Urban and Industrial Air Quality Assessment and Management: Internet based solutions

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ABSTRACT

Urban and industrial air quality management faces new and continuing challenges, driven by new legislation and public awareness on the one hand, industrialization and the growth of urban conglomerates and increases in power consumption and traffic on the other. While dispersion modeling for air quality studies is a well established field, the challenge is to integrate scientific tools of analysis with the environmental planning and management process, to involve a large and diverse audience and participants in the policy and decision making processes, and to support new functions such as the information of the public. This requires to integrate air quality models in a conceptual framework that includes and explicitly addresses policy relevant elements such as the control of emission sources including economic criteria, monitoring of ambient air quality and the compliance with standards, and impacts on human health and the environment.

AirWare is an integrated environmental information system for air quality assessment and management (http://www.ess.co.at/AIRWARE). In a sequence of international research projects and numerous application in cities all around the world, AirWare has been developed from a dedicated engineering system implemented on special hardware in the technical division of a users institution, for a few trained specialists, to an Internet based distributed client-server system for a much broader user group with support for public information systems.

INTRODUCTION

Urban air quality management problems include:

- Multiple sources of information, ranging from census data compiled every few years to continuous on-line monitoring systems;
- A range of scales in space and time from street canyons to metropolitan areas, from short-term episodes to annual averages;
- Distributed (and mobile) emission sources with pronounced temporal patterns that include industry, households, and traffic;
- Direct regulatory and indirect economic control on emission sources, involving complex human behavior;
- Multiple objectives and criteria for the different actors and the regulatory framework.

This, obviously, defines a rather complex problem domain, which also includes a broad range of actors, stake holders and audiences in the decision and policy making process. With the shift from more or less authoritarian and technocratic to participatory decision models that characterize the political evolution of the last several decades, technical and scientific information, and the free and open access to this information, has become an important element in the political process. Consequently, information technology plays an increasingly important role where technical and scientific issues are involved, as is certainly the case in urban environmental management (Fedra 2000a).

Related to the monitoring, and in particular driven by any violation of standards and thus failure to comply with existing regulations, is the formulation of general policies and strategies to reduce emissions and thus ambient concentrations, to comply with emission-related standards. Major emission sources are controlled by regulations, usually related to the commissioning of industrial plants, power plants, or waste incinerators. Mobile emission sources again are regulated by a number of strategies including general engine exhaust characteristics, vehicle inspection programs and strategies affecting fleet composition, and fuel quality requirements. A third major group of regulatory tasks is related to environmental impact assessment for a number of projects and activities.

In all these cases, the use of models provides useful information (e.g, Zanetti 1990). Simulation models can support air quality monitoring for a better spatial coverage and resolution or involves scenario analysis that explores WHAT-IF questions, forecasting the expected behavior of the system in response to a set of changes projected into the future. Examples would be a regular daily forecast of expected ozone concentration, or the forecasting of the effect of a new road construction on ambient air quality in an environmental impacts assessment.

Finally, most countries have requirements for free public access to environmental information, both as a passive right-to-know and as an active mandate to inform the affected public by governmental institutions or companies. The ultimate objective, however, must be to improve environmental planning, policy making and management, end eventually, the environment, and the urban environment in particular. This decision support function addresses a broad audience, namely all the actors involved in the policy and decision making processes as well as the institutions and individuals involved in operational environmental management. Better and shared information is one of the elements of an improved decision making process. Problem awareness, an understanding of causes and effects, but also the costs of impacts, and costs and benefits of alternative strategies are the basic elements of this information, which must include technological, environmental, socio-political, and economic criteria (Fedra and Haurie, 1999).

Air quality management involves a number of basic building blocks that form a conceptual framework for the analysis and formulation of management strategies and policies as the ultimate goal:

- Sources of emission, represented in various emission inventories for industrial, commercial, or domestic sources and the transportation system, as well as land-use related sources (biogenic emissions of VOCs, particulate matter from soils and street surfaces);
- Monitoring system observing ambient air quality and historical trends with emphasis on the peak values that may exceed regulatory standards;
- Dispersion and transformation processes, driven by emissions, meteorology, and local topography, that translate emissions into the ambient concentrations, represented by air quality simulation models;
- Impact assessment, which translates the ambient concentrations into costs in a general sense (e.g., in terms of public health and environmental damage);
- Control strategies which basically attempt to limit emissions, relocate them, or mitigate impacts where that is possible, with fuel quality constraints, end of pipe technologies, or temporary traffic restrictions being of the more noticeable instruments (Fedra and Haurie, 1999);
- Communication tasks including various levels of regular reports, event driven warnings such as smog alarms, as well as the continuous information of the public on ambient air quality.

The use of complex analytical functions and model in particular requires a good understanding of the methods used, and their limitations, for a reliable interpretation of results. Consequently, a set of tools and models that is freely accessible to anybody over the Internet carries the danger of use outside the design parameters and misinterpretation of the results. To address this problem, AirWare not only uses a fully interactive, graphical and symbolic user interface, but incorporates a rule-based expert system that can guide and control user requests and assure the completeness, consistency, and plausibility of data and scenario assumptions.

AirWare: a guided tour

AirWare is designed for a broad range of applications, and can be configured for the support of specific national regulations. The main function groups that the system supports are:

- Data management and time series analysis (emission inventories, monitoring including real-time data acquisition)
- Planning, design, impact assessment, optimization (emission control)
- Scenario analysis, forecasting (regular or event based)
- Communication: reporting and public information.

They are supported by a corresponding set of main functions and numerous auxiliary generic tools such as the fully integrated GIS (Fedra, 1996) and the embedded expert system, as well as data import and export facilities.

Monitoring time series analysis: A central component is the support of monitoring stations and networks, both for historical data and real-time data acquisition. Monitoring station descriptions contain one or more time series or data streams. The data sets are displayed and analyzed under interactive control, analyzed e.g., for compliance with the respective regulations, and are also used to provide meteorological inputs and comparison data for the simulation models. They can also be used for various data assimilation schemes for real-time forecasting. Monitoring data analysis functions include basic statistics, station and parameter comparison, correlations tests for compliance with standards, pattern analysis (seasonality, trends), spatial interpolation, animation.

Emission inventories: Emission inventories are supported for industrial point sources, commercial/ residential area sources (area sources) , street networks (line sources), and, where applicable such as for airports, volume sources. Emission sources are stored not only with the basic data required by the simulation models, but with an open list of properties for administrative purposes. A major element is to capture the dynamics of emission sources which may use explicit time-series such as for larger industrial stacks, or generic patterns that can be used to construct an emission estimate for any arbitrary date and point in time.

Emission sources are georeferenced, linked to the embedded GIS (Fedra, 1996). Tools to display, edit, and analyze the emission data including ranking and benchmarking provide graphical display and analysis tools including estimation tools (rule-based expert system). Emission sources provide automatic, complete and consistent input to the simulation models both for scenario analysis and real-time forecasting.

Simulation models: Basic models in AirWare include a set of fast and efficient screening level models designed for fully interactive use, including ISC3/AERMOD (short term, 24 hours, seasonal long-term), DWM 3D diagnostic wind model, PBM photochemical box model, and a 3D Eulerian code, TIMES. For more complex tasks that require computational efforts beyond the constraints of a fully interactive response, AirWare provides links to external models including Lagrangian and 3D dynamic photochemical models (e.g., UAM-V, CAMx, etc.) and meteorological pre-processors (e.g., MM5). For these models, interactive scenario editors as well as tools for the post-processing of results are provided, while the models themselves are solved as a batch or background job, possibly on a remote high-performance compute server, compute cluster or grid, or a parallel machine. For very large number of (low level) sources including city-scale street or transportation networks with thousands of links and nodes, a convolution method with a range of scaleable computational kernels is used. This approach supports very high resolution in the meter range for realistic near-field gradients, and overcome the limitations of the Gaussian approach by using a near-source mixing- zone approach similar to the CALINE series of models.

For complex terrain where Gaussian models are insufficient, a 3D diagnostic wind field model is used (DWM): it provides input for a dynamic multi-layer Eulerian dispersion model, TIMES. For regular or event driven real-time forecasts, this (or any of the other models) can be embedded into a real-time expert system framework that manages the compilation and pre- processing of all required inputs including rule-based quality control and exception handling, running one or more of the models in cascade or parallel, and the post- processing including reports and alarms also for mobile clients..

Impact assessment and emission control strategies: Once the basic concentration fields for the various pollutants have been computed, this information is displayed in the form of topical maps over an appropriate background map, with the colour coding based on the applicable air quality standards, or defined interactively by the user. In a subsequent step, the system can identify and displays areas where standards are exceeded, population exposure, or calculate air quality indices from a combination of model results. If and when standards are violated or observed and predicted concentration too high, measures have to be taken by reducing emissions. Depending on the type of emission source, this may involve a combination of different mechanisms. In general, any such strategy involves costs, for investment and for operation (Fedra and Haurie, 1999). To design cost-efficient optimal strategies, an optimization model is used for processing the results of the long-term (seasonal or annual) model results. For each source or source class, cost functions and efficiencies for alternative emission reduction strategies are defined. The model then finds, based on a net present value concept, the best reduction strategy for a given budget, or the least cost strategy to meet a given air quality standard.

Internet/Intranet support: The functions of the AirWare system are accessible over the Internet or within an institutional Intranet and include the possibility to also support mobile clients like PDAs or SmartPhones with specific messages like reports and alarms. This not only provides support for distributed institutions without high-bandwidth connectivity, it also offers the possibility for a range of information services for a wide range of different user groups including the general public. In turn, efficient access through the Internet makes it possible to offer all the functions and services of a system like AirWare in an internet-based outsourcing or ASP (Application Service Provider) model. The end users do not need to obtain and maintain the technical infrastructure for complex data analysis, including modelling and model based forecasts – these services can be located with an appropriate provider. Cost efficiency through the sharing of high-performance IT infrastructure, as well as the special expertise required for more complex analysis and model applications, make this an attractive option for public-private partnerships around environmental data and information services.

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