Multiple Regression Model for Traffic Related Non-Exhaust PM Emissions in the Urban Environment

O. Tchepel[1], D. Dias[1], P.M. de Carvalho[2,3], N.A.G. Martinho[2,3], M.C.G. da Silva[2]*

[1] CITTA, Department of Civil Engineering, University of Coimbra, 3030-788 Coimbra, Portugal oxana@uc.pt
[2] ADAI – LAETA, Department of Mechanical Engineering, University of Coimbra, Coimbra, Portugal
[3] School of Technology and Management, Polytechnic Institute of Leiria, Leiria, Portugal

Abstract

Road transport is one of the main emissions sources of Particulate Matter (PM) in urban areas. Additionally to direct emissions by exhaust, non-exhaust emissions related with resuspension of particles, abrasion from brakes and interaction between a vehicle's tyres and the road surface must be quantified in order to guarantee completeness of PM emission estimate in air quality assessment. The prime objectives of this study is to derive a methodology for quantification of overall non-exhaust PM traffic emissions to be used in air quality modelling focusing on urban areas. For this purpose, experimental data were processed and considered as inputs to the multiple regression model to analyse the effects of independent continuous predictor variables on the non-exhaust emissions. Several assessments were performed allowing to achieve a correlation of r = 0.81 between the original and fitted time series based on traffic-induced turbulence, surface moisture and wind speed data selected for the regression analysis. The contribution of non-exhaust sources to the total traffic related PM10 emissions is varying between 2% to 84% with an average contribution of about 48%.

Keywords: road traffic, non-exhaust emissions, urban air pollution.

Introduction

High atmospheric levels of particulate matter (PM) and exceedances of the legislation PM limit values is one of the main environmental issues in most European cities. Without a doubt, road transport is an important source of airborne particles in urban areas. Therefore, a development and implementation of methodologies allowing quantification of road traffic emissions are required in order to improve the scientific knowledge on cause-effect relationship and to find potential solutions to decrease PM pollution levels in the cities.

Additionally to the exhaust emissions from road transport, quantification of non-exhaust PM is currently a research priority due to it important contribution (up to 60%) to the total traffic related PM emissions (APART, 2009). Non-exhaust emissions are produced by abrasion from brakes, from interaction between a vehicle's tyres and the road surface, and vehicle induced resuspension of previously deposited particles.

Although non-exhaust emissions are very important for air quality studies, the methodologies on their quantification are still limited, particularly for the dust resuspension (Barlow et al., 2007). The lack of information on spatial and temporal variability of the overall non-exhaust traffic emissions make difficult their implementation in air quality modelling and management.

The prime objective of the current study is to derive a methodology for quantification of total non-exhaust PM traffic emissions to be used in air quality modelling. This approach is looking for the completeness of the traffic emission estimations to ensure their suitability for air quality modelling while the individual contributions of vehicle tyre, brake wear, road surface wear and particle resuspension to the total emissions are not addressed.

Method and data

To define the modelling algorithm for non-exhaust emissions, experimental data on atmospheric concentrations obtained for PM were used in a combination with meteorological data and detailed vehicle counting. The measurement campaigns were performed in the central part of a medium-sized Portuguese city (Leiria) in November 2010. Traffic flow for the study area is about 10 000 vehicles per day with the bus contribution of about 6%. Location of the measurement point, as well as location of central bus station is shown in Figure 1.

Figure 1: Study area in Leiria (Portugal) centred on the measurement point location.

Number of particles with the diameter between 0.3μm to 10μm (Figure 2) combined in 5 size bins were obtained with 5 min temporal resolution during the campaign using optical particle counter and then converted to PM concentration.

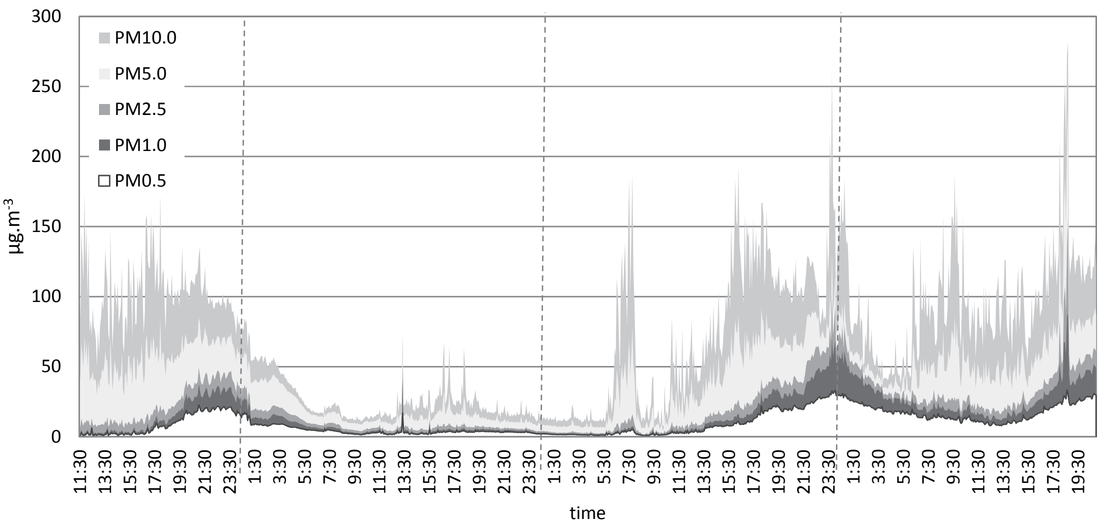

Figure 2: Time series of PM concentration measurements by different size bins.

Based on the different pattern obtained for fine and coarse PM fractions, the non-exhaust emissions were attributed to the diameter bins above 2.5μm for the future analysis. Despite some uncertainties, this assumption is in accordance with the previous studies confirmed that non-exhaust PM are dominated by coarse fraction (EMEP/EEA, 2013).

The inverse algorithm was applied to convert the concentration measurements into emission rates. For this purpose is assumed that PM concentration (C) measured at street level is influenced by direct contribution from local pollution sources (C_{direct}) and the urban background contribution ($C_{background}$):

$$C = C_{direct} + C_{background}. \qquad (eq.\ 1)$$

Prior to the inverse model run, the background contribution was removed from the original concentration measurements allowing separating the contribution from local pollution sources. For this purpose, time series obtained from the nearest rural background station were considered after the data filtering as describe by Tchepel et al. (2010).

A Gaussian plume theory is used to establish the relationship between emission rate (Q) and atmospheric PM concentrations (C) related with the direct contribution from a plume travelling with a speed u_b and which at a distance x from the source has a vertical dispersion σ_z :

$$dC_{direct} = \sqrt{\frac{2}{\pi}}\frac{dQ}{u_b \sigma_z(x)} \qquad \text{(eq. 2)}$$

It is assumed that the vertical dispersion parameter is governed by mechanical turbulence only and generated by wind and vehicle traffic in the street. The traffic induced turbulence σwo at street level is estimated as following (Berkowicz et al., 1997):

$$\sigma_{wo} = b\left(\frac{N_{veh} \times V \times A}{W}\right)^{1/2} \quad \text{(eq. 3)}$$

where *b* is an empirical constant (*b*=0.3) related to the aerodynamic drag coefficient, *Nveh* is the number of vehicles per time unit, *V* is the average vehicle speed, *A* is the horizontal area occupied by a single car and *W* is the width of the street canyon. Therefore, traffic induced turbulence increase with the traffic flow and decrease with canyon width. The inverse application of the plume model provides quantitative estimates of the emission rate and their variations in time.

As a final step, a multiple regression analysis is implemented allowing prediction of non-exhaust emissions as a function of independent continuous predictor variables:

$$\hat{Y} = b_0 + b_1(x1) + b_2(x2) + b_3(x3) + \cdots + b_k(xK) \quad \text{(eq. 4)}$$

For this purpose, several regression analyses were performed to evaluate a range of independent variables and significance of their contributions. Thus, wind speed, traffic induced turbulence and moisture content of the road dust layer were selected. The last parameter was estimated using EPA methodology (EPA, 2006) taking into account precipitation and evaporation rates.

Results and Discussion

Based on the inverse algorithm described above, emission rate for PM with the diameter between 2.5μm and 10μm ($PM_{2.5-10}$) was obtained as presented in Figure 2 and assumed as non-exhaust emissions for the future analysis. Temporal variations of these emissions rate are influenced by traffic flow and meteorological conditions. Thus, precipitation events observed during the second day of the campaign contribute to significant decrease in emission rate as depicted in the figure.

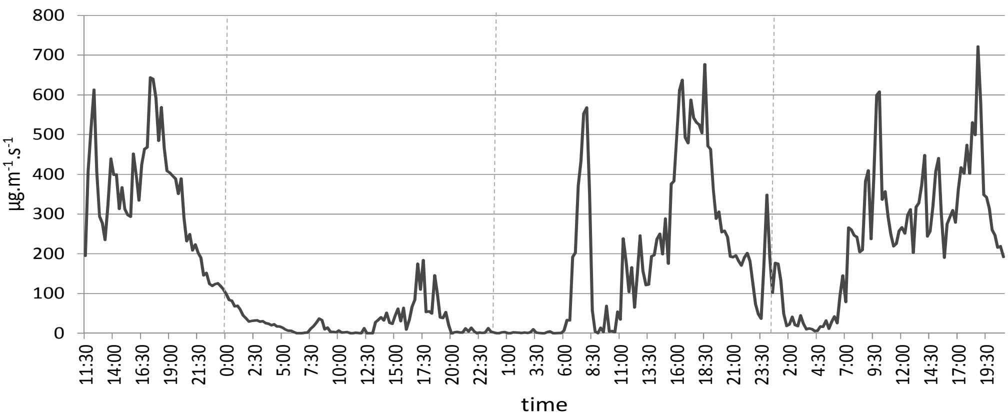

Figure 2: Emission rate for $PM_{2.5-10}$ obtained by inverse modelling algorithm.

The time series of non-exhaust emissions obtained from the previous step are considered for the regression analysis. In order to obtain a multiplicative model, all variables were log-transformed. The parameters estimated from the multiple regression analysis for the selected variables are presented in Table 1.

Table 1: Parameters estimated by the multiple regression analysis

	Param.	Std.Err	p	-95% Cnf.Lmt	+95% Cnf.Lmt
Traf. ind. turbulence	2.19315	0.287423	0.000000	1.62094	2.76536
Wind speed	-1.12310	0.273525	0.000098	-1.66765	-0.57855
Moisture content	-1.90931	0.416180	0.000017	-2.73786	-1.08076

The output from the regression model has a coefficient of correlation (r) of 0.81. The resulting equation for prediction of non-exhaust emissions, EF [$g.m^{-1}.s^{-1}$] is:

$$EF = \frac{0.2\,\sigma_{wo}^{2.19}}{u_b^{1.12}\,M^{1.91}} \quad \text{(eq. 5)}$$

It is expected that 95% of the future data will fall within equation with exponents of 1.62 and 2.765 for the traffic induced turbulence, -1.668 and -0.578 for the wind term, and -2.737 and -1.081 for the moisture term. The range of the conditions used in the regression analysis was 0.12 - 0.64 m.s^{-1} for the traffic induced turbulence (σ_{wo}), 0.5 - 4.4 m.s^{-1} for the wind speed at street level (u_b), and 6.7 – 20% for the moisture content (M) of the road dust layer.

The scatter plot of log-transformed predicted values versus observations is presented in Figure 3a. Additionally, normal probability plot of the residuals is depicted in Figure 3b.

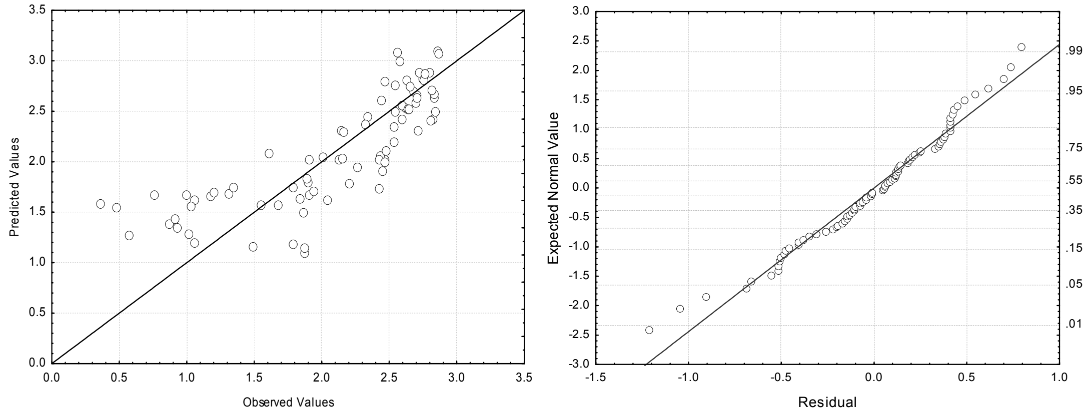

Figure 3: (a) Predicted versus observed log-transformed emission values and (b) normal probability plot of the residuals.

To provide a complete estimate of traffic emissions to be used in air quality modelling, exhaust emissions were also quantified using previously developed TREM model (Tchepel et al., 2012) and contribution of non-exhaust emission to the total PM emissions is analysed (Figure 4). The emission data presented in Figure 4 are influenced by temporal variations in the traffic flow, including total number of vehicles and % of buses, and the meteorological conditions on wind speed and precipitation.

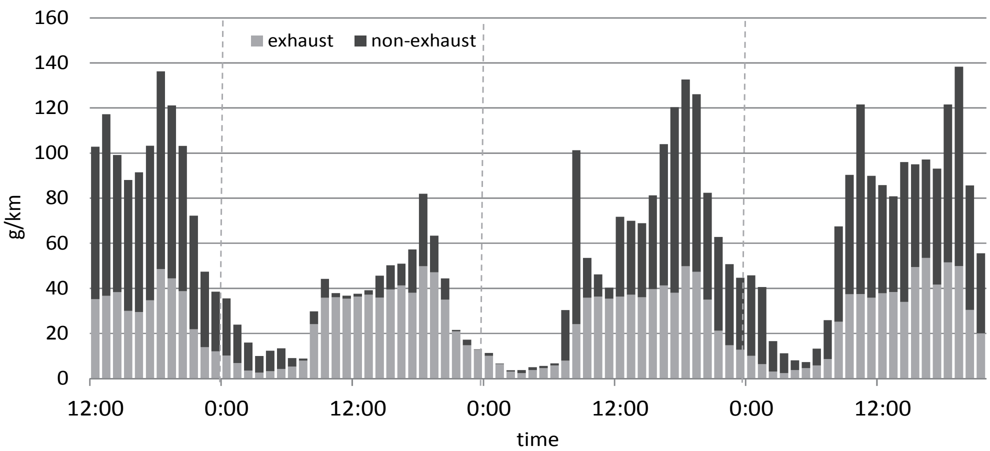

Figure 4: Traffic related PM10 emissions (exhaust + non-exhaust) estimated for the study area taking into account traffic flow and meteorological conditions.

As could be seen in Figure 4, besides the similar daily fluctuations of exhaust emissions during the study period, non-exhaust emissions are significantly variable in time and their contribution to the total traffic-related PM10 emissions is varying from 2% to 84% with an average contribution of about 48%.

Conclusions

A new prediction model to quantify non-exhaust PM emissions from road traffic in an urban environment is proposed in this study. Based on multiple regression analysis, parameters are determined to predict the emission values as a function of traffic induced turbulence, wind speed and moisture content of the road dust layer. A correlation between predicted values and original time series of r =0.81 is achieved. The analysis of total traffic-related PM emissions for the study area reveal an average contribution of non-exhaust sources of about 48% with significant temporal variations. The methodology proposed in this work aims to improve a completeness of traffic related emission estimates to be used as inputs in air quality modelling.

Acknowledgements

The measurement campaigns were performed in the framework of TransUrb (PTDC/TRA/73637/2006) project. The research grant of D. Dias is supported by EMSURE project (CENTRO-07-0224-FEDER-002004).

References

APART (2009) PM10 emission factors of abrasion particles from road traffic. EMPA/PSI report.

Barlow TJ., Boulter PG., McCrae .S., Sivell P., Harrison RM, Carruthers D., Stocker J. (2007) Non-exhaust particulate matter emissions from road traffic: summary report. Published Project Report PPR231.

Berkowicz, R., Hertel, O., Larsen, S.E., Sørensen, N.N. and Nielsen, M. (1997) Modelling traffic pollution in streets. Report.

EMEP/EEA (2013) Air pollutant emission inventory guidebook, European Environmental Agency, 12/2003.

EPA (2006) AP 42, Fifth Edition, Volume I, Chapter 13: Miscellaneous Sources.

Tchepel O., Costa A.M., Martins H., et al. (2010). Determination of Background Concentrations for Air Quality Models Using Spectral Analysis of Monitoring Data *Atmos. Environ*., 44: 1, 106-114.

Tchepel O., Dias D., Ferreira J., Tavares R., Miranda A.I., Borrego C. (2012), Emission modelling of hazardous air pollutants from road transport at urban scale. *Transport*, 27:3, 299-306.