

The Evaluation of a New Kinematic Emissions Model on Real and Simulated Driving Cycles

2010-01-1564

Published
05/05/2010Livia Della Ragione and Giovanni Meccariello
Istituto Motori CNR

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ABSTRACT

The evaluation of vehicles real emissions circulating in urban areas is a basic activity for planning and management of implemented traffic measures aiming at emission control and air quality improvement.

National, region, and city emission inventories require overall average emission estimation based on modeling technique with a few input parameters such as fleet composition and mission profile, represented by average speed.

But in the field of emission modeling an important open issue is the very expensive costs of experimental campaigns needed to obtain driving cycle statistically representative of driving behavior, also if only in a specific link of a network.

A possible approach to deal with this problem is represented by the use of traffic microscopic simulation models which are capable to simulate individual car motion on the basis of traffic conditions, road characteristics and management rules. Here we want to investigate the possibility integration of traffic simulation models and emission factors model, from the point of view of emission modeling results.

So in this paper a new statistical approach capable to consider more attributes than the simple mean speed to characterize driving behavior is considered. This meso scale emission model, named KEM, Kinematic Emission Model, is able to calculate emission factor, considering as input the driving cycle. In particular, micro-simulation models can determine instantaneous kinematic characteristics of each vehicle moving on the simulated transportation network, thus providing the needed input parameters to the emission models. Its prediction emission factor has to be estimated as a consequence of the effect of some variables characterizing

the different modes, that is idling, acceleration, deceleration and cruise, better than mean velocity of driving cycle.

In this paper some results concerning regulated pollutant emission are presented. For a defined case study, that is EURO II gasoline cars in a 1200-1400 displacement, the KEM model coefficient and predicted value for emission are calculated. After, some comparison are presented between measured and predicted emission value on a urban supplementary driving cycle, and on some simulated driving cycle coming from four different car following micro-simulation models, that use the supplementary driving cycle as starting cycle. Two different types of results are obtained. From the point of view of micro simulation models, it could be asserted that at least one of them should be calibrated, based on acceleration profile rather than solely on mean velocity of driving cycle. This feature has also a strong impact on the emission values resulting from modeling phase, generally for all pollutants, but especially for NO_x. In fact it shows extremely high values for a specific microsimulated cycle. In general, the goodness of fit of KEM model to experimental measured emission is good. Also a comparison with COPERT IV curve for each pollutant is presented. The sensitivity assessment of KEM model, which is able to discriminate emission predicted values, resulting from the small differences between driving cycles generated from the micro simulation, is shown. So in conclusion, these differences couldn't highlighted by emission model that using only the average speed as input parameters.

INTRODUCTION

In the past, the main focus of environmental impact study has been devoted to increasing performance of transportation systems than to mitigate pollutant emissions. Nowadays the assessment of the applied transportation policy on sustainable mobility and its influence on emissions is still sometimes unknown. Moreover the tools for their evaluation have been



only partially evaluated. At the present there are different models able to evaluate the effect of transportation system policies and others able to estimate traffic emissions. Moreover there is also a number of works and technical issues aiming to motivate the integration of some existing traffic and emission models. However, until now, not so many studies attempted at evaluating the reliability of the results in terms of emission factors which is possible to obtain from these integrated frameworks, perhaps for some difficulties in retrieving the driving cycle and emissions experimental data needed to perform these analyses. So in this paper we try to retrieve some evidence of possible results using a combination of traffic and emission models, in terms of emission factors coming from a kinematic emission model KEM, developed in Istituto Motori CNR ([Rapone et al., 2008](#)).

BACKGROUND OF EMISSION AND TRAFFIC SIMULATION MODELS

In this section an attempt is made for briefly summarizing the most relevant emission and traffic simulation models.

Relatively to emission models, it is possible to consider a kind of global classification presented in [Ajtay et al., 2008](#), where emission models can be categorized in two groups of increasing level of complexity, that is bag emission models and instantaneous emission models.

More generally to obtain emission factors consolidated methods make reference to vehicle mean velocity, which can be directly measured or even obtained by vehicle flow and density. Available models COPERT IV ([Ntziachristos et al., 2006](#)), MOBILE ([US EPA, 2006](#)) and its evolution MOVES (Motor Vehicle Emission Simulator) ([US EPA 2009](#)), EMFAC (EMission FACTors) ([CARB, 2002](#)), HBEFA (Handbook Emission Factors for Road Transport) ([Keller and de Haan, 2004](#)), MEET (Methodologies for Estimating air pollutant Emissions from Transport) ([Joumard et al., 1999](#)) and so on, make reference only to mean velocity to provide emission factors. In particular COPERT IV, developed in Europe by the LAT (Laboratory of Applied Thermodynamics-Aristotle University), is an average speed model for centralized emission estimation. INFRAS (Switzerland), has developed the HBEFA mode, which considers kinematic aspects through traffic situations, intended as a combination of road and traffic parameters. Moreover the latest version of VERSIT+LD ([Smit et al., 2005](#)) model follows the kinematic approach resulting in a new generation emission factor model based on a multiple regression model, that calculates emission factors for passenger cars as a function of driving cycle characteristics. TRL Transport Research Laboratory ([Barlow et al., 2007](#)) have been developed a set of meso and micro scale models; in particular the PHEM model (Passenger cars and Heavy duty vehicle Emission Model), VeTESS (Vehicle Transient

Emission Simulation) model and the extended version of MODEM.

However to assess the emission impact of all those transportation policies and strategies based on the dynamic traffic management, it is very important to take into account the instantaneous operating conditions of the vehicles and thus it should preferably to use types of models like instantaneous emission models. Also in the framework of the ARTEMIS EU project ([Joumard et al., 2007](#)) different models have been developed, classified as traffic situation models and kinematic models. In particular the latter type tries to take driving behavior into account and to link emissions with kinematics. During this project, Rapone et alii developed a statistical approach, able to consider more attributes than the simple mean speed to characterize driving behavior. As a consequence, a large number of kinematic parameters were used to characterize the kinematics of driving cycles and a meso-scale emission model, named KEM (Kinematic Emission Model), was developed ([Rapone et al., 2005](#), [Rapone et al., 2008](#)). It uses a multidimensional approach, based on a detailed description of the vehicles speed profile, in order to predict average emissions on micro-trips (driving pattern). This approach is implemented into a decision support system (DSS), useful for mobility analysts and for traffic environmental impact assessment ([Meccariello et al., 2008](#)).

Although resulting less complex than other models, to apply this kind of emission model, experimental campaigns needed to obtain driving cycle statistically representative of driving behavior result to be still extremely costly. A possible approach to deal with this issue is represented by the use of traffic microscopic simulation models which are capable to simulate individual car motion on the basis of traffic conditions, road characteristics and management rules. In particular, for each specified road and related traffic conditions, micro-simulation traffic models can determine instantaneous kinematic features of each vehicle moving on the simulated transportation network, thus providing the needed input quantities of emission models. The integration of emission and traffic flow models is not only suitable to provide emission models with vehicles kinematics but it is desirable also to achieve tools capable of more accurate and relevant analyses on the effect of policies and measures on the transportation system. Car-following models are, indeed, the core of any traffic simulation model since they simulate the way a vehicle accelerate or brakes as a reaction to the stimuli provided by the vehicle it has in front (namely its leader). The impact on emissions of driving dynamics like the variation in average speed, acceleration and deceleration, power demand and time spent stationary, are implicitly taken into account by the statutory cycle. Resulting emissions factors are therefore valid for driving cycles "similar" to those used to fill the bag. The approximation that arises since actual driving cycles are confused with statutory ones is

widely acknowledged in the literature (Brackstone et al., 1999). Furthermore, the problem of reproducing driving cycles for emission calculation is even more complex, since the way in which car-following models are calibrated (even when detailed trajectory data are used) may not be the most appropriate with a view to calculating emissions.

METHODOLOGY

The traffic/emission integrated framework is structured in some different phases. A first phase of data collection is required, to obtain the collected platoon trajectory. Trajectories have been measured through differential measures of vehicle instantaneous positions by using Differential Global Position System in Kinematic mode (K-DGPS). Thanks to differential correction performed on phase measures of two GPS signal carriers, provides receivers position with a frequency equal to 10 Hz and an expected precision in static mode of about 8-10 mm. Experiments have been carried out in real urban traffic conditions, within Naples metropolitan area, with four equipped vehicles. Then a platoon simulation is performed in which for the first vehicle the real trajectory is considered, the trajectory of the second vehicle is calculated on the basis of the real trajectory of the first one and the trajectories of all the following vehicles are calculated on the simulated trajectories of their respective leaders using parameters calibrated in the previous phase (Della Ragione, 2009). Four car-following models are considered in this paper: the Newell car following model (Newell, 2002), which is considered as reference model, given its simplicity, the Gipps car-following model (Gipps, 1981) which is one of the most commonly used models, the Wiedemann Action Point model (Wiedemann, 1974) which is another well known car-following model and finally the linear Helly model (Helly, 1959) which recently is finding new applications attempts.

Finally real emission and simulated emissions can be compared in order to validate the integrated framework.

The approach developed for the emission factor model identification consists of different tasks, and it is reported in figure 1. In the right line, the first step is data acquisition with instrumented vehicles driven by a consistent driver population in different geographical areas, to collect experimental data on driving behavior related to different road networks, traffic conditions and specific features of each geographical areas, with vehicles of different segment and technology. So a database representative of driving behavior, vehicle kinematics related to different traffic networks and conditions, displacement classes and different technologies (i.e. EURO I-IV) of vehicles is build, as in ARTEMIS EU Project (Joumard et al., 2007).

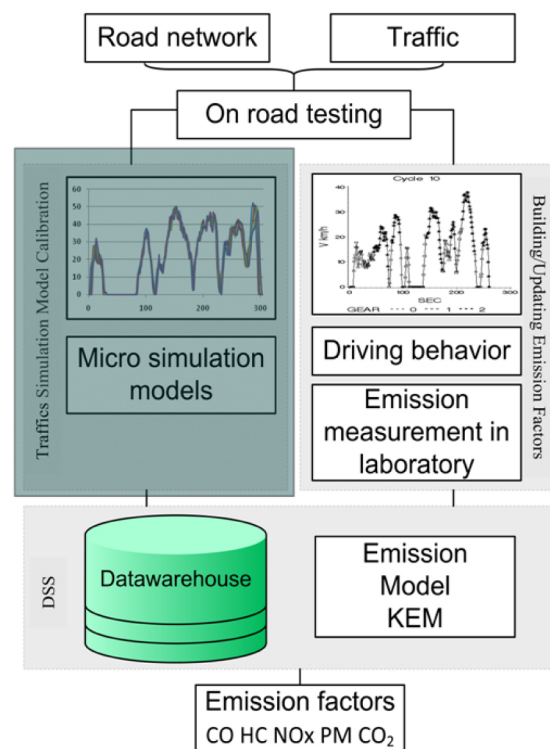


Figure 1. Emission model logical flows.

A considerations must necessarily be made: the high costs of these experimental campaigns in connection with the strong necessity of continuously updating the database is a problem, so to overcome these aspect, the micro simulation traffic models could be an optimal solution. But in any case it is fundamental to apply some multivariate statistical analysis on experimental data to define groups of driving cycles, vehicle operating conditions, and after-treatment emissions catalytic system (Della Ragione et al., 2001).

The KEM model considered here, was developed considering emission measurements and driving cycle coming from Artemis database (Joumard et al., 2007). From statistical point of view, the core of this approach is founded on a regression method capable to consider in the same model relation within Y variables (i.e. emission data), relation within X variables (i.e. kinematic parameters characterizing a driving cycle), and last among Y's and X's. X variables are able to characterize standstill, acceleration and deceleration, constant speed and cruise phases of vehicle motion.

In KEM the response considered is the measured unit emission mass of CO, HC, NO_x, CO₂ (expressed in g/km), measured in a driving cycle (DC), that is a portion of a trip. The explicative variables are identified by considering emission variation as explained by the variation in exhaust mass (function of energy spent by the vehicle in a driving cycle). So the explicative variables that characterize the

kinematics of driving cycles are related to the dynamic vehicle equation:

$$M \approx \int P(t)dt \approx \int_t (a_0 + a_1 * v(t) + a_2 * v^2(t) + M_{ve} * a(t)) * v(t) dt \quad (1)$$

where M is the total mass of exhaust, $P(t)$ the engine power, $v(t)$ the speed, $a(t)$ the acceleration and M_{ve} the vehicle effective mass.

So the X variables are related to the dynamic vehicle equation, plus idling time to consider standstill phase emission production and a further term relative to the reciprocal of distance, denoted $InvDist$, to take into account that unit emission mass is calculated as emission mass in a test divided DC's distance. The regression equation is:

$$\ln Y_{ij} = a_0 + a_1 mv + a_2 mv^2 + a_3 mv^3 + a_4 m_{va_pos} + a_5 Trunning + a_6 Tidle + a_7 InvDist + \varepsilon_{ij} \quad (2)$$

where mv is mean speed, mv^2 is mean square speed and mv^3 is mean cubic speed; m_{va_pos} is the mean product of instantaneous speed (v) and acceleration (a) calculated for positive values of a and v ; $Trunning$ is the running time and $Tidle$ is the idle time of the driving cycle, $InvDist$ is the reciprocal of the trip length, a_0 is the constant and $a_1 - a_7$ are the regression coefficient.

Since a logarithmic transformation was applied to the response variables, quantities predicted by model $[E(\ln Y)]$ must be retransformed in original scale, to get emission factors in original unit g/km (Duan, 1983).

EXPERIMENTAL AND NUMERICAL APPLICATIONS

In the next paragraph the emission model used will be presented. It is opinion of the authors that the analysis of the results of the integration between traffic and emission models is not only useful for the emission estimation but it will give a better insight also on the capability of traffic models to trustworthy resembling kinematic features of simulated vehicles. In the approach presented here emission model was developed considering emission measurements and DC coming from Artemis database. In this paper we present the predicted results and comparisons, based on the model coefficient and estimation obtained from the case study Euro II gasoline, displacement 1200-1400. But in the development of ARTEMIS Project they were developed emission models for all possible combinations of feeding-displacement-homologation class keeping in mind the availability of

ARTEMIS database data. About eleven case studies and derived models were defined, but some of them were founded on a few data and so they were a little less reliable.

SUPPLEMENTARY DRIVING CYCLE ANALYSIS

Using the PCA method (Buroche et al., 1983) it is possible to analyze and represent additional driving cycles as supplementary point. In this way we can immediately aware of the kinematic features of the new DC, compared to those used for the model construction. It is possible to recognize if the cycle is structurally different from those extract from the database as shown in figure 2. With this approach it could be analyzed, simultaneously, analyze the similarity of simulated DC (as supplementary observation) with some Artemis DC and it could be also evidenced some differences within inner the simulated DC. The simulated DC's (blue color), considered as supplementary point in the work set, have kinematics characteristics similar to Handbook.R, Oscar.G2, A.Urban.2, because they are in close proximity to these DC, but the DC named HellyS2 shows some differences from the other simulated DC.

This is because its kinematics characteristics are somewhat different from the other DC (Della Ragione et alii, 2009). In fact its m_{va_pos} value appears to be very high.

A data set may also contain moderate outliers. Moderate outliers could be identified by the residuals of each observation. This typical distance, DModX (Eriksson, 2006), could be calculate from the model in the X -data. We can also evaluate the critical distance corresponding to the 0.05 probability level.