# APPLICATION OF URBAN STREET CANYON MODELS FOR PREDICTING VEHICULAR POLLUTION IN AN URBAN AREA IN DUBLIN, IRELAND.

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## INTRODUCTION

In most European cities, traffic is the most important source of air pollution, with the highest ambient concentrations often found on streets in urban centres. Vehicular pollution dispersion models are therefore essential computational tools for predicting the impacts of emissions from road traffic. These include models for evaluating air quality in street canyons, where the existence of a recirculating vortex leads to unique pollutant transport and dispersion conditions. In this context, two urban street canyon models, namely STREET and OSPM, were investigated at Pearse Street, an important traffic route in the centre of Dublin city. STREET (Johnson et al., 1973) is a simple semi-empirical model that calculates series of hourly concentrations at different receptor locations within a street canyon. The OSPM (Berkowicz, 2000) is also a semi-empirical model and calculates on-street concentrations as the sum of three separate components, viz, direct transport of pollutants from source to receptor, recirculation due to due to flow of pollutants around the vortex generated within the street canyon and the urban background. This paper evaluates both of these models by comparing modelled and measured series of hourly CO and $NO_x$ concentrations for a receptor point within the street canyon. The analysis extends over a two-month period for which measured traffic flows and background pollutant concentrations were available for input to the model calculations.

## DISPERSION MODELLING

STREET (Johnson et al., 1973) is a semi-empirical model that calculates series of hourly calculations at different receptor locations within a street canyon. The total concentration (C) of the pollutant is assumed to be the summation of the urban background concentration ($C_b$) and concentration due to vehicular emissions ($C_s$) generated within the canyon.

$$C = C_s + C_b \qquad (1)$$

The $C_s$ concentration component is derived from a simple box model (Johnson et al., 1973) that gives the concentrations of the pollutant on the leeward and windward sides of the street. The windward side is defined the as the side of the street to which the wind blows at roof level, while the leeward side is the side of the street from which the roof wind blows. The concentration on the leeward side of the street is computed using equation (2)

$$C_s^L = \frac{KQ}{\left(U + U_s\right)\left(\sqrt{x^2 + z^2} + h_o\right)} \qquad (2)$$

where $K$ is an empirical constant parameter, $Q$ is the rate of release of emissions in the street, $x$ is the horizontal distance between the receptor and the centre of the nearest traffic lane, $z$ is the height of the receptor, $h_o$ is a constant that accounts for height of initial pollution dispersion (empirical value of 2 m), $U$ is the roof level wind speed and $U_s$ is a constant that accounts for the additional air movement induced by vehicle traffic (empirical value of 0.5m/s). In this study, a value of K = 7 was used in line with previous studies on the STREET model (Vardoulakis et al., 2002). Qin and Kot (1993) estimated the value of K to be 6 for their work in an asymmetric street canyon in China whereas Bogo et al. (2001) reportedly used a K value of 8 for a similar study in Buenos Aires.

On the windward side, the initial expression for $C_s$ given by Johnson et al. (1973) was revised by Dabberdt et al. (1973) to take into consideration the decrease in concentrations due to entrainment of fresh air through the top of the canyon. The resulting equation for calculating concentrations on the windward side of the street is given in equation (3)

$$C_s^w = \frac{KQ}{W(U+U_s)}\left(\frac{H-z}{H}\right) \qquad (3)$$

where $H$ is the height and $W$ is the width of the canyon. For parallel or near parallel winds, the average of the windward and leeward concentrations calculated using equations (2) and (3) is adopted for both sides of the street. Variations of this model have been investigated in other studies (Qin and Kot, 1993).

The OSPM model (Berkowicz, 2000) is based on principles that are similar to the CPB model proposed by Yamartino and Wiegand (1986). Concentrations of exhaust gases are calculated using a combination of a plume model for the direct contribution and a box model for the recirculating component of the pollutants in the street. As a consequence, the concentrations obtained on the windward side are lower than those on leeward side. The total concentration of pollutant at a receptor on the street is given by equation (4)

$$C_s = C_d + C_r + C_b \qquad (4)$$

where $C_s$ is the total concentration, $C_d$ is the direct contribution, i.e., the direct flow of pollutants from vehicles to monitor, $C_r$ is the recirculation component due to the wind vortex and $C_b$ is the urban background concentration of the pollutant. $C_d$ is calculated using a Gaussian plume model. Emissions are assumed to be constant throughout the street and are modelled as a number of infinitesimal line sources aligned perpendicular to wind direction at street level. The dispersion of the plume is assumed to be attributable to convective and mechanical turbulence in vehicle wakes. The effects of thermal stratification on turbulence are not considered and the stability class is assumed to be always neutral. Traffic-induced turbulence is dependent on traffic intensity, average vehicle speeds and average vehicle dimensions. $C_r$ is computed using a box model in which the underlying principle is that the inflow rate of the pollutants in the recirculation equals the outflow rate, and that the pollutants are thoroughly mixed in the zone. The relevant mathematical formulations have been reported by Buckland (2000) and Vardoulakis et al (2002).

## RESULTS AND ANALYSIS

Pearse Street is a four-lane one-way route in the centre of Dublin City, with an approximately East-West orientation and an average daily traffic flow of 60,000 vehicles, of which 10% are HDVs. Continuous monitoring of hourly CO and NOx concentrations is performed by Trinity College Dublin at a long-term air quality monitoring station on the southern side of the street. The sampling point is located 6m from the kerbside and 1m above street level. Comparison of measured and modelled concentrations is carried out for two months: May and June 2006. Hourly meteorological conditions recorded at Dublin Airport were used as input for both models, following correction of wind-speed for city-centre conditions. Hourly traffic flows on the street were measured by the traffic control system operated by Dublin City Council and inputted directly into both models. Composite emission factors were calculated using vehicle fleet characteristics data for 2005. Separate daytime and nightimes emission factors were employed to allow for the varying effect of congestion on vehicle speeds. The average speed of the vehicles during the daytime was approximately 20km/hr, but this rose to approximately 35km/hr at night, resulting in daytime (0900-1800) emission factors of 2.04g/km (CO) and 0.65g/km ($NO_x$) and nightime emission factors of 1.30g/km (CO) and 0.52g/km ($NO_x$). Hourly background concentrations were obtained from an urban air quality monitoring station operated by Dublin City Council at Winetavern Street, which is located approximately 1 km west of Pearse St, and approximately 100m from the nearest trafficked street.

Statistical and graphical analyses of the modelled and measured concentrations results are presented in Tables 1 and 2 and Figures 1 and 2 for both pollutants. Tables 1 and 2 present model evaluation parameters that compare different aspects of the modelled and measured concentration datasets. The index of agreement (IA) represents the level to which the hourly model predictions agree with measured concentrations, with an IA value of 1 implying that the monitored and predicted data are in complete agreement. The NMSE is a fundamental statistical performance parameter. The normalization ensures that the NMSE will not bias towards the models that overpredict or underpredict. An NMSE value of 0.5 implies an average factor of two between predicted and monitored values. The Pearson's correlation coefficient (R) describes the proportional change with respect to the means of the two quantities in question. These three parameters are measures of the correlation of the predicted and monitored time series of concentrations. The fractional bias (FB) is a measure of the agreement of the mean concentrations and its values range from -2 to +2, where a value of -2 implies extreme underprediction and a value of +2 implies extreme overprediction. The factor of two (F2) is a coarse but easily understood measure of the likelihood that an individual model result will lie within a factor of two of its equivalent measured value. Definitions and further information on these parameters is given by Kukkonen et al, (2001).

*TABLE 1: Model evaluation parameters for May 2006.*

| | CO | | | $NO_x$ | | |
|---|---|---|---|---|---|---|
| Parameter | Mon[1] | STREET[2] | OSPM[3] | Mon | STREET | OSPM |
| Mean (microgram/m$^3$) | 596.7 | 479.7 | 643.5 | 195 | 163 | 212 |
| IA | 1 | 0.78 | 0.93 | 1 | 0.92 | 0.97 |
| NMSE | 0 | 0.12 | 0.03 | 0 | 0.18 | 0.06 |
| R | 1 | 0.86 | 0.94 | 1 | 0.72 | 0.88 |
| FB | 0 | -0.23 | 0.06 | 0 | -0.18 | 0.08 |
| F2 (%) | 100 | 100 | 100 | 100 | 100 | 88 |

[1]Monitoring results; [2]STREET results; [3]OSPM results.

*TABLE 2: Model evaluation parameters for June 2006.*

| | CO | | | $NO_x$ | | |
|---|---|---|---|---|---|---|
| Parameter | Mon[1] | STREET | OSPM | Mon | STREET | OSPM |
| Mean (microgram/m$^3$) | 854.1 | 772.2 | 830.7 | 192 | 187 | 214 |
| IA | 1 | 0.88 | 0.97 | 1 | 0.94 | 0.97 |
| NMSE | 0 | 0.07 | 0.01 | 0 | 0.12 | 0.05 |
| R | 1 | 0.64 | 0.92 | 1 | 0.72 | 0.92 |
| FB | 0 | -0.09 | -0.02 | 0 | -0.02 | 0.11 |
| F2 | 100 | 100 | 100 | 100 | 100 | 71 |

[1]Monitoring results; [2]STREET results; [3]OSPM results.

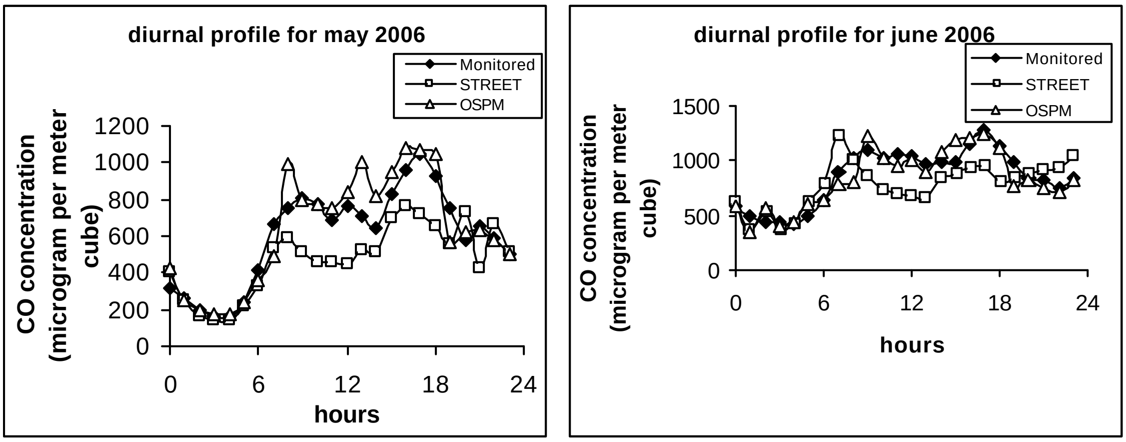


*Figure 1. Diurnal variation of CO*

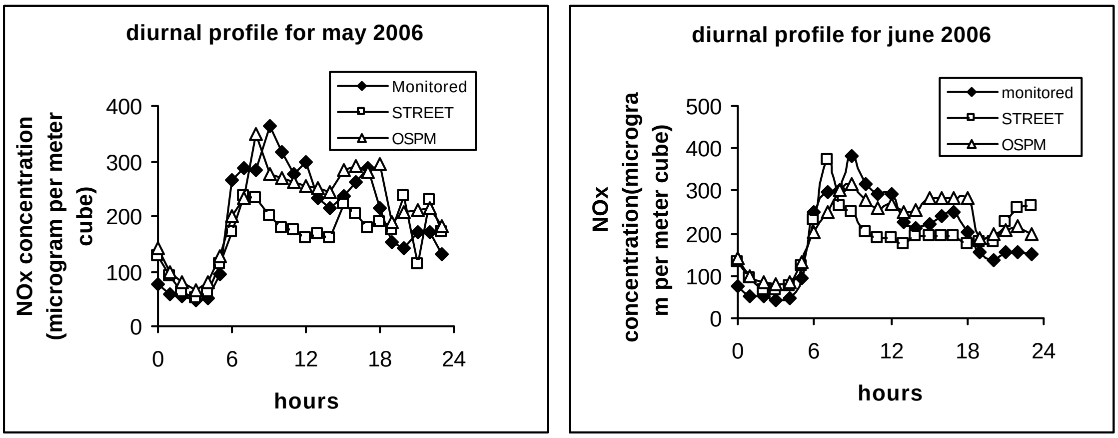


*Figure 2.Diurnal variation of $NO_x$*

**DISCUSSIONS**

The mean and NMSE values in Tables 1 and 2 show that the mean concentrations predicted by the STREET model tend to slightly underpredict the monitored results, whereas the OSPM tends to slightly overpredict the model results, with the exception of the $NO_x$ concentration in June 2006 which both models underpredict. The FB values suggest that there is substantial agreement between measured and predicted values with both models. It is observed from the statistical analysis that high IA values were obtained using both the models, with the OSPM value suggesting better model performance than the STREET model. These results imply that a high percentage of the modelled results were substantially error-free, which suggests that a proper modelling approach was followed. The Pearson's correlation coefficients obtained with both models are high, but the OSPM model clearly performed better than the STREET model in this regard. This confirms that more of the factors affecting short-term concentration variations are correctly represented in the OSPM formulation, given that the same meteorological, traffic and background concentration datasets were used in both cases.

Overall, the model evaluation parameters for the OSPM are better than those for STREET except for the fractional bias (FB) and factor-of-two statistics for $NO_x$ in June 2006. The results do not indicate that model performance is different for the two pollutants considered.

Figures 1 and 2 present the average diurnal variations of the measured and modelled concentrations of CO and $NO_x$ for the two months considered. The monitored CO profile displays morning and evening peaks coinciding with periods of maximum travel demand. The evening peak is higher than the morning peak because traffic congestion on Pease Street is worst at this time of day, causing average vehicle velocities to fall and unit emissions to rise. This variation is successfully captured by both models, particularly the OSPM which produce a diurnal concentration profile very similar to that monitored. Similar levels of agreement are observed in the modelled and measured NOx results, with the STREET model again tending to underestimate the impact of increased daytime traffic flows. For this pollutant, maximum concentrations occur during the morning rush-hour, and this is better predicted by the OSPM models.

## CONCLUSIONS

When compared with monitored data, concentrations calculated using STREET and OSPM both successfully predict observed variations in air quality. From the statistical parameters presented it is quite evident that both models are successful in predicting long-term average concentrations. It is seen that the OSPM results correlate better with the monitored data than the STREET values. It may be concluded that for urban street canyon the OSPM is able to predict the concentration of pollutants better than the STREET model. However, the STREET model remains reasonably accurate, in spite of its simplicity which allows it to be more readily incorporated into transport network models of urban areas. In this study, very good data were available for background air quality and traffic flows. In practice, model performance can be expected to deteriorate when inferior input data are employed. Further, the ability of both models to predict $NO_2$ rather than $NO_x$ concentrations on Pearse St remains to be evaluated.

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