

Traffic induced air pollution in Milan city: a modelling study

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Traffic induced air pollution in Milan city: a modelling study

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Abstract

In the frame of the ESPRIT Program, the SIMTRAP project (SIMulation of TRaffic induced Air Pollution) has been promoted to develop and to apply to some test cases a modelling system supporting decision makers in air quality and traffic planning. The architecture consists of the integration and the parallelisation of two models: a dynamic traffic model and a photochemical model describing the atmospheric dispersion of the pollutants. This article describes the system and its application to the metropolitan area of Milan.

1 Introduction

In metropolitan areas there is a growing need to reconcile the efficiency of transport with the good air quality, since both of these factors affect the quality of life of the inhabitants. It would therefore be useful to have a modelling tool able to weigh both of them at a time, enabling transportation policy-makers to find strategies bearable by the environment. One among these possible tools has been applied to the metropolitan area of Milan and has been developed in the frame of a project of the ESPRIT-Program.

The system taken into account consists of the integration of two models, a dynamic traffic simulation model and a photochemical dispersion model, and it is equipped with an interface for the implementation of scenarios about traffic, meteorology and emissions. The road network graph simulated by the traffic model covers the area of 38 municipalities surrounding Milan, while the meteorological and dispersion model has been applied to an area measuring about 100 x 100 km² centred on the province of Milan area. Possible scenarios have been outlined such as the traffic closure of the centre of Milan and the change of the fleet composition owing to the effectiveness of some European directives.

2 Description of the system

The SIMTRAP system effectively integrates two previously existing simulation packages and adds a GIS toolkit with built-in functionality for decision support to facilitate user interaction and analysis of the results. Two considerations guided the choice of the transport model:

- To reflect the diurnal profile of traffic-related emissions, the model must be dynamic.
- Since ozone develops in a relatively slow photochemical process and intermediate products drift with the wind during its generation, the study area must be large enough so that boundary effects do not dominate. An area of 100 by 100 km is absolutely necessary, 200 by 200 km is desirable.

These two requirements are hard to satisfy simultaneously, because the first one rules out static assignment models, whereas a study area of the size needed is beyond the capabilities of today's microsimulators.

In SIMTRAP we use DYNEMO, a simulation tool for both urban and rural road networks. Regarding movement of vehicles, DYNEMO is a mesoscopic model in the sense that the unit of traffic flow is the individual vehicle rather than the temporal and spatial aggregates used in static assignment models. Their movement, however, is governed by the average traffic density on the link they traverse rather than the behaviour of other individual vehicles as in microscopic models.

For each junction within a network signal control or priority rules can be specified separately. Furthermore, vehicles can revise their calculated routes during the trip e.g. in response to dynamic information or guidance. Observation points can be specified anywhere within the road network where traffic volume, mean speed, pollutants etc. are recorded. This functionality provides the spatial distribution of traffic-induced primary pollutants (CO and NO_x).

During the traffic flow simulation, state information about each vehicle is recorded which, together with the vehicle type and the link type,

determines the current emission of the vehicle. Emission computation takes into account emission factors, cold start correction factors and cold start distances from (CORINAIR[1]) and (UBA[7]). The model equation is designed to accommodate both sources.

At GMD FIRST, the DYMOS system (Sydow[6]) has been developed implemented and extensively tested during the last 5 years. DYMOS is a parallel implemented simulation system to analyse the generation, dispersion and chemical transformation of gaseous air pollutants and different aerosols. The model is well suited to reproduce most frequent occurring kinds of smog situations:

- winter smog: high concentration of inert (regarding the model domain) pollutants (e.g. SO₂, NO_x, dust, etc.) caused by high pressure situations.
- summer smog: high concentration of ozone and other photochemical oxidants caused by strong insolation.

DYMOS consists of the air pollutants transport model REWIMET (Heimann[4]) and the air-chemistry model CBM-IV (Gery[3]). The major system components are given in Figure 1.

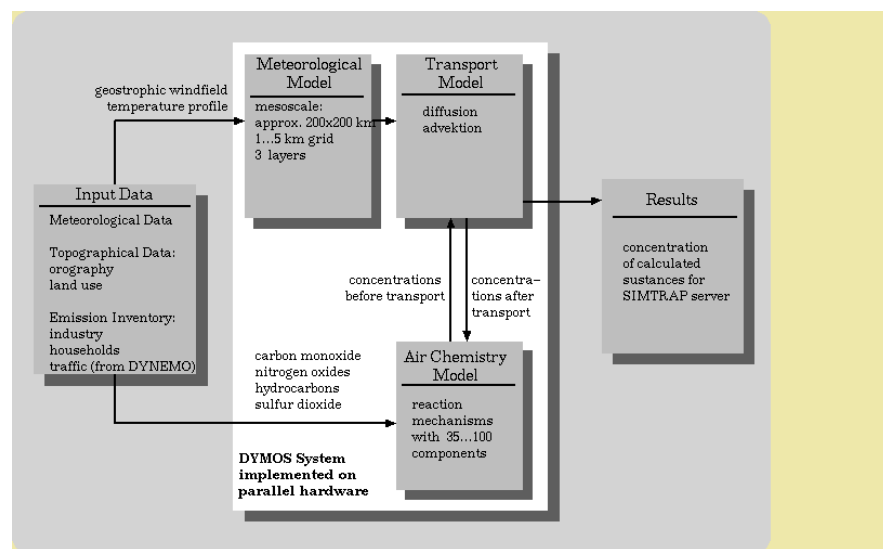


Figure 1: Graphical representation of the concepts behind the DYMOS pollution model

The data entry and visualisation facilities of the models, DYNEMO and DYMOS, are limited to their respective application areas, traffic and air pollution. For an integrated planning tool, the integration must be as seamless as possible from the users' point of view, too. For this purpose, the ACA Toolkit (Zhao[8]), developed and marketed by ESS

GmbH, is used as the graphical interface. This toolkit supports state-of-the-art window-based and menu-driven user interaction, but in addition offers a built-in geographical information system (GIS). The GIS functionality is not only used to view and analyse simulation results, but also to define the simulation scenarios themselves.

To cope with the extensive study area, both the traffic flow model and the air pollution model were parallelised. Furthermore, the computationally expensive simulation is separated from the user interface, so that user interaction requires only a normal desktop machine. The server running the models can either be in the same LAN as the user workstations or be accessed over the Internet.

3 Description of traffic simulation data

The road network graph has been developed in the past years by ATM to simulate through a static assignment model the functionality of the road network of Milan municipality in the current scenario as well as in scenarios resulting from town planning changes or from variations of parking and traffic regulations. The current road network graph is shown in the figure 5.

In 1995 the graph has been expanded beyond the municipality area to include other 38 municipalities in the neighbourhood of Milan for a total of 63 km², 3595 arcs and 1500 km in the modelled network. The region covered by the graph has been divided in 589 traffic zones, 351 of these in Milan municipality and 238 in the rest. The traffic entering the area or passing through is positioned at the border in 70 fictitious zones representing the main admission routes.

In the same period the OD survey started by interviewing at home a sample equal to 10% of population (about 300 000 persons) and 40 000 motorists (about 15% of total) on the roads entering the area. The data collected, regarding the trip request of people living within the area or entering daily, are divided depending on the time band, on means used (public mean, car, cycle, bicycle), on motives (work, school, shopping and so on). On the base of these information the OD matrix as well as the relations between the mobility and the causing factors have been obtained. These factors can be used for other goals, such as the forecasting of the future mobility request.

For the calibration of the OD matrix a traffic static assignment model has been applied to the road network graph, comparing the results of the assignment with the traffic surveys available at the moment.

The composition of the circulating fleet is assumed homogeneous for concentric rings covering the city and the neighbourhood and has been determined through the length of the vehicles passing through survey points spread over the study area and grouped on the base of the ring

they belong to. DYNEMO uses emission factors referred to the vehicle classes pre-EURO, EURO 1 and EURO 2 for cars, heavy good vehicles and buses, further divided on the base of the kind of fuel and of the cubic capacity. This required fleet composition has been reached by passing through an intermediate classification in accordance with the COPERT II methodology (Joumard[9]) in use for the existing traffic emission inventory of the province of Milan.

For this reason a correspondence has been established between the length classes and the kind of vehicle (car, bus, lorry, ...) and then between those ones and COPERT II categories. Finally a correspondence has been established between DYNEMO classes and the fleet composition already available according to COPERT II. The greatest effort has been to find an association between the European regulations which the two methodology refer to define classes.

4 Description of meteorological, air quality and emission data

Input data required by DYMOS are illustrated in the figure 1.

In particular topographical data are necessary for the calculation of the wind field and of biogenic emissions. The figure 3 illustrates the land use map of the study area, got by revising the CORINE Land Cover (European Environment Agency[10]), as the interface of the system shows it.

Every province of the study area disposes of a network measuring the main pollutants and meteorological variables. Measurements are collected non stop and principally at the ground level. Since SIMTRAP uses a photochemical model, the most interesting scenarios have been chosen based on photochemical pollutants production, such as ozone. Therefore only summer scenarios have been envisaged.

Figure 2. Trend of nitrogen oxides and ozone concentrations measured at a station near Milan on July 9, 1997

By analysing data relative to 1997, three interesting weeks have been selected: all selected periods are characterised by high ozone average daily values.

The scenario currently stored at SIMTRAP server is relative to a July week. In particular the ninth July has been chosen: you can see in the figure 2 that the ozone highest concentration is reached in the middle of the day and that it's in antagonism with nitrogen oxides concentrations.

Figure 3. Land use of the study area

In urban areas the road traffic is the main source of nitrogen monoxide. Consequently traffic affects the ozone production too, as it develops in the atmosphere by the reactions between nitrogen oxides and some organic compounds in the presence of strong insulation.

In regards to emissions, at the moment no winter scenario has been implemented, therefore households emissions haven't been included in input data.

Most industrial emissions have been calculated by disaggregating in time and space the emissions provided at annual and provincial level by CORINAIR 90 project. Finally traffic emissions haven't been computed only by DYNEMO, because, as it can be deduced from the figure 4, the data available allow the application of the dynamic model to a small part of the study area. It has been considered necessary to supply the system with the emissions on the rest of the area, even if in a static way, because the traffic is an important source. Emissions have been computed thanks to the EMITR model, developed and currently used at Provincia di Milano (Gualdi[11]) according to the COPERT II methodology, and have been used as an input datum of DYMOS. EMITR has been applied to the output of a model, utilised in the frame of "Piano della viabilità extraurbana" of Provincia di Milano, which produces the traffic flows on each arc of the territory of the province of Milan.

Figure 4. Static traffic emissions and the road network where DYNEMO is applied

On the outside emission values were available from Regione Lombardia, obtained by the disaggregation at municipality level of emission values derived from CORINAIR 90.

The figure 4 shows the road network graph and the traffic emissions on a grid with cell size equal to 1 km.

Starting from the base case, some emission scenarios can be taken into account: for example the shares of the emission sources can be varied for each kind of pollutant, in order to estimate which is the weight of each source on concentrations calculated and which is the weight of each pollutant emissions, particularly nitrogen oxides and organic compounds, on ozone production.

5 Results of the application

The usage of the dynamic model for the forecasting of traffic flows on the arcs of the network has been possible by translating and adjusting the data of the static model into the new requirements and the new

formats. First this process has been developed by using the sequential version of the dynamic model, every time the need was evident to detail or to correct the data, so that DYNEMO could work correctly and have a satisfactory comparison with the results of the static model, shown in the figure 5. In particular, it has been necessary to describe for each junction the values of the time penalties assigned to each turning. The results of this setting up allowed a good comparison between the flows calculated by the two models: the correlation coefficient got by the comparison is equal to 0.9482 . This has been judged satisfactory enough to carry on the project by simulating some scenarios by means of the parallel system.

Some alternative scenarios have been implemented acting separately or simultaneously on the basic components of the system: the road network, the mobility demand and the fleet composition.

In regards to the road network, two situations have been envisaged: the base case and the case with no entry into the central zone of the city. The mobility demand includes, besides the base OD matrix referred to the winter period, the summer matrix and an alternative matrix modelling an exposition event. Also in case of the closure of the inner city the OD matrix has been obviously modified, because the central zones can't be origin or destination zones.

In regards to the fleet composition, there is the intention of simulating the impact of the renewal of the fleet, also taking into account the application of some European directives coming into force between 2000 and 2005.

6 Conclusions

The SIMTRAP project is going to conclude and the very application of the system is starting just now, because of the long period necessary to adjust the input data of DYNEMO.

Nevertheless it can be said since now that the sharing to this project was positive. In fact for the first time a dynamic model has been used and the problems related to its usage have been faced. Partners with different abilities was involved, so that it was possible to profit by experiences in different fields such as the computer science and the technical management of traffic and air quality problems, particularly in regards to their modelling aspects. Furthermore the application of the system to scenarios not used or not implemented yet will be useful to estimate the future trend of traffic and air quality in Milan area and the impact of the strategies envisaged in consequence of the trend foreseen.

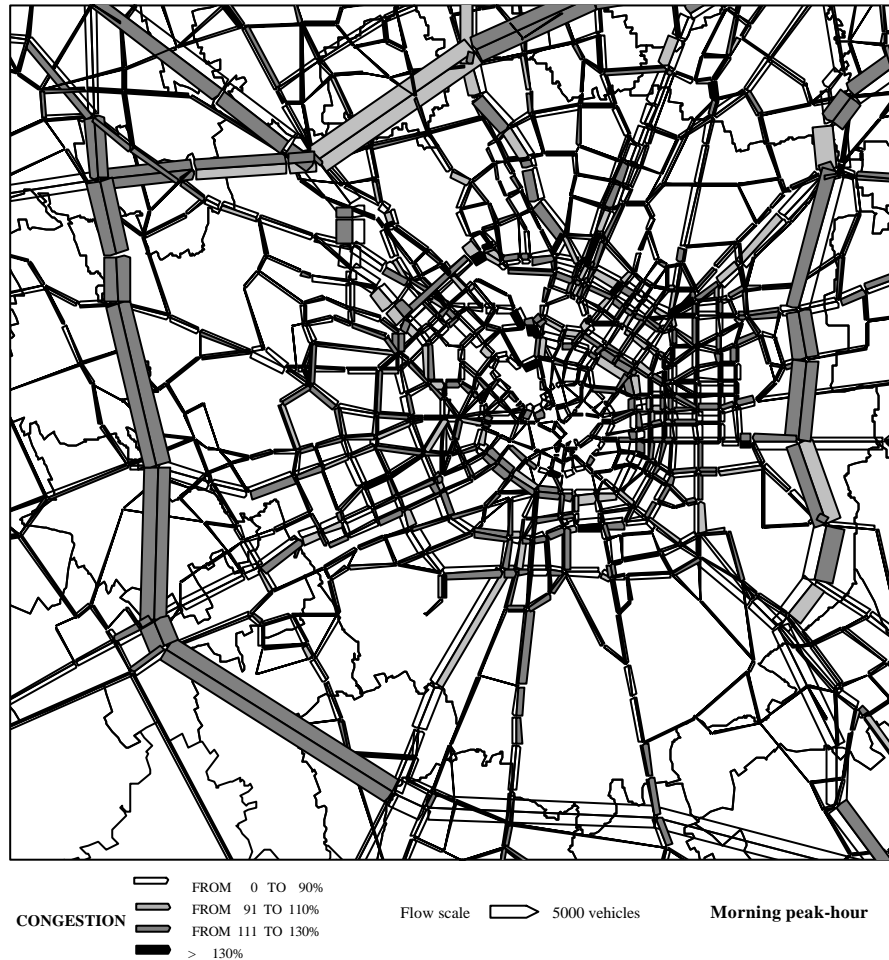


Figure 5. Congestion degree on each link during the morning peak hour, got from the static assignment

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