Contribution of Silvana di Sabatino to the TRAPOS WG-TPT meeting in Cambridge, 25.02.2000:

Parameterisation of the vehicle produced turbulence and its implications for an operational dispersion model

TASK:

- To improve the understanding of the physical mechanisms occurring in the urban dispersion of pollutants under low wind conditions and in particular to investigate the effect of mechanical vehicle-produced turbulence at the street canyon scale.
- To improve the performance of operational models under low wind conditions.

METHODOLOGY:

- Development of simple analytical parameterisations for the traffic produced turbulence based on the physics of the pollutant diffusion/dispersion processes in the street canyon;
- Implementation and evaluation of these models in an advanced operational dispersion model (ADMS-Urban).
- Analysis of some study cases for typical low wind conditions

PARAMETERISATION FOR VEHICLE PRODUCED TURBULENCE:

Parameterisation 1: OSPM

In the widely used Operational Street Pollution Model (OSPM, Hertel and Berkowicz 1989), developed by the Danish National Environmental Research Institute, vehicles in a street canyon are treated as moving roughness elements.

Their mechanical effect on turbulence is parameterised by assuming that the roughness elements have an overall associated variance of the velocity fluctuation depending on the square of the velocity. It writes (Berkowicz 1989) as:

$$\sigma_{wmt}{}^2 = b^2 U^2 D \qquad (1)$$

where:

U is the average vehicle speed;
b is a constant factor related to the aerodynamic drag coefficient;
D is the density of the roughness elements in the canyon given by:

$$D = \frac{N_v A}{UL}$$

where:

N_v is the number of vehicles passing in the street per time unit;
A is the plan area occupied by a single vehicle
L is the width of the street.

Parameterisation 2: alternate model

Moving vehicles produce turbulent kinetic energy in the street canyon. From the analysis of the terms of the turbulent kinetic energy equation, in absence of strong insolation and in absence of industrial and domestic heating, two mechanisms are important: the turbulence production and dissipation.

The balance between turbulent kinetic energy per unit mass of air and dissipation reads as:

$$\frac{C_D \, {}^1\!/_2 \, \rho_{air} U^3 A_{fr}}{\rho_{air} V_{canyon}} = c w'^3 \, L_c^{-1} \qquad (2)$$

where

L_c is a length scale
c is an empirical constant to be determined.
C_D is the aerodynamic drag coefficient
A_{fr} is the frontal area of the vehicle projected towards the flow direction
ρ_{air} is air density
V_{canyon} is the volume of the canyon
w' is a velocity scale associated with the turbulence generated by the vehicles

From (2) it follows

$$w'^2 = \left(\frac{N' \, {}^1\!/_2 \, C_D A_{fr} U^3}{c L_*} \right)^{\frac{2}{3}} \qquad (3)$$

where

N' is the number of vehicles per unit length;
L_* is a length scale of the turbulent motion produced by the vehicles;
A_{fr} is the frontal area of the car projected in the direction of the wind flow

COMPARISON OF THE TWO PARAMETERISATIONS:

Both parameterisations (1) and (3) require the determination of a coefficient: *b* in the case of OSPM and *c* in the alternate parameterisation.

Hertel and Berkowicz (1989) recommended *b*=0.3 for OSPM. For the alternate parameterisation we use $L_*=L$ (the width of the street) however other characteristic length are equally appropriate, for example the sqaure root of the canyon area cross-section. We have chosen, arbitrarily $c=1$ for $L_*=L$. With this choice we estimated the ratio w'/σ_{wmt} given by the square root of the ratio of equation (3) and (1) to be ~ 3 to 4. Table 1 reports some values of w'/σ_{wmt} obtained for some typical values of traffic and vehicle speed.

Table 1

N' *Vehicles/hour*	A_{fr} M^2	*A* M^2	*L* *M*	*U* *km* (ms^{-1})	w'/σ_{wmt}
1000/U	*2*	*5*	*20*	*40 (11.1)*	*3.5*
1000/U	*2*	*5*	*10*	*40 (11.1)*	*3.1*
1000/U	*2*	*5*	*40*	*40 (11.1)*	*4.0*

MODEL IMPLEMENTATION IN ADMS-Urban:

The parameterisation (1) and (3) were introduced in ADMS-Urban in order to study their effect on the prediction of the concentration.
For parameterisation (3), besides the fact that our estimation of the velocity scale associated with the movement of the vehicles is higher, the implementation of it in ADMS-Urban did not give, for the cases investigated, appreciable effect on the prediction of the concentration. Figure 1 is an example of model calculations performed with both parameterisations for a day with low wind condition. It refers to a street canyon (Bank Monitoring Site) with an aspect ratio W/H=0.79 (where W is the width of the canyon and H is the height of the canyon).

The conclusion for this case was that there is no operational advantage in using (3) instead of (1) but we believe that parameterisation (3) is more physically based than the parameterisation (1), though still lacking knowledge of the empirical constant *c*.

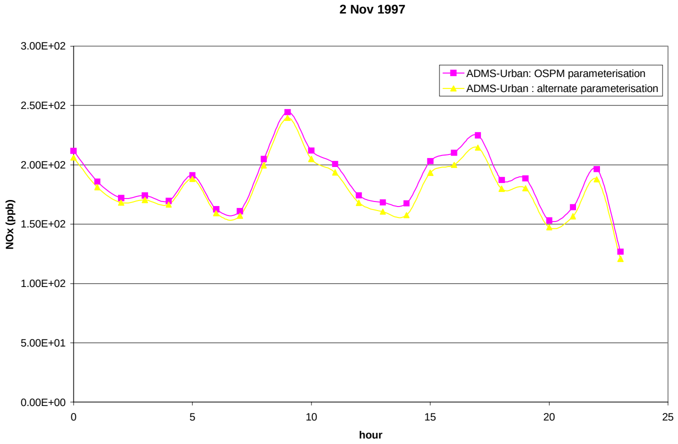


Fig 1.

ANALYSIS OF STUDY CASES:

At this stage, based on the analysis carried out above, we formulated a question: is the traffic produced turbulence important when applied to real situation?

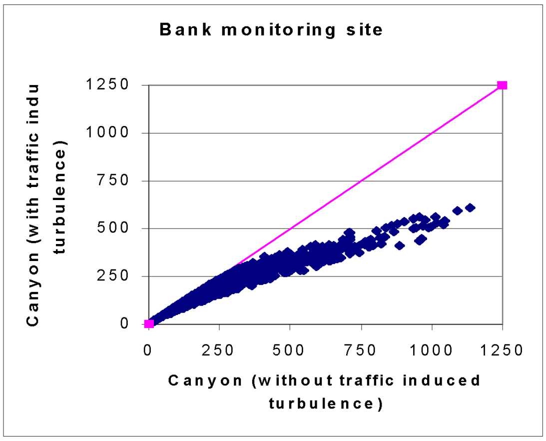
In order to answer this question some test cases were performed.

<u>Test case 1:</u>

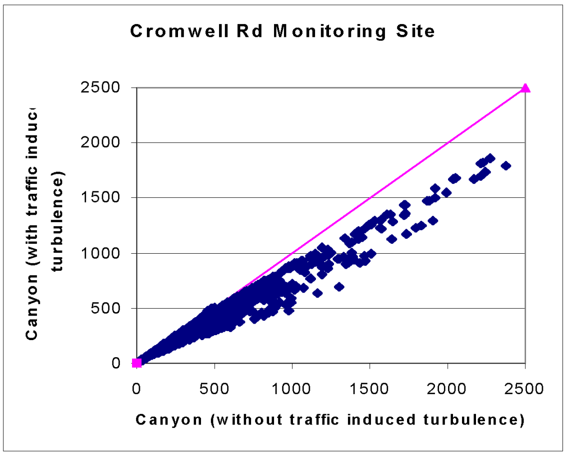
ADMS-Urban calculations were performed using 1 year meteorological data for 4 street canyons in London with different aspect ratios (Fig. 2 in a separate file).

From the Figure we can observe that there is an effect played by the traffic produced turbulence. This effect increases as the aspect ratio increases. However, the number of cases for which this effect is relevant is only a fraction of the total cases .

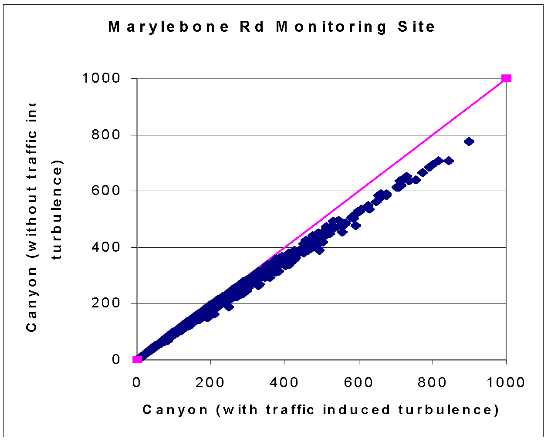
Width =19 m, Height=15 m, Aspect Ratio=0.79



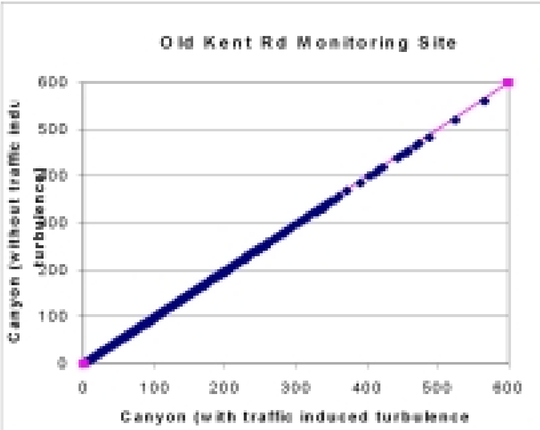
Width=19 m, Height=8.7 m, Aspect Ratio=0.46



Width =63 m, Height=24 m, Aspect Ratio=0.38



Width=40 m, Height=7m, Aspect Ratio=0.175



Test case 2: comparison of time series concentration against model prediction at low wind speed

Concentration data

The concentration data used for this study are the monitoring data from 1997 provided by London Research Centre (LRC).
They refer to a network of monitoring stations situated in Central London that record hourly concentrations for a number of major pollutants including NOx, NO_2, PM_{10} and SO_2. Table 2 contains a brief summary of the site used in this study.

Table 2. Monitoring sites

Name	Borough	Area	Receptor Height
Bloomsbury	Camden	Urban gardens	3
Bridge Place	Westminster	Urban office	12
Marylebone Road	Westminster	Roadside in street canyon	2.3
Swiss Cottage	Camden	Kerbside	2.3

Meteorological Data

Both standard meteorological data from Heathrow airport 1997 and from London Weather Centre 1997 were used.
The difference in wind speed and wind direction measured at the two meteorological stations were observed to be quite large.

Model runs (ADMS-Urban)

A minimum Monin-Obukhov length of 100 m was empirically set to account for heat produced in the city.

Table 3 summarises the characteristics used in the computer runs.

Table 3

	Heathrow	**London Weather Centre**
Wind speed level	10 m	38 m
Roughness length	0.2m	2 m
Minimum LMO	100 m	100 m

In order to simplify the work and identify key aspects in the model performance only NOx (NO + NO_2) was modelled at this stage.

Simulation of Camden and Westminster borough includes grid emission sources (for all London) and background sources. For each site (refer to Table 1) and for each meteorological data three model runs were performed:

1) includes all emissions (grid sources + road sources) in the borough;
2) includes grid sources + few roads around the receptor;
3) as in 2) but without canyons i.e. building height set to zero.

Analysis of the model prediction

The analysis of time series of concentration of NOx in Marylebone Road was expected to give some insights on the effect due to the traffic produced turbulence when compared with NOx concentration for Bloomsbury which has similar traffic emissions.

As a consequence model predictions of NOx for these two sites (Marylebone Road and Bloomsbury) were compared with each other and against measured data during four days of light wind conditions.

It was difficult to deduce, for these cases, any special contribution due to the traffic produced turbulence. From the comparison between model results and observations for the 4 cases studied the uncertainty on the meteorological conditions (expressed in terms of boundary layer height and its vertical structure) resulted to be key factors in the model calculation.

Additional model run were performed for these two sites for days which recorded very high concentrations of NOx in Marylebone Road and quite low in Bloomsbury.
Again from the model results was not possible to derive specific conclusions on the effect due to the traffic produced turbulence.

WORK IN PROGRESS

zero wind speed:

- Solution of the Diffusion equation
- Parameterisation of diffusivity coefficient derived from mixing box experiments