A Modeling System for the Management of Traffic Related Air Pollution in an Urban Area

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1 Introduction

City administrations are required, by national and regional regulations, to impose air pollution abatement measures in the case of critical episodes. Such measures usually consist of some kind of traffic restrictions, where either parts of the city are closed to private traffic, or cars without catalytic convertes cannot be used. These restrictions can be burdensome on the citizens and costly for the city, and are often criticized for not being effective at reducing short-term air pollution. In addition, the long-term effects on air pollution of urban planning must be evaluated. For these reasons, a modeling system has been developed to be applied to the territory of Brescia, a city of 200000 in Northern Italy. Brescia boasts 0.66 private vehicles per person, and while car trips within the city have decreased (-13% between 1981 and 1991), commuter traffic has been increasing (+43% in the same years).

The modeling system presented in this work consists of two parts: the code HERMES (Hourly Emissions from Road Mobility Evaluation Software) that applies the EMEP/CORINAIR methodology[4] to the estimate of traffic emissions of CO, NO_X and VOC species on a road-by-road basis; and a modified version of the model APRAC3[6] to calculate the pollutant concentrations generated by traffic. The models have been applied to evaluate the effects on air quality of a number of possible traffic control strategies under consideration by the city authorities.

2 The modeling system

2.1 The emission model HERMES

HERMES[3] is the application of the EMEP/CORINAIR methodology to the urban area of Brescia, designed to estimate the emissions of traffic-related air pollutants with a bottom – up approach. The road network has a total extension of about 650 Km, over an area of about 12 x 12 Km. The entire network has been divided into 970 geographically-referenced road links, each between 0.5 and 1.5 Km long, that are treated as linear sources. Based on traffic volume data recorded by 158 magnetic inductance loops, each road link has been characterized in terms of: hourly trends of average speed (8 classes), maximum number of vehicles per hour (11 classes) and vehicle composition (6 classes). Vehicle category composition follows the 1996 EMEP/CORINAIR indications. To describe the current situation (baseline scenario) the average Italian fleet composition of the year 2000 has been used[2].

HERMES applies the emission factors for urban roads suggested for the COPERTIII program[5]. No correction for road slope has been included, while yearly corrections for fuel composition have been taken into account. To calculate temperature-dependent cold and evaporative emissions, the mean 1-hour average temperature for each season has been introduced.

The model estimates the traffic hourly emissions of CO, NO_X, PTS, SO_2, total VOC, CH_4, benzo(a)pyrene, benzene, 1-3butadiene (b13) and formaldehyde (frm). The hourly values of traffic emissions from each road link are integrated over time and space, in order to obtain seasonal emission maps with a 1x1 Km resolution. The mean 1-hour average emissions for each season have also been calculated.

2.2 The dispersion model APRAC

A modified version of the dispersion model APRAC3[6] was used to calculate pollutant concentrations. The model evaluates the dispersion of traffic-emitted pollutants from linear sources (road links) using hourly recorded meteorological data. An appropriate background value has been added to account for pollutant accumulation and the contribution of other sources. The complete modeling system allows the user to estimate an ‘average day’ trend of mean 1-hour concentrations for each season at discrete or gridded receptors.

2.3 Evaluation of the modeling system

Following CORINAIR classification, HERMES can be assumed to give emissions estimates in the “B uncertainty level”, i.e. within a 20 - 60% error range, based on the type of input data used.

In order to evaluate the level of accuracy of the entire modeling system, the mean 1-hour concentrations calculated for the current emissions scenario were compared with the values obtained from measurement data. The bias and the gross error were calculated and the results are reported in table 1. The model accuracy is about 40%.

Table 1 Model comparison with measured concentrations.

	Bias	Gross error
CO	- 0.26	0.32
NO_X	- 0.39	0.54
C_6H_6	- 0.06	0.33

3 Application to traffic scenarios

3.1 The baseline scenario: emissions maps

Figure 1 shows the emissions maps of CO and NO_X for the winter 2000. The emissions distributions are influenced both by the intensity of the traffic flows on each road link, and by the characteristics of the traffic. The emission peaks are found in the center of the city and along the highways. The low emissions in the north-east and north-west corners correspond to the area of the hills, where traffic is minimal. The area to the south is outside the city limits and was not included in the calculation. The higher NO_X emissions along the highway (visible in the S, running almost E – W) are due to the increase in the emission factors at higher speed. On the contrary, CO emissions are higher in the center of the city, where velocities are typically lower.

The seasonal changes are due to the dependence of cold and evaporative emission factors on ambient temperature. Also, fuel consumption increases during the colder months, due to an increase in the mileage run with a cold engine. The ratio of total emitted pollutants in the different seasons, normalized to the winter values, are reported in table 2.

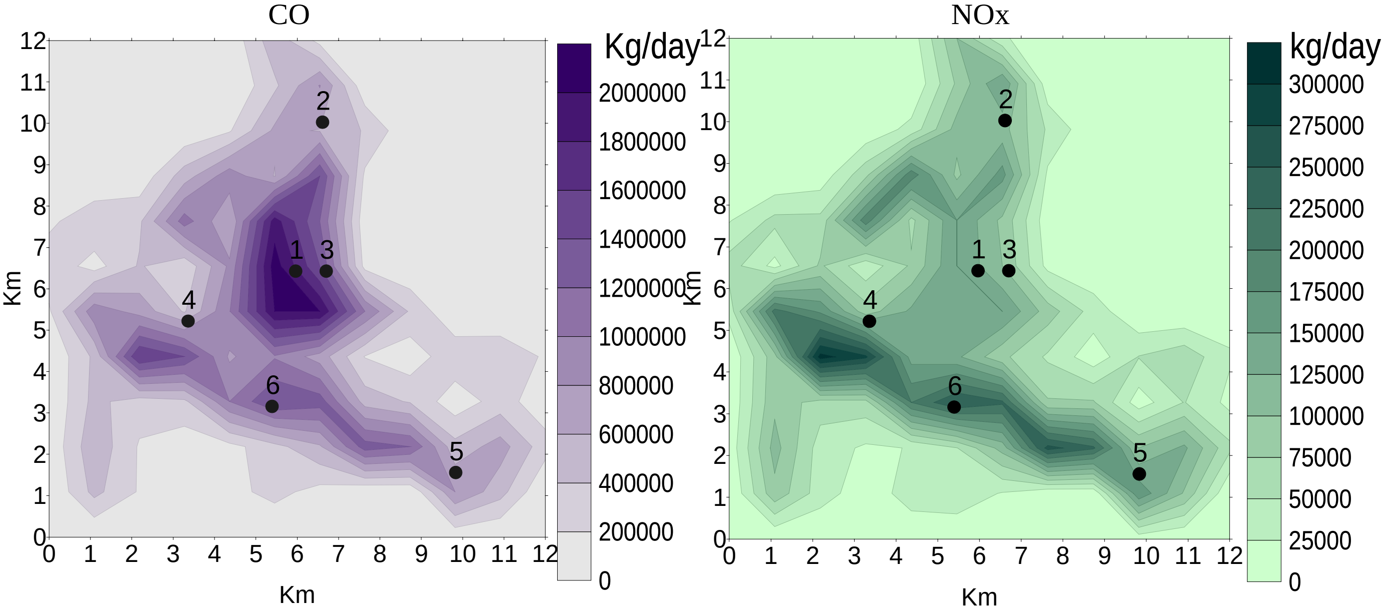


Figure 1 Emissions maps of CO and NO_X for winter 2000. Numbered dots represent the position of discrete receptors.

Table 2 Normalized seasonal trend of calculated emissions.

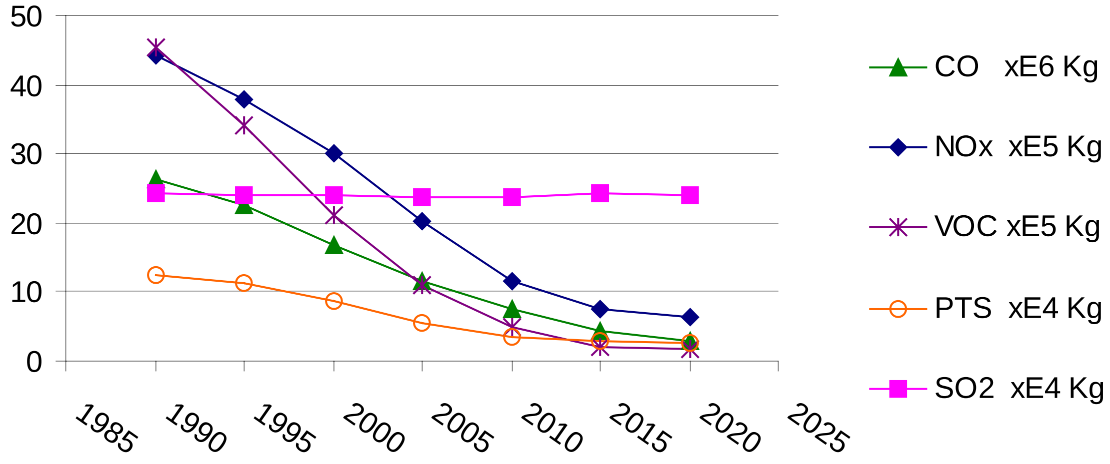
	Winter	Spring	Summer	Autumn
CO	1.00	0.97	0.96	0.99
NO_X	1.00	0.98	0.97	0.99
SO_2	1.00	0.58	0.47	0.94
PTS	1.00	0.83	0.77	0.96
VOC	1.00	0.90	0.97	0.98
CH_4	1.00	1.00	1.00	1.00
BaP	1.00	1.00	1.00	1.00
BNZ	1.00	0.90	0.96	0.98
FRM	1.00	0.90	0.95	0.98
B13	1.00	0.92	1.00	0.98

3.2 Effects of vehicle renewal and policies in the transport sector

The changes in the fleet composition due both to vehicle renewal and to policies in the transport sector cause a reduction in emissions over the years. To evaluate this effect, HERMES was used introducing the Italian fleet composition[2] for the years 1990 – 2020, and taking into account fuel composition changes. The City of Brescia reports that the total number of vehicles circulating in the area increased only by 3% between 1987 and 1997, therefore the total number of vehicle was considered constant through the years.

The total amount of pollutants emitted per year is shown in figure 2. For most pollutants, a reduction of about 80% over the whole period is predicted, while SO_2 emissions are not expected to change, since they depend only on fuel consumption, which is assumed to remain constant. An overall reduction of 98% in VOC emissions is observed. The effect is due, up to the year 2000, to the increased use of catalytic converters after 1995, leading to a reduction of 38%, and an 8% decrease due to a change in the benzene content of gasoline (from 2.1% to 0.8% in volume) in 1996.

Figure 2 Total amount of pollutants emitted per year.



3.3 *Traffic control strategies*

The modeling system was applied to evaluate the impact on air quality of some traffic control strategies and traffic management plans already adopted or under consideration by the City authorities[1]. Among the actions being considered are the elimination of traffic lights and the introduction of different speed limits. Two different scenarios have therefore been identified. The first assumes no traffic congestion, and average speeds between 30 and 50 Km/h for typical low-speed, high-traffic urban roads, and between 70 and 100 Km/h range for urban highways. The second scenario simulates the so-called "30 Km/h zone" strategy, i.e. the reduction of the speed limits to 30 Km/h. This limit has already been imposed in some areas of the city.

The scenarios were simulated by appropriately modifying hourly vehicle flux and average speed trends. The percentage variations in emissions over the area with respect to the baseline scenario are reported in table 3. As expected, CO emissions are strongly abated in the first scenario, while the 30 Km/h zone is less effective. NO_X is reduced by more than 10% in both cases. The adoption of the first scenario introduces some improvements in VOC emissions, but a further reduction of the average speed (second scenario) causes an increase, of up to 10% for some species, since emissions factors exhibit a minimum around 60-80 Km/h.

Table 3 Percentage variation of emissions over the entire area calculated for the two traffic control scenarios.

Scenario	NO_X	SO_2	CO	PTS	VOC	CH_4	C_6H_6	FRM	B13
No congestion	-13	-9	-44	-5	-3	-4	-3	-2	-2
30 Km/h zone	-12	-2	-24	+3	+8	+10	+7	+9	+8

The road-scale resolution of the model can be exploited to identify not only overall variations but also the possible local effects of a given scenario, which mostly depends on the characteristics of the nearby roads. In the "no congestion" scenario large hourly variations in the average speed are eliminated in the center of the city, while along the highways the average speed is decreased. The "30 Km/h zone" scenario is simulated by an average speed reduction.

The overall effect of both strategies is a reduction of CO concentrations of 80% or more and typically of less than 10% for the other pollutants. Table 4 shows the percentage variation in pollutant concentrations when the "no congestion" strategy is simulated, with respect to the baseline scenario. Along high-speed roads (receptors 2, 4, and 5) VOC concentrations can increase by up to 10%, while NO_X concentrations are reduced more significantly than elsewhere.

Table 4 Percentage variations of concentrations calculated at some discrete receptors for the "no congestion" scenario.

Receptor	NOx	CO	VOC	CH_4	BNZ	FRM	B13

1	-3.0	-87	-11.5	-13	-11.6	-11.4	-11.6
2	-5.4	-82	+6.0	+12	+5	+8.4	+7.3
3	-2.6	-89	-16	-18	-16	-16	-16
4	-6.0	-85	+0.6	+0.9	+0.3	+1.4	+0.85
5	-11.5	-87	+3.0	+3.3	+2.5	+4.3	+3.3
6	-12	-88	-3	-5.6	-2.5	-3.8	-3.6
Average	-5.7	-86	-3.5	-3.4	-3.7	-3.5	-3.3

4 Conclusions

The modeling system presented in this work, developed for the city of Brescia, combines a road-scale emissions model (HERMES) with a well-tested dispersion model for traffic sources (APRAC3). The system has been implemented to run on a PC, it is easy to use and relatively fast (180 minutes on a 600 MHz Pentium III processor for the baseline scenario). The degree of accuracy has been estimated through a comparison with monitoring data, and is about 40%.

Its characteristics make the modeling system suitable as a tool to be used by City Authorities to predict the comparative effects of different possible traffic control plans or air pollution reduction measures, both overall and with local-level detail. The applications of the model showed that the most effective factor in controlling traffic-related air pollution is to avoid traffic congestion, rather than to reduce the average speed, as previously planned by the City Administration.

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