TRAFFIC PRODUCING TURBULENCE SCHEMES WITHIN OPERATIONAL STREET POLLUTION MODELS: EVALUATION USING ROADSIDE MEASUREMENTS

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ABSTRACT
Production of turbulence due to vehicular traffic is recognised as being a dominant factor in the dilution of pollutants in street canyons under low wind speed conditions. Fast-response operational dispersion models often perform rather poorly under these conditions. Such a behaviour has been attributed to the lack of accurate Traffic Producing Turbulence (TPT) formulations within dispersion models.

In this paper, two alternative TPT schemes presented in literature were implemented in the well validated WinOSPM (the Danish Operational Street Pollution Model) in addition to the original model formulation, and their performance compared.

INTRODUCTION
Nowadays, a growing fraction of the world population is becoming city dwellers, contributing to the further rise of mobility demand and vehicular traffic load in cities. Urban air quality is a major concern for people living in urban areas and local authorities dealing with its assessment. Operational dispersion models, such as the WinOSPM (the Windows version of the Danish Operational Street Dispersion Model) (Berkowicz, 2000), are increasingly employed to assess the impact of traffic pollution and to help identify appropriate abatement strategies (because of their relative low running cost required). However, urban dispersion models, such as WinOSPM, perform relatively poorly under low wind speed conditions (Di Sabatino et al., 2003). This may be due to the lack of accurate Traffic Producing Turbulence (TPT) parameterisations in the models. Under low wind speed conditions (neglecting the production of turbulence due to thermal effects), the production of turbulence due to vehicle traffic can become the dominant process in the dilution of pollutants emitted at street level. Moving vehicles add a further mechanical process that creates turbulence, enhancing the mixing of the pollutants at street level, where the emissions are released.

In this paper, two TPT schemes proposed in literature were tested within WinOSPM, in addition to the original model formulation. Three independent datasets of CO concentrations within urban street canyons, were used. The performance of different TPT formulations implemented into WinOSPM were compared against the original model formulation.

TRAFFIC PRODUCING TURBULENCE SCHEMES
Within WinOSPM, the TPT component σ_{w0} is expressed as:

$$\sigma_{w0}^2 = \left(D^2\, n_v\, S^2\, W^{-1}\right) v^2 \qquad (1)$$

where, D is the drag coefficient exerted by the vehicles, n_v the density of vehicles per unit length of the street (composed by the density of passenger cars and of heavy duty vehicles)(m^{-1}), W the canyon's width (m), S^2 the planar area of the vehicles (m^2), and v their velocity ($m\ s^{-1}$). Di Sabatino et al. (2003) presented a theoretical model to estimate the TPT in street canyons. Three traffic regimes were postulated: light (non-interacting vehicle wakes), intermediate (interacting vehicle wakes) and large (strongly interacting vehicle wakes) traffic density n_v. Theoretical considerations showed that the turbulence production increased linearly with n_v for the low traffic flow (Equation 2a), depended on $n_v^{2/3}$ for intermediate traffic flow (Equation 2b), and for large traffic flow regime σ_{w0} did not depend on n_v (Equation 2c).

$$\sigma_{w0}^2 = c_1\, n_v\, D^{2/3}\, h^3\, S_c^{-1}\, {v_1}^2 \tag{2a}$$

$$\sigma_{w0}^2 = c_2\, (n_v\, D)^{2/3}\, h^2\, S_c^{-2/3}\, {v_2}^2 \tag{2b}$$

$$\sigma_{w0}^2 = c_3\, D^{2/3}\, h^{4/3}\, S_c^{-2/3}\, {v_3}^2 \tag{2c}$$

where v_i are the vehicle velocity for light, intermediate and large traffic densities, and c_i the related coefficients. S_c (m^2) is the section of the canyon where the TPT effects are important.

TPT analyses were also undertaken by Mazzeo and Venegas (2005), using CO data collected in Goettinger Strasse (Hannover). The traffic vehicles were categorised into seven groups for leeward conditions (depending on the traffic volume and the estimated traffic velocity) and into two groups for windward conditions. The authors found a satisfactory TPT correlation with the density of vehicles n_v by applying the following relationship:

$$\sigma_{w0}^2 = 6.9 \cdot 10^{-6}\, exp\left(3.68 \cdot 10^{-2}\, n_v\right) v^2 \tag{3}$$

METHODOLOGY

WinOSPM was tested using hourly CO concentration data for the street canyon sites in Table 1. Three TPT schemes were evaluated:

(I) The original model formulation based on Equation (1);
(II) The theoretical scheme proposed by Di Sabatino et al. (2003) based on Equations (2);
(III) The empirical formulation of (3) proposed by Mazzeo and Venegas (2005).

Numerical implementation within WinOSPM was straightforward for the TPT schemes (I) and (III). On the other hand, schemes (II) required the specification of the transition between traffic flow regimes, and the specification of the parameters c_i. To this scope, the transition between the traffic regimes was characterised by adopting the results obtained from the flow regimes developing over a two-dimensional street canyon proposed by Oke (1988). Parameters c_i were evaluated by imposing the TPT continuity as the traffic density varies from light to intermediate to large. Full details are given in Solazzo et al. (2007).

The TPT schemes (I), (II), and (III) were evaluated using datasets of roadside CO concentration collected in European cities: Goettinger Strasse, (Hannover), Schildhornstrasse (Berlin), Jagtvej (Copenhagen).

Table 1. Geometry of the street canyon sites and traffic properties in term of Annual Average Daily Traffic flow (AADT), density of vehicles n_v, and weighted vehicle speed.

	H/W	n_{lanes}	AADT	n_v (m^{-1})		Weighted average vehicle speed (m s^{-1})	
				passenger vehicles	heavy-duty vehicles	passenger vehicles	heavy-duty vehicles
Goettinger	0.8	4	30,000	0.029	0.0050	11.42	10.45
Jagtvej	0.7	4	22,000	0.024	0.0010	10.83	7.78
Schildhorn	0.8	4	45,000	0.047	0.0025	10.81	9.86

Table 1 summarises the canyon aspect ratios, and the number of street lanes. Traffic-flow conditions over the entire monitoring period are also given, in terms of Annual Average Daily

Traffic flow (AADT). Average traffic density n_v, and the weighted average vehicles speed, categorised in passenger vehicles and heavy duty vehicles are also reported.

RESULTS AND DISCUSSION

Figure 1 shows the variation of σ_{w0}^2 as a function of n_v, when the TPT formulations (I), (II) and (III) are adopted. Analysis of Figure 1 showed that for the light traffic regime all tested schemes predicted similar TPT levels. However, for the intermediate traffic regime, very different turbulence levels were observed for different schemes. The TPT increased linearly for scheme (I), sharply decreased for scheme (II) as expected from Equation (2b), and exponentially increased for scheme (III) reaching very high values. In the case of Jagtvej (Figure 1b), schemes (I) and (II) gave very similar results of relatively low TPT, while scheme (III) calculated much higher values.

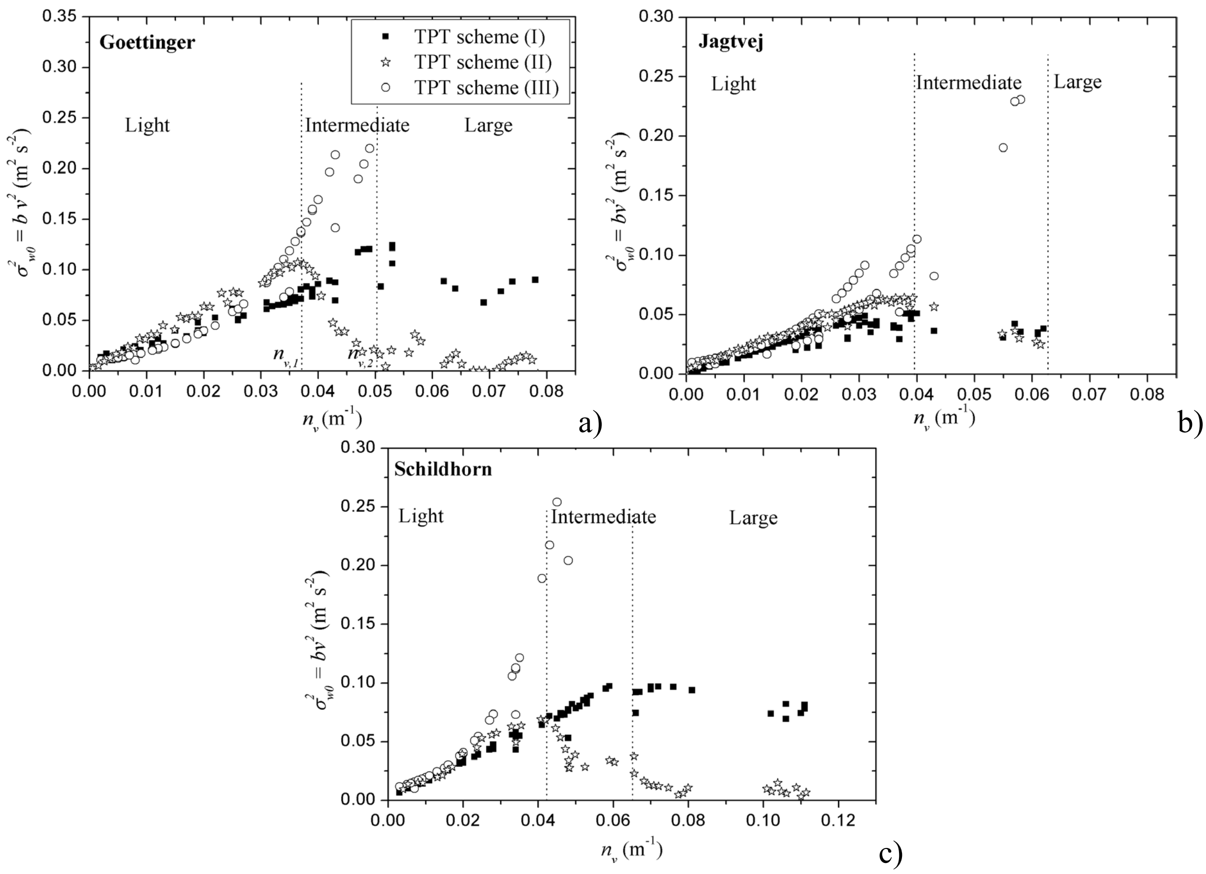

Fig. 1; TPT magnitude predicted by: scheme (I) original WinOSPM (filled squares), (II) Di Sabatino et al. (2003) (stars) and (III) Mazzeo and Venegas (2005) (circles) for (a) Goettinger, (b) Jatgvaj and (c) Schildhorn. Traffic density regions indicated with dotted line.

For large traffic densities, scheme (II) does not depend on n_v and the TPT values depend only on the fraction of passenger and heavy duty vehicles.

Dependence of model performance on wind speed and direction

Low wind speed analyses (u_{roof} < 1.5 m s^{-1}), under leeward and windward conditions were carried out. Overall, results in term of correlation coefficient R, and FAC2 (fraction of predictions within a factor of 2 of observations) (Table 2) showed that, in most cases, the model performed better for windward conditions and that significant improvements were achieved by adopting TPT scheme (II).

Table 2. Wind speed and direction analysis: leeward conditions and $u_{roof} < 1.5\ m\ s^{-1}$.

TPT scheme		WinOSPM (I)		Di Sabatino et al. (2003) (II)		Mazzeo & Venegas (2005) (III)	
Wind direction		Leeward	Windward	Leeward	Windward	Leeward	Windward
Goettinger	R	0.70	0.75	0.73	0.74	0.60	0.75
	FAC2	86 %	95 %	89 %	95 %	80 %	94 %
Jagtvej	R	0.94	0.86	0.93	0.87	0.91	0.85
	FAC2	93 %	77 %	93 %	85 %	66 %	84 %
Schildhorn	R	0.76	0.86	0.83	0.87	0.44	0.81
	FAC2	64 %	85 %	80 %	88 %	56 %	73 %

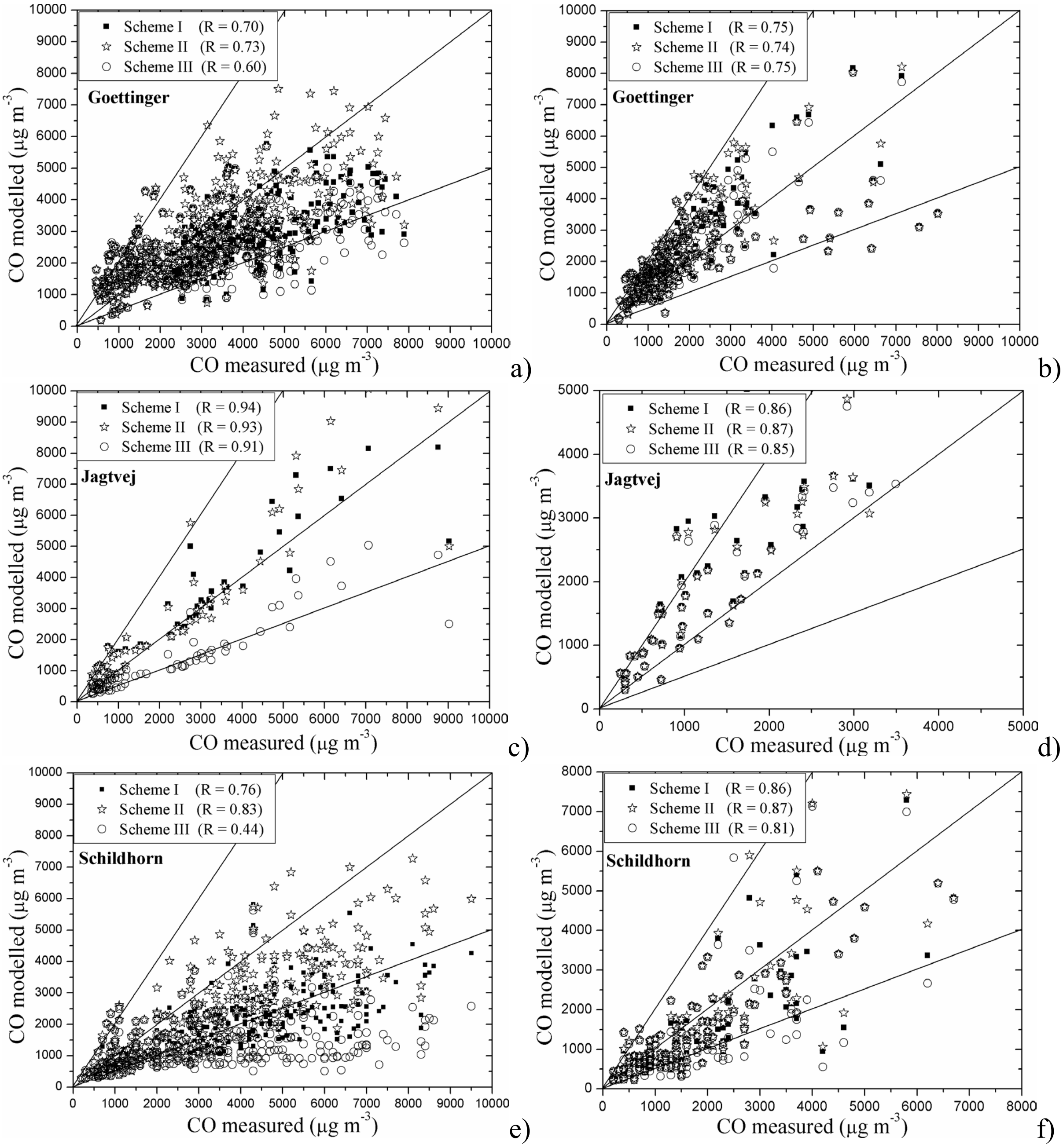

Fig. 2; Measured vs. modelled CO concentrations for Goettinger (a and b), Jatgvej (c and d) and Schildhorn (e and f) for leeward (left side) and windward (right side) condition and $u_{roof} < 1.5\ m\ s^{-1}$. TPT schemes (I) original WinOSPM, (II) Di Sabatino et al. (2003) and (III) Mazzeo and Venegas (2005) are compared.

In Figure 2, measured vs. modelled CO concentrations for leeward and windward conditions, with u_{roof} < 1.5 m s^{-1}, are shown. The diagonal continuous line represents the prefect agreement (R = 1), whereas the other two straight lines indicate the FAC2. Results in Figure 2 can be interpreted with the aid of Figure 1. Lower TPT levels (scheme II) result in higher CO concentrations, allowing values in Figure 2 to be shifted within the FAC2 region. By contrast, high TPT levels (scheme III) do not appear to improve the overall model performance and generally lead to under-predictions. Overall, it can be observed that the model has a tendency to under-predict CO concentrations for leeward wind conditions and to over-predict for windward conditions.

CONCLUSIONS

In this paper, two TPT formulations recently proposed in literature were tested within WinOSPM, in addition to the scheme originally implemented in the model. From the results obtained, the following conclusions could be drawn:

- WinOSPM performed satisfactory for regular canyons, closely reproducing the observed CO concentrations.
- However, the statistical evaluation results showed that the TPT formulation significantly influenced the overall model performance, with a greater impact for leeward wind conditions.
- The three TPT schemes predicted similar turbulence levels for light traffic density. By contrast, the predicted TPT levels were substantially different for high traffic density. In that case, the average traffic speed is reduced due to congestion, resulting in decreased mechanical turbulence in the street.
- TPT scheme by Di Sabatino et al. (2003) significantly improved the overall performance of the model, whereas the original model formulation seemed to over-estimate TPT levels for high traffic density. However, the implementation of scheme (II) requires the specification of parameters (c_i) that need to be empirically determined.

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