



Evaluation of CO dispersion models applied to a Milan city database

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Abstract

This paper describes the principal results obtained in evaluating the performance of three modelling techniques (CALINE4, CPB-3, and Johnson's formula) in simulating CO concentrations in three streets of Milan with different facility types and location. The models have been applied to compute 1-hour CO concentrations along a period of two months. Moreover the application of a lagrangian model (GEM) to one of the three streets is illustrated.

1 Introduction

Traffic is certainly one of the main sources of atmospheric pollution: in urban area it is the prevalent source of carbon monoxide and is responsible for the presence of other pollutants, as nitrogen oxides, benzene and particulate.

In the frame of the CNR (Research National Council) research project entitled "Traffic planning and air pollution in urban areas" the PMIP of Milan collaborating with Italtel-Telesis and CNR has carried out a study in order to describe the dispersion of a pollutant inside a street canyon. The first phase of the project regards the intercomparison of different dispersion models in order to evaluate the most adequate to be applied during the field experiment in Milan as provided in the second phase of the study.

2 The database

The modeling techniques have been applied using the traffic data (hourly traffic volumes counted for each lane) measured by the Urban Police Force during November and December '89 at Viale Marche, Via Monreale and Via Senato. These three streets have been chosen because represent different facility types and locations and are characterised by urbanistic structures typical in Milan.

132 Computer Techniques in Environmental Studies

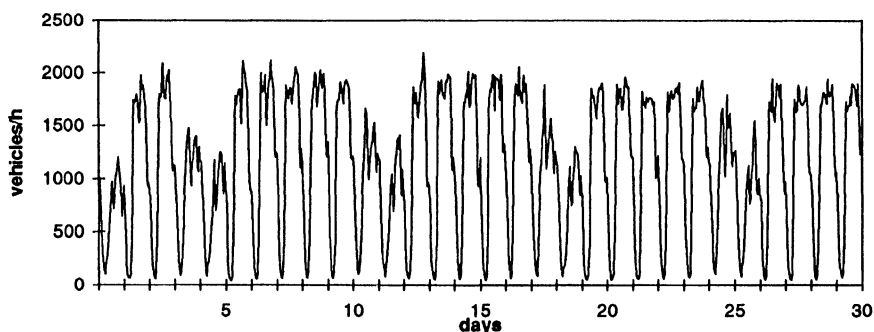


Figure 1: Traffic volumes of November '89 in Via Senato.

Milan has a concentric structure with radial penetration axes joining Milan with motorways and neighbouring towns. The three streets considered are briefly described below:

- Viale Marche is a thorough-fare which is part of the Milan ring-road;
- Via Monreale is a low-traffic side street;
- Via Senato is a street canyon with high traffic intensity.

It is evident for all the three sites that different temporal trends characterise working-days and holidays, even if daily traffic volumes depend on the street (Manini¹). From traffic analysis for the two months under study it can be noticed that:

- In Viale Marche the vehicles number is very elevated, also in the night-time, and keeps on similar values on the different days of the week: only festivities cause evident changes of the daily trends.
- In Via Monreale traffic volumes are medium-low during working-days. Vehicles number decreases during holidays excepting Sundays in correspondence with the soccer-match played in the near stadium.
- Via Senato is situated in the centre of the city, so traffic volumes are high in the morning of the working-days. Already for Saturday vehicles number tends to decrease and reaches the minimum value during holidays.

As an example, Figure 1 shows the hourly traffic volumes recorded in Via Senato during November '89.

The hourly traffic volumes have been used to calculate traffic CO emissions relating to each street, as described afterwards.

With regard to meteorological parameters (temperature, wind speed and direction, stability class, solar radiation), it has tried to use for each site the values observed by the monitoring station situated on the spot (belonging to the Air Quality Monitoring Network of the Province of Milan). The data of Viale Marche, owing to the lack of data for several hours, have been integrated with the values measured by the monitoring station situated in Via Monreale. Moreover the monitoring station of Via Senato is not equipped with meteorological analysers; so have been used the data measured in Viale Marche. In fact this station, in spite of some missing data, is the more adequate to

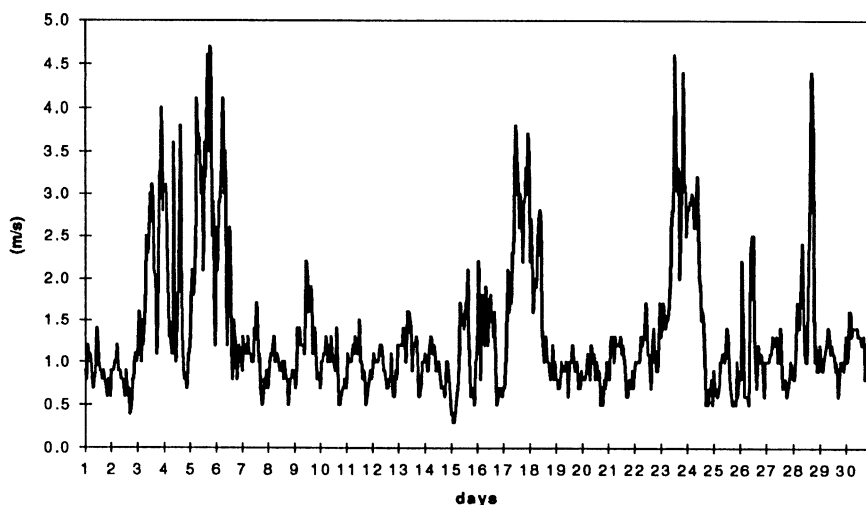


Figure 2: Wind speed trend in Milan during November '89.

describe the meteorological situation in Via Senato, because it is the nearest monitoring station working in the considered period.

Analysing the months of November and December '89, the following meteorological considerations can be briefly noted (Tebaldi²; Tebaldi³). The temperature has kept mild during the first ten days in November and the second ten days in December, whereas harsh temperatures have been recorded during the last week in November, at the beginning and particularly at the end of December. A high atmospheric pressure field has concerned the North of Italy during the second ten days in November and a another one from the end of the month to the beginning of December. The rainfalls are almost completely concentrated in the first week of November. Regarding the anemological conditions in Milan during the period under study the wind speed has kept low values (about 1 m/s) except some isolated episode. Only during short periods we have recorded values above 2.5 m/s and sometimes wind speed reached even 4.5 m/s. Figure 2 shows, as an example, the temporal trend of the wind speed in Milan during November '89.

3 The modelling techniques

To simulate the spatial distribution of pollutant concentration inside a street it is necessary to use a microscale dispersion model. The choice of the modelling technique depends on the particular topography considered since there is no model suitable for all situations. So the results obtained by different models have been compared for each street.

In this study four models have been considered: CALINE4 (Benson⁴), CPB-3 (Yamartino⁵; Yamartino⁶), Johnson's formula (Johnson⁷), GEM (Lanzani⁸; Lanzani⁹). The first one is a line source Gaussian model; the second one is a

134 Computer Techniques in Environmental Studies

Plume-Box model; the third one is an empirical box model and the last one is a Lagrangian particle model. These models require four different kinds of data:

- topographical characteristics of the street (street width, buildings height, number and width of the lanes);
- meteorological parameters (wind direction and speed, wind direction standard deviation, stability class, temperature, solar radiation);
- traffic characteristics (vehicle number and speed per lane);
- composite emission factors per lane.

Moreover the background concentration of the pollutant is required.

In this study meteorological parameters and CO concentrations have been extracted from the databases of the Province of Milan Air Quality Monitoring Network while traffic data from measurements made by Urban Police Force of Milan. The model FATEMVE (Tamponi¹⁰) has been used to calculate the composite emission factors. This module is based on the CORINAIR (Co-ORDination Information AIR)-COPERT'90 method of the European Economic Community (Bocola¹¹; Eggleston¹²) adapted for the Italian situation.

An appropriate processor, MSP (Milan Street Processor), applies at user's request one or more models described above, extracting the hourly input data from traffic and meteorological datasets sequentially for several days. To obviate the circumstance in which, as in the present one, no information about the vehicle travelling speed is available, user can choose one of five empirical curves relating speed with traffic volumes for five different kinds of street. Since this choice is difficult, it is opportune to test several options for the same street. At last all the dispersion models require the background concentration of the pollutant. As a starting point for estimating the background the minimum among the 4:00, 5:00 and 6:00 a.m. measured concentration values for every day is used. If this datum is not available, the background is evaluated from the average daily minimum reached in the month.

4 Results

The dispersion models CALINE4, CPB-3 and Johnson's formula have been applied over a period of two months: November and December 1989. Figure 3 shows the concentrations predicted by the three models as a function of the concentrations observed in Viale Marche, Via Monreale and Via Senato during the two months. From these graphs, it is evident that CPB-3 is not adequate to describe the situation of Viale Marche and CALINE4 is not suitable to simulate the concentrations of Via Monreale and Via Senato.

Comparing the observed CO concentrations time series over the period of study to the results of the three models, it can be deduced that:

- in the case of Viale Marche, CALINE4 is the model which best describes the experimental data. Figure 4 shows, as an example, the CO concentrations measured during November '89 and the values predicted by CALINE4. It can be noticed that the model tends to underestimate particularly when the wind speed is high (≥ 2.5 m/s) and the wind direction is parallel to the street

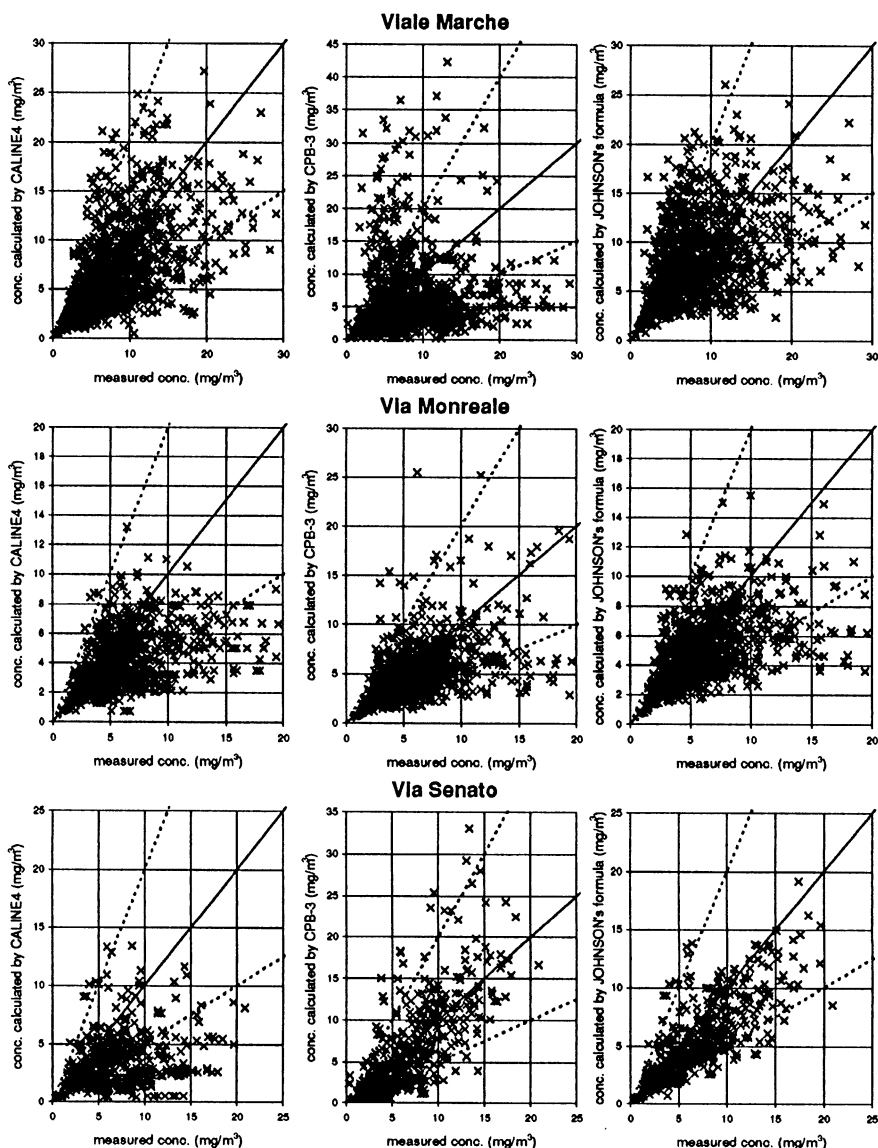


Figure 3: CO concentrations of November-December '89 in the three sites considered: values predicted by CALINE4, CPB-3 and Johnson's formula vs. observed values. The solid line (bisector) is the perfect fit; the dotted lines delimit the factor-of-two region.

axis.

- with regard to Via Monreale, the best results are obtained by CPB-3 model. As an example Figure 5 shows the CO concentrations measured during

136 Computer Techniques in Environmental Studies

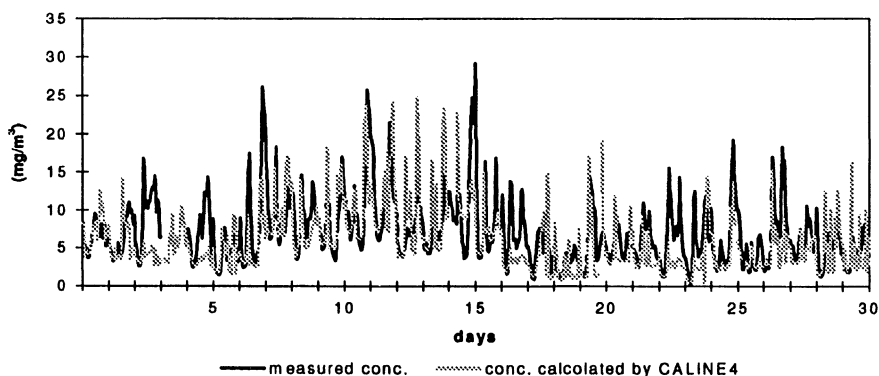


Figure 4: Comparison between observed and computed CO concentration time series of November '89 in Viale Marche.

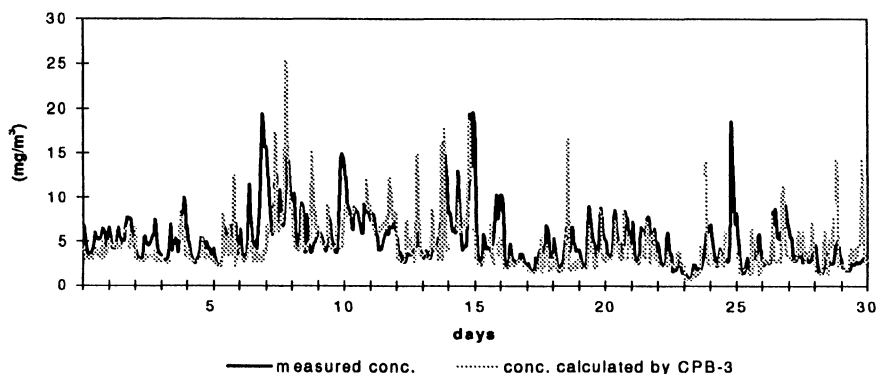


Figure 5: Comparison between observed and computed CO concentration time series of November '89 in Via Monreale.

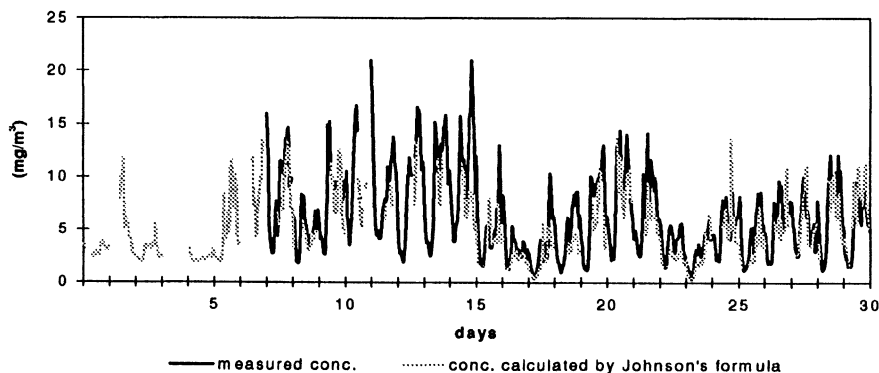


Figure 6: Comparison between observed and computed CO concentration time series of November '89 in Via Senato.

November '89 and calculated by CPB-3.

- in the case of Via Senato the best model is Johnson's formula, even if it tends to lightly underestimate the concentrations. For example the concentrations observed during November '89 and predicted by Johnson's formula are reported in Figure 6.

Model GEM has been applied for Via Senato only: in fact the typical canyon structure of this street speeds up the elaboration time of the model. Nevertheless the elaboration can last for several hours if the stationary condition is not reached. To obviate this problem, only the data referring to wind speed with component perpendicular to the street axis greater than 1 m/s have been processed. Moreover, to reduce computation time, whole traffic volume has been concentrated in the middle lane, since concentrations on pavement at man's height are similar to those obtained dividing the traffic into the lanes. Figure 7 shows the calculated values as a function of the observed concentrations.

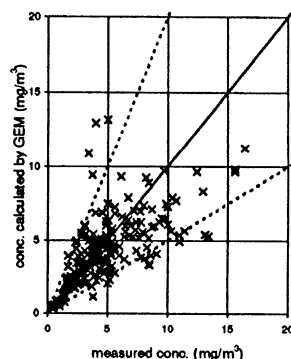


Figure 7: CO concentrations of November-December '89 in Via Senato: values predicted by GEM vs. observed values (wind speed > 1 m/s).

5 Statistical parameters

A statistical evaluation was performed for each model and for each street using some statistical parameters recommended by the U.S. Environmental Protection Agency (EPA¹³; DiCristofaro¹⁴). Among these we can number *NMSE*, *BIAS*, *FB* (*Fractional BIAS*) and *CPM* (*Composite Performance Measure*), defined by:

$$NMSE = \frac{\overline{(C_C - C_M)^2}}{\overline{C_M} \cdot \overline{C_C}}$$

$$BIAS = \frac{\overline{C_C} - \overline{C_M}}{\overline{C_M}}$$

$$FB = \frac{2 \cdot (\overline{C_C} - \overline{C_M})}{\overline{C_M} + \overline{C_C}}$$

$$CPM = \frac{1}{2} AVG(ABF(i)) + \frac{1}{2} AFB(1)$$

where C_M is the measured concentration, C_C is the calculated concentration, the line above the concentrations means the average value, $ABF(1)$ is the absolute value of the *Fractional BIAS* for the one-hour averages, $ABF(i)$ is the absolute value of the *Fractional BIAS* for each diagnostic category i and $AVG(ABF(i))$ is the average of $ABF(i)$ weighted for each category.

To calculate *CPM* the dataset has been divided in three subsets referring to the following categories:

138 Computer Techniques in Environmental Studies

- wind speed ≤ 2 m/s and stability class neutral or stable;
- wind speed ≤ 2 m/s and stability class unstable;
- wind speed > 2 m/s and all stability classes.

The wind speed (v) ≤ 2 m/s and neutral/stable category is weighted more than the other two categories because of the importance of this category for regulatory modelling purposes. Thus, the average of $AFB(i)$ is

$$\begin{aligned} AVG(ABF(i)) = & 0.5 ABF(v \leq 2 \text{ m/s, Neutral/Stable}) + \\ & + 0.25 ABF(v \leq 2 \text{ m/s, Unstable}) + \\ & + 0.25 ABF(v > 2 \text{ m/s, All stabilities}) \end{aligned}$$

Table 1 shows the values of the correlation coefficient r and statistical parameters $NMSE$, $BIAS$, FB and CPM calculated for each model and for each street considering the whole dataset (November-December '89). Besides the conclusions already drawn previously, it can be deduced that all the models tend to underestimate on the average the CO concentrations ($BIAS$ and FB values always negative).

With regards to the application of GEM to Via Senato (only using cases with perpendicular component of wind speed > 1 m/s), the values of the statistical parameters are similar to those obtained for CPB-3 model and Johnson's formula infact $r = 0.68$, $NMSE = 0.26$, $BIAS = -0.10$ and $FB = -0.11$.

To assess differences in model performance under different model regimes, for each site we have computed the values of r , $NMSE$, $BIAS$ and FB concerning three subsets related to the three meteorological categories considered. It can be noticed that, when wind speed is greater than 2 m/s, for

Tab. 1. Statistical parameters computed referring to observed and predicted concentrations of November and December '89 at each site.

Street	Model	r	$NMSE$	$BIAS$	FB	CPM
V.le Marche	CALINE4	0.58	0.35	-0.15	-0.16	0.19
	CPB-3	0.13	1.00	-0.24	-0.27	0.38
	JOHNSON	0.47	0.33	-0.01	-0.01	0.12
V. Monreale	CALINE4	0.53	0.46	-0.32	-0.38	0.35
	CPB-3	0.56	0.31	-0.16	-0.18	0.17
	JOHNSON	0.59	0.29	-0.19	-0.21	0.20
V. Senato	CALINE4	0.30	1.19	-0.51	-0.68	0.67
	CPB-3	0.74	0.34	-0.09	-0.10	0.13
	JOHNSON	0.79	0.22	-0.22	-0.25	0.25

every street *NMSE*, *BIAS* and *FB* values approaching more zero are those referring to Johnson's formula.

The performance of each model as regards the peak concentrations has been put in evidence for every site calculating *FB* and *CPM* for the 25-highest concentrations. It can be remarked that for the wind speed ≤ 2 m/s and neutral/stable category CPB-3 overestimates at all three sites. After a careful examination of the time series of the observed and predicted concentrations and of the meteorological parameters, it can be deduced that CPB-3 tends to overestimate particularly with atmospheric stability when wind speed is low (< 0.7 m/s) and wind direction is parallel to the street axis.

6 Conclusions

This study certainly is not exhaustive but could be extended in the future: models for example could be applied to several kinds of streets with more detailed information and an updated database.

In any case, the results point out that each of the three modelling techniques evaluated shows very different performances in simulating concentration of CO at the three streets under study. This is comprehensible because every street represents a typical case in terms of emissions and urbanistic characteristics.

Evaluating the obtained results, it must bear in mind that the lack of some input data has caused some approximations. In fact the composite emission factors have been calculated for the vehicle fleet composition of the year 1991 and for estimated vehicle speeds. Moreover in some cases the meteorological parameters are measured not on the spot, but in the closest meteorological station. In spite of these approximations, we can draw the following conclusions:

- CALINE4 is the model which best describes the experimental data in the case of the broader road, Viale Marche, even if generally tends to underestimate the concentrations;
- CPB-3 model and Johnson's formula show the best outcomes for Via Monreale and Via Senato respectively, giving similar results.

It can be noticed that these specific urban canyon modelling techniques simulate quite well CO levels in Via Monreale even if this is not a typical street canyon like via Senato, but a street with buildings on both sides.

The results of the application of GEM to Via Senato are very interesting and encourages to go on with tests. Plans for the future could be to extend evaluation of this model to a more detailed database.

Acknowledgements

This research was supported by the CNR (Research National Council). We thank Urban Police Force and ATM (Azienda Municipale Trasporti) of Milan for useful informations. In particular we are grateful to Dr. G. Lanzani for providing very precious suggestions about application of model GEM.



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