15% for CO, 5 to –10% for NOx and HC. Bigger differences were found when low concentration values were measured (Schweizer (1998)).

The results for the Diesel measurements were similar to those of gasoline cars. For CO2 the modal values correspond very well with the bag results with differences of about +/-0.5%. The results for HC were similar, the average differences are up to +/- 1% with a maximum of 3%. The results for CO and NOx were not so good and they varied strongly with the car tested. NOx differences ranged between – 2% and +20%. The modal values for CO exceeded the bag values by between 5% and 30%. Differences on the higher end occurred mainly when extremely low concentrations were measured.

Reproducibility of measurements

Another problem is the reproducibility of measurements, especially when dealing with cars with a low emission level. When putting a car on the chassis dynamometer the results of two tests with the same boundary conditions might not necessarily correspond. To investigate the dispersion and reproducibility of similar emission measurements a specific measurement program was performed within the EMPA/BUWAL – study (Schweizer (1998)). The test vehicle was a gasoline vehicle with catalytic converter, model year 1996. 15 different driving patterns were used for the chassis dynamometer tests. The tests were driven by 4 different drivers and an automatic system (robot). The results showed standard deviations which strongly depended on the driving pattern itself (dynamics of the pattern) and on the pollutant. The results of the standard deviation cover a range between a few percent for smooth cycles and up to 80% for more dynamic cycles. The average is between 20% and 40% for CO and NOx and less for HC. As expected good reproducibility was found for CO2 (fuel consumption).

3.2. Influence of the measurement program for creating emission matrices

In general, when creating the emission matrix, all modal data are used that have been collected from measurements using standard cycles such as FTP 75, NEDC, etc. and real world driving cycles. The application of standardised driving cycles ensures comparability of data from differing origins. But standardised cycles have little to do with real driving trends on roads. The possibility exists, that through the application of emission data from standardised driving cycles which primarily serve for licensing vehicles, the actual emission behaviour of a vehicle is not correctly reproduced. Which driving cycles are best suited to generating the emission matrix also has to be determined. Identifying which deviations are to be expected between calculated and measured emission quantities for real world driving patterns is also of interest.

Systematic investigations were carried out with a relatively small number of vehicles for which the emission matrices of the necessary variability exist. The results for Diesel engines are based on data from TU Graz (Sturm et al. (1998)), those for gasoline engines on data from BUWAL (1994), and EMPA (Schweizer (1998)). Emission matrices for individual vehicles are necessary here, since such fundamental investigations must always be carried out on an individual vehicle first. Whether the results obtained for a single vehicle are in keeping - at least in trend - with those for all vehicles of the same category is analysed at a latter stage.

Emission matrix

The amount of data needed to create an emission matrix is very large. Of course one increases the number of emission values in the fields of the emission matrix through a larger number of vehicles, but simultaneously, the spreading of individual values in the same matrix field can also increase substantially so that a very large number of measurements (vehicles) is necessary to be able to make statistically safe, quantitative emission statements. The measurement data for such a test is not presently available on a sufficient scale.

Figure 1 shows fields of an emission matrix - defined by speed and acceleration– generated from a test with the New European Driving Cycle (NEDC). For these fields of the matrix, corresponding emission values are given. Figure 2 on the other hand, shows those fields that are necessary when calculating the emissions of a real world driving pattern. When comparing both of these figures one notices that most of the fields that appear for real driving behaviour, are not occupied at all in the matrix of the NEDC-test. That means that for these fields, no measured emission values exist.

Consequently, a calculation of the real world driving pattern can only lead to realistic emission values when the adequate emission information is available.

Influence of driving cycles

As already mentioned, it would be desirable to assign an emission value to every possible engine load of a vehicle. This would mean that the driving pattern needed to create the emission matrix would also contain all these load-points. This is not possible for practical reasons and also not absolutely necessary.

To examine the influence which the use of different driving cycles for creating the emission matrices can have, the following work program was chosen:

Chassis dynamometer tests were carried out using standardised and real world driving cycles. The emissions were recorded with a high time resolution as modal values and as bag values according to the CVS method.

Emission matrices were created based on the emission information from the modal values of the chassis dynamometer tests. They contained emission information starting from only a few driving patterns up to the use of all measured data (all driving cycles).

Calculations were performed on the basis of the emission matrices with the particularity that the emission information (modal values) from the driving pattern in mind was not incorporated in the emission matrix.

The results gained were then compared with the measured ones.

This procedure was applied to Diesel and gasoline cars. The work program and the driving cycles are described in detail in Sturm et al. (1998). For the work in question, attention is directed mainly to inner-city traffic flows and thereby to real world driving conditions at lower speeds. Due to different measurement programs for Diesel and gasoline cars, different real world driving cycles were applied for the chassis dynamometer tests.

Influence of driving cycles - results for Diesel fuelled passenger cars

The following driving cycles were applied to generate the data for the emission matrices used:

Standardised driving cycles: FTP-75 (hot part) and NEDC (hot).

Real-world-driving-pattern: city main street (CMS) with high dynamics, city secondary street (CSS) with low dynamics. Both real world driving patterns originate from extensive investigations into driving conditions in an urban area (Sturm (1997)).

Table 1 gives the computation cases with the driving cycles used for generation of the emission matrices and the driving pattern used for the recalculation and comparison with measurement data. The calculations were carried out with an emission matrix in which the emission values are stored according to the parameters ”speed” and “speed x acceleration”. The increments used amounted to 10 [km/h] for the “speed” parameter and 2.5 [m^2/s^3] for the “speed x acceleration” parameter. The reason why these particular parameters and increments were chosen will be explained later.

Figure 3 shows the results for Diesel cars. Percentage deviations from a reference value are depicted. The reference value is always the measured amount of emission for the respective driving cycle (sum of the modal-recorded emission values). As expected, on re-calculating the FTP-cycle (case A), the deviations for all pollutant components were very slight. The amount of emission is, after all, calculated from those matrix values that were used to generate it. Differences have to appear, because the same emission fields in the matrix can be covered by different events - although they have the same parameters (v, a x v).

When using both standardised driving cycles (FTP, NEDC), one gets a denser assignment of the emission matrix fields. At the same time, the emission level of certain individual fields also changes since a greater number of measured and collected emission values now determine the value of a matrix field. The greater density of information is of course not required for the recalculation of on of the standardised cycles (cases B1 and B2), but already effects an alteration to the emission level of individual fields - on those very fields to which the values of both driving cycles contribute.

The differences get worse when the real world driving cycles are recalculated from emission matrices based on “standardised” information only (cases C1 and C2).

It is expected that with the use of emission information from real world driving the accuracy increases. To prove this the emission information of the high dynamic case (CMS) was used – in addition to the “standardised” one – and the low dynamic driving pattern (CSS) re-calculated and vice versa (cases D and E). But instead of improving the results they got worse. An improvement was finally reached when the emission information from all the driving patterns was considered (cases F1 and F2).

Based on the performed investigations, the following indications were found:

The sole use of emission values from standardised driving patterns (FTP and NEDC) is insufficient.

It is seen to be advantageous for the calculation of NOx - and HC -emissions when emission information from real world driving patterns is included in the emission matrices.

But, calculation results improve only if the proper emission information is incorporated in the matrix. That means: If highly dynamic driving behaviour occur, an emission matrix with emission information from highly dynamic cycles has to be used and vice versa for low dynamic cycles (see cases D and E).

In addition to these general findings, the following results were obtained:

The CO_2-emission and the corresponding fuel consumption are correctly reproduced.

The calculated NOx – and HC- emissions are accurate to +/- 10%.

The CO-emissions behave differently. A predicted overvaluation for the “highly dynamic” CMS-cycle is offset by an undervaluation for the “low dynamic” CSS-cycle. It must be noted that the CO-emission level is very low therefore changes in emission levels up to +/- 20% are small in quantity.

Influence of the driving cycles – results for gasoline fuelled passenger cars

The existing data were gained through the modal analysis of chassis dynamometer measurements with the following driving cycles:

Standardised driving cycles: FTP-75 (bags 2&3), US-Highway-cycle, NEDC (hot).

Real world driving pattern: city, speed limit 50 km/h (BUWAL T50), speed limit 30 km/h (BUWAL T30). The two real-world driving cycles resulted from driving pattern examinations carried out by EMPA (BUWAL (1994)).

The methodology used for performing the examinations of passenger cars with gasoline engines was the same as that used for passenger cars with Diesel engines. 27 vehicles with different engine capacities, built between 1991 and 1993 (BUWAL (1994)) were examined.

Due to the fact that the measurement program for gasoline cars was different, the computation cases had to be newly defined (Table 2). The calculations were carried out with emission matrices in which the emission quantities were stored according to the following parameters: speed (v), and speed x acceleration (a x v). Increments of 5 km/h for the parameter “speed” and 1,3 m^2/s^3 for the parameter “speed x acceleration” were chosen.

For the calculations and comparison, the data of the individual vehicles were subdivided into three classes according to engine capacity - small cars ≤ 1400 cm^3 (9 vehicles); middle class cars 1400 - 2000 cm^3 (9 vehicles); upper class cars > 2000 cm^3 (9 vehicles). The results for different driving cycles and pollutants varied from class to class. Notwithstanding this the general results were more or less the same. Therefore, the following results cover all gasoline vehicles. The individual results can be found in Sturm et al. (1998).

Merging all emission matrices means in this case that an average vehicle is considered to consist of 1/3 of each individual layer. The emission values of the individual vehicles differ very much from the respective mean layer value (per capacity class). The maximum differences between the recalculated value for a single vehicle and the average of the measurements of specific vehicle classes are very large. The differences are in the order of - 95% to +280%. When viewing only the average values of the calculations for all single vehicles within the specific vehicle classes and comparing the results with the recalculation based on an emission matrix containing all vehicles, the differences are in a range of +/–20%.

Figure 4 shows the differences between calculation and measurement for gasoline vehicles. Of course, the calculation in case A led to the smallest deviation, since in this case the FTP-75 was recalculated from an emission matrix which was generated from the former‘s cycle only. The recalculation of the standardised driving patterns (B1 and B2) shows a sufficiently accurate correspondence (+/- 10%), while the result in the FTP-75 achieves a better match.

In the case of calculating real world driving patterns from “standardised” emission information only, the differences grow to huge numbers for CO and HC (underestimation up to – 55%, cases C1 and C2). This underestimation may simply be due to the use of emission values from different driving cycles. The CO emission of T50 is about 2.5 times and the HC emission up to 2 times higher than the respective emission value of the FTP-75. Contrary to the results for Diesel engines the accuracy grows as soon as emission information from one real world driving pattern is included (cases D1 and D2). And it increases further when the emission information from both real world driving cycles is used (cases E1 and E2). But in both cases an underestimation for CO and HC due to the re-calculation occurs. This is due to the high HC and CO emissions which were measured for the two real world driving cycles.

Based on these findings, the following statements can be made concerning calculations on the basis of emission maps:

It turned out that the inclusion of real-world driving patterns into the emission matrices is absolutely necessary for the calculation of CO and HC emissions.

It has to be tested whether it is better to ignore the data from FTP- and NEDC-cycle - especially when looking at CO and HC.

That means – as for Diesel engines, and maybe of even greater importance – it seems to be necessary, that a distinction between “high dynamic” and “low dynamic” emission matrices has to be made.

The overall results based on the calculations performed are:

The calculation of the CO2 emissions is accurate in the case of city driving cycles.

The values for CO and HC emissions are too low. The reason for this is that the real world driving cases have much higher emission levels than do standardised cycles.

The calculation of the NOx emissions is correct.

More or less the same findings resulted from the recent EMPA/BUWAL work on the limitations of currently available emission data for modal modelling (Schweizer (1998), INFRAS (1998)). Investigations similar to those mentioned above were undertaken, but much more emphasis was put on the use of real world driving cycles. These investigations proved that the dynamics of the driving pattern is a decisive parameter. This can be seen in

Figure 5 were the measured and calculated CO emissions for a gasoline vehicle, TWC, model year 1996, based on a “high” and a “low dynamic” driving cycle is shown. Although the mean speed of the driving pattern does not differ very much, the measured emission values (bag – values) differ by a factor of 8. The emission matrices used for the inter-comparisons incorporated a certain dynamics, because of the dynamics of the driving patterns used for chassis dynamometer tests. These matrices are created using emission information from standardised and real world driving patterns. The names “EMPA, EMPA+, EMPA-, TÜV, TÜV+” indicate certain mixtures of emission information according to (INFRAS (1998)). The main result is: If emissions have to be estimated for real world driving with more dynamics than that in the emission matrices the result will be an underestimation (case “driving pattern: high dynamic”). If the real driving behaviour has less dynamics (case “driving pattern: low dynamic”) the calculation will overestimate the emission quantities considerably. The results between model simulations and real measurements can easily differ by a factor of two.

These findings lead to the result that an additional parameter beyond the modal values of velocity and acceleration has to be taken into account to describe the dynamics of the driving cycle and to assign the emission values to” high” and “low dynamic” emission matrices.

Figure 5 shows another important fact. Both driving patterns used do not differ very much when average speed is looked at; 77 km/h and 62 km/h respectively. When using an average speed model here, the results would differ between 62 and 77 km/h by some 10 to 20%, but not by a factor of 8. This does not say anything about the quantitative accuracy, but the qualitative result would be definitely wrong if an instantaneous model is not used.

3.3. Influence of model parameters

Models for calculating the pollutant emissions from emission matrices are based on the fact that the operational behaviour of a vehicle is determined by way of parameters that in turn make possible the allocation of corresponding operational behaviour to the emission values. The operational behaviour of a vehicle may be defined from the parameters instantaneous speed (v) and acceleration (a). These parameters can easily be derived from the driving patterns. Whilst speed and acceleration directly represent the driving pattern, the performance that is necessary to drive the vehicle can be described by the parameters speed and speed x acceleration.

Earlier model developments used primarily the parameters speed and acceleration [8], whilst more recent calculation models draw upon the parameters speed and speed x acceleration [9].

The emission values collected are measured on the chassis-dynamometer and stored as average values over particular time intervals (typically 1 second) in a matrix. The parameters for storage are the speed and the acceleration, or the product of speed x acceleration respectively. The typical increments for these parameters amount to 5 km/h for speed and 0.1 m/s^2 for acceleration. The smaller the increments are, the better the subsequent check against real world driving, assuming that all fields of the emission matrix are covered. Exactly this is the weak point however, since the application of only a few driving cycles to generate the emission matrix, means fields of the matrix inevitably remain empty (without recorded values). When a larger increment is selected (e.g. 10 km/h, 0.25 m/s^2), the frequency of missing matrix records is noticeably lower, the wide increments can however lead to alterations in driving behaviour not being sufficiently taken into account.

The object of the investigation is also therefore, the question of whether these differences in method are relevant for the calculation of emissions.

To investigate the influence of different methodologies (a, v, a x v) and increments calculations were performed with varying the parameters “a,v”, “a x v, v”, and increments for “v” (5, 10 km/h), “a” (0.1, 0.2, 0.4 m/s^2) and “a x v” (1.3, 2.5, 5 m^2/s^3). The number of matrix fields ranged between 90 for the coarsest grid and 1125 for the finest. Since the emission values are, as described above, stored in matrices with a particular "grid-size", an interpolation scheme may be used in the arithmetical model to deduce emission amounts. The way the actual emission values are interpolated between the matrix values can lead to differences in results for the emission calculations. To investigate this influence, different interpolation schemes were applied to calculate emissions. One procedure used only the emission value from the nearest matrix-field, while the other procedure provided for the application of a triangular interpolation between the next neighbouring grid-points.

On performing the calculations for gasoline and Diesel cars according to the described conditions, practically no difference was found between the results of the calculations when using both methodologies (“a, v”; “a x v, v”). The “v, a x v” - matrices showed a slight advantage, if one observes the occupancy of the matrix fields in the range of interest for city driving. Here, with close increments, there is only a small number of unoccupied fields. The use of “v, a x v”-matrices and therefore preferred. In addition, the findings of all investigated cases concerning various increments and interpolation schemes showed no preference for any specific increment or interpolation scheme (Sturm et al. (1998)). This is a little astonishing, but it seems to be a result of too little emission information and/or the insufficient treatment of the dynamics of the driving patterns within the matrix cell values.

4. CONCLUSION AND DISCUSSION

The use of instantaneous emission models is a well known approach to estimate traffic emissions or at least emission factors. Contrary to average speed approaches, driving dynamics - which is of major importance in emission estimation - can easily be taken into account. But the instantaneous emission models are based on emission matrices which are created under certain boundary conditions. Several investigations aim to define the application range for the use of currently available emission data, and to improve the methodology such that the use of instantaneous emissions models for real micro-scale applications becomes possible. All investigations covered within this report resulted in the following:

The use of instantaneous emission approaches (modal modelling) is recommended when emissions have to be estimated and/or when measures have to be evaluated in which driving behaviour and dynamics is of major interest. Standard average speed models are not suitable for such tasks.

During the measurements of “highly dynamic” real world driving cycles all vehicles showed much higher specific CO and HC emissions than during standardised test cycles. The use of emission information from standardised cycles results in a lowering of the level of the emission vales in the emission matrix and therefore in a marked underestimation in the results of the calculation of real world driving cycles; very “low dynamic” driving patterns result in an overestimation.

When using modal modelling certain constraints have to be put on 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, and it may be even better to exclude data from standardised cycles.

The generation of emission matrices has to be based on driving cycles which cover the whole region of relevant emission matrix fields.

The driving dynamics implicitly taken into account when creating the emission matrix have to be similar to that of the real world driving pattern for emission estimates to be 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.

It will be the task of the next future to improve the instantaneous emissions model by introducing an additional parameter which classify the driving dynamics and 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 highly and low dynamic situations. However it is at the moment 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 come up with a universally usable description of the over-emissions which have to be described as function of the dynamics of the driving pattern (e.g. motor enrichment functions for TWC).

Remarks: All the findings in this report are based on a relatively small sample of tested cars. Furthermore the real world driving cycles used for the investigations were taken from a big sample at random without using statistical analyses. The emission matrices used for the calculations contain for the most part only a few real world driving cycles. Therefore, the results presented here are preliminary findings which have to be tested by further investigation.

Acknowledgements: The work presented here was partly funded by the European Commission within the 4th framework research program. The data for gasoline engines were provided by BUWAL, Switzerland, as part of COST 319 activities.

References

Sturm P.J., Schinagl G., Hausberger S., Reiter C., Schweizer T., Keller M., de Haan P. Instantaneous Emission Data and Their Use in Estimating Road Traffic Emissions, MEET Deliverable No. 6, 4th European Framework Project, DG VII, 1998

Schweizer T.; Nachführung der Emissionsgrundlagen Strassenverkehr: Anwendungsgrenzen von Emissionsfunktionen, Analyse der Messdatenstreuung, EMPA-Bericht 166’558, BUWAL-Arbeitsunterlage 4, Dübendorf, 1998

INFRAS. Anwendunggrenzen von Emissionsfunktionen: Ergänzende Analysen zum EMPA-Messprogramm 1997. Im Auftrag BUWAL, BUWAL-Arbeitsunterlage 6, Bern

P. Ahlvik, S. Eggleston, N. Gorißen, D. Hassel, A.-J. Hickman, R. Joumard, L. Ntziachristos , R. Rijkeboer, Z. Samaras, K.-H. Zierock; COPERT II, 2nd Edition , 1997

Hassel D, Jost P., Weber F.-J., Dursbeck F., Sonnborn K.-S and Plettau D.: Das Emissionsverhalten von Personenkraftwagen in der BRD im Bezugsjahr 1990, Berichte 8/94, Erich Schmidt Verlag, Berlin, 1994, 331p.

Keller M., Evequoz R., Heldstab J., Kessler H. Luftschadstoffemissionen des Straßenverkehrs 1950-2010, BUWAL Schriftenreihe Umwelt Nr. 255, BUWAL, Bern, 1995

Zachariadis Th., Samaras Z. Comparative assessment of European tools to estimate traffic emissions; Int. J. of Vehicle Design, Vol. 18, No.3, 1997, pp. 312-325.

Pischinger R. and Haghofer J. Eine Methode zur Berechnung des Kraftstoffverbrauches und der Schadstoffemissionen von Kraftfahrzeugen aus dem Geschwindigkeitsverlauf, XX Fisita Congress, SAE 845114, 1984, 12 p.

Jost P., Hassel D. and Sonnborn K.-S.: Neue Systematik zur Ermittlung von Emissionsfaktoren für Pkw, in Pischinger R. (Edt.): Proc. Int. Symp. “Traffic Induced Air Pollution“, Vol. 64, Reports of the Institute for Internal Combustion Engines and Thermodynamics, Technical University Graz, 1992, p 115-131.

Sturm P.J., Pucher K., Almbauer R.A. Determination of Motor Vehicle Emissions as a Function of the Driving Behaviour, in: Proceedings of the Conference “The Emissions Inventory; Perception and Reality”, Air & Waste Management Association, 1994, pp 483-494

Jost P., Hassel D., Weber F.-J.. Emission and fuel consumption modelling based on continuous measurements; Deliverable No. 7 of the DRIVE Project V1053, TÜV-Rheinland, 1992, Köln

Joumard R., Jost p., Hickman J., Hassel D. (1995): Hot passenger car emissions as a function of instantaneous speed and acceleration; The Science of the Total Environment 169, 1995, pp 167 – 174

André M., Hickman A.J. and Hassel D.: Operating Characteristics of Cars in Urban Areas and Their Influence on Exhaust Emissions, Proceedings of the Drive Conference, Brussels, Feb. 4-6, 1991, 14 p.

BUWAL. Ergänzungsmessungen zum Projekt "Luftschadstoffemissionen des Straßenverkehrs in der Schweiz 1990 – 2010", Arbeitsunterlage 17, Bundesamt für Umwelt, Wald und Landschaft, Bern, 1994, 40 p.

Sturm P.J. Application of Computational Methods for the Determination of Traffic Emissions, J.Air&Waste Manage.Assoc. 47, 1997, pp 1204-1210

Table 1. Inventory of the computation cases

Computation case	Emission data record from driving cycles	Calculation driving cycle	Computation case	Emission data record from driving cycles	Calculation driving cycle
A	FTP-75	FTP-75	D	FTP-75, NEDC, CMS	CSS
B1	FTP-75, NEDC	FTP-75	E	FTP-75, NEDC, CSS	CMS
B2	FTP-75, NEDC	NEDC	F1	all*	CMS
C1	FTP-75, NEDC	CMS	F2	all*	CSS
C2	FTP-75, NEDC	CSS			

*all = FTP-75, NEDC, CMS, CSS

Table 2. Computation cases: passenger cars with gasoline engines

Computation case	Emission data record from driving cycles	Driving cycle calculated	Computation case	Emission data record from driving cycles	Driving cycle calculated
A	FTP-75, NEDC	FTP-75			
B1	FTP-75, NEDC	FTP-75	B2	FTP-75, NEDC	NEDC
C1	FTP-75, Highway, NEDC	BUWAL T50	C2	FTP-75, Highway, NEDC	BUWAL T30
D1	FTP-75, Highway, NEDC, BUWAL T30	BUWAL T50	D2	FTP-75, Highway, NEDC, BUWAL T50	BUWAL T30
E1	All available data	BUWAL T50	E2	All available data	BUWAL T30

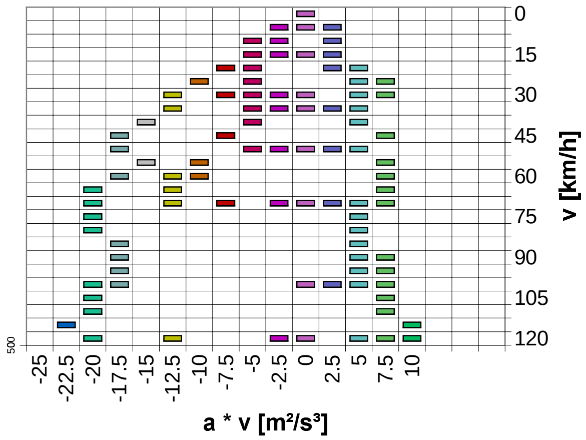

Figure 1. Emission matrix based on the New European Driving Cycle (NEDC)

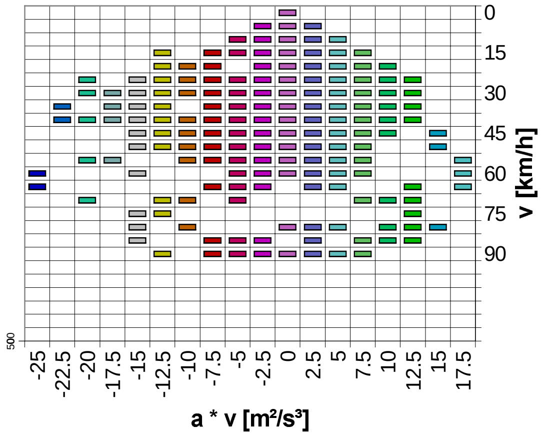

Figure 2. Emission matrix needed for a typical urban driving pattern

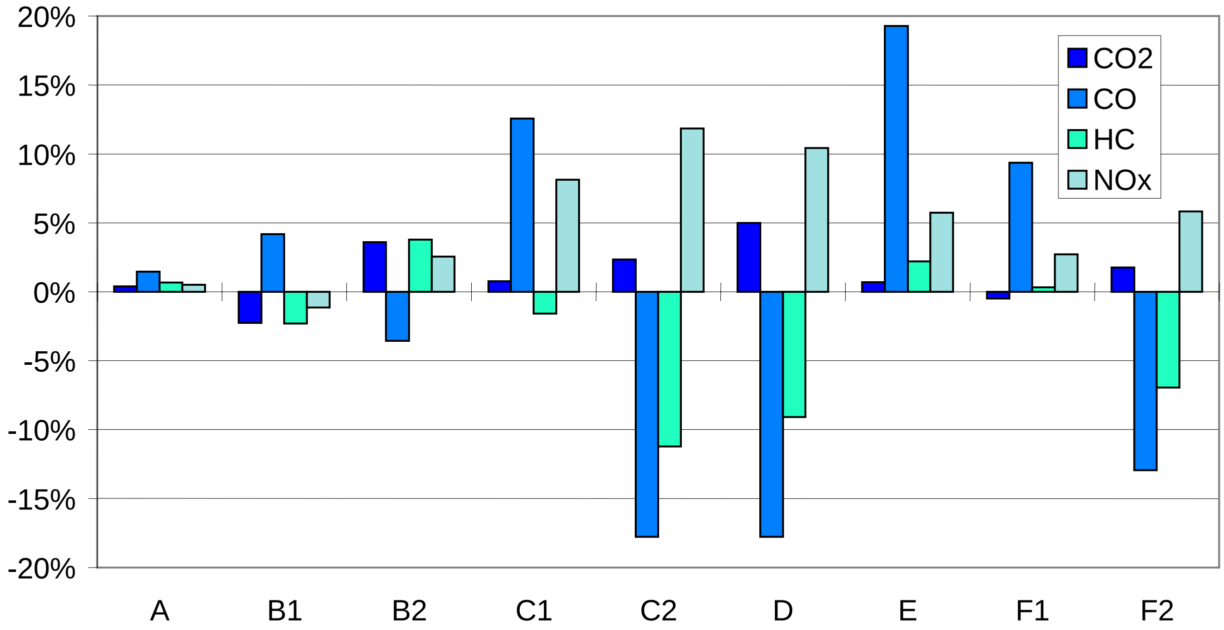

Figure 3. Differences between calculation and measurement ; Diesel vehicles, (description of computation cases A to F2 see Table 1)

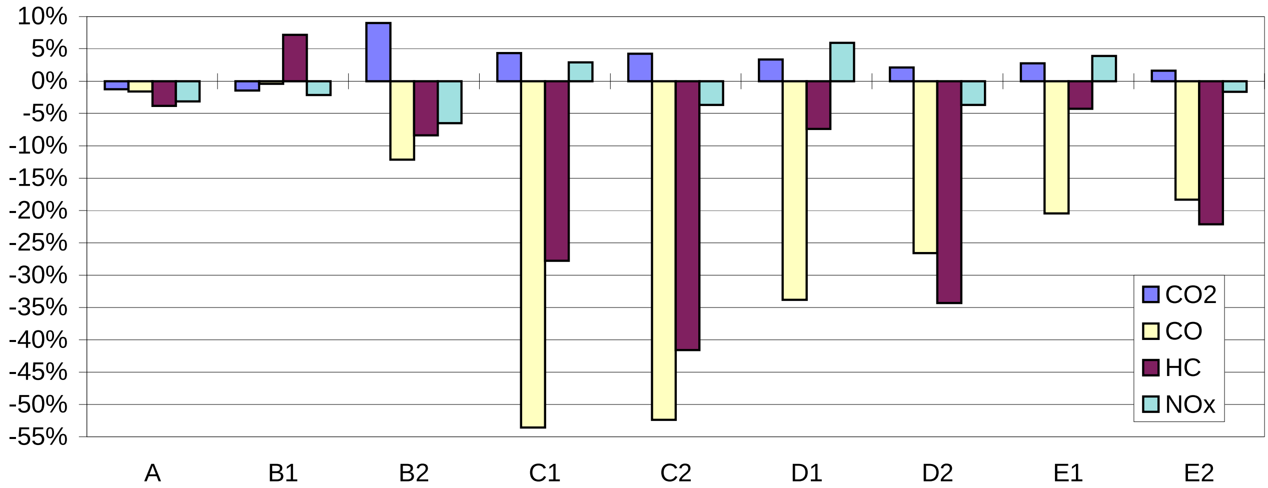

Figure 4. Difference between the calculation based on the emission matrix of all gasoline cars and the mean emissions of this vehicle category (measurement)

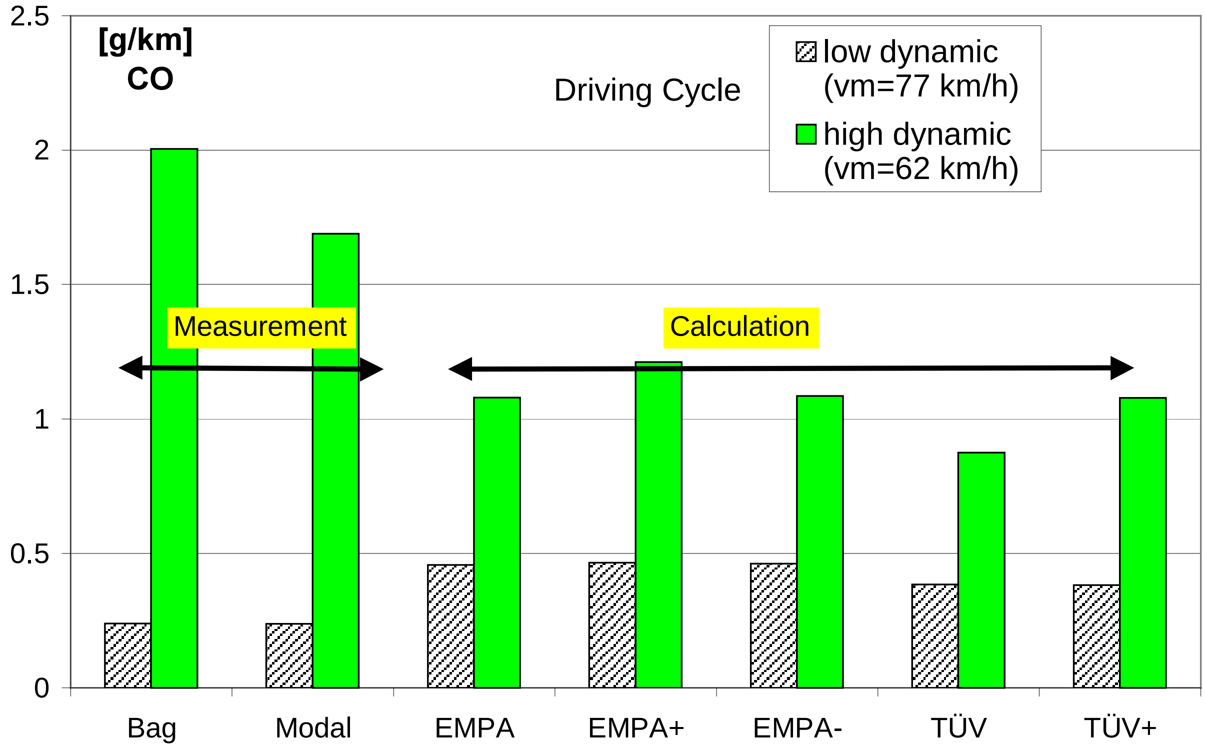

Figure 5. Comparison between measurement and calculation for gasoline vehicles; different driving cycles (low and high dynamic) and different emission matrices