Paolo Zannetti '78

'77

PROCEEDINGS OF THE INTERNATIONAL SYMPOSIUM

SIMULATION '77

Editor: M. H. HAMZA

MONTREUX, JUNE 22 - 24, 1977

ACTA PRESS

AIR QUALITY MANAGEMENT: PROPOSAL FOR A COMPUTER ORIENTED APPROACH

E. Runca, P. Zannetti and P. Melli
IBM Scientific Center
Venice, Italy

ABSTRACT

Analysis of the manifold problems facing experts involved in Air Quality Management and of the methodologies developed in order to solve them, shows that so far an organic definition of a computer oriented system, able to meet the user's requirements, has been only partially attempetd. Efforts in this direction have been restricted up to now to an automation of the collection of air quality and meteorological data and to simple elaborations of these data (averages, pollution level trends, wind rose, stability categories, etc.). In particular the more advanced methodologies already developed (i.e., sophisticated techniques for Data Base organisation; advanced languages for data handling; diffusion, statistical, and decision models, etc.) have not been yet combined to provide the user with a system for a rational management of air quality.

The needs of the general user may be concerned with the investigation of the features of their atmospheric environment (analysis), decisions on which actions must be undertaken either in order to minimise damages by temporarily modifying emissions (control), or to optimise future developments of the area (planning). This paper discusses the possibility of organising available methodologies in a compact and organic computer oriented system able to meet the above requirements.

In particular it is shown how a regional authority, running an air quality network, could use such a system for the identification of the most relevant aspects of their air quality problem, for a real-time control of pollution episodes, and for the definition of the effects derived by significant new sources. Furthermore, the proposed system allows a flexible definition of the parameters relevant to the phenomenon in the area of application.

The above system can be extended to include the other aspects of the problem, e.g. health and agricultural effects, thus allowing a more complete air quality management of a region.

INTRODUCTION

The rapid growth of both urban centers and industrial activities causes dramatic changes in the environmental equilibrium, thus raising a series of manifold problems whose understanding and solution are a real challenge to modern society. An important aspect of this challenge, which will be considered in the following, is air pollution.

The difficulty in facing this problem is inherent in identifying a criterion for a correct evaluation of its gravity as well as in providing suitable tools for its correct solution. As to the first point experts have early realised that a unique standard for a given pollutant cannot be defined, since a pollution level resulting not dangerous for human health may affect seriously other aspects of the environment, such as artistic patrimony, crops, and climate. The problem of defining these standards is still open and requires the contribution of politicians, physicians, meteorologists, agriculture experts, and ecologists. In addition, provided that the damage caused by a certain pollution level be correctly evaluated, the solution is still a hard task due to its social and economic costs. In finding the above solution the cooperation of industrial authorities, economists, public authorities, planners, and politicians is indispensable. In practice, the control of air quality is a problem requiring a wide spectrum of information in addition to a series of suitable methodologies for optimising the intervention. Due to the complexity of the problem, to the variety of its aspects, to its dynamics, and to the different people involved, it is required that the above methodologies be combined together into an organic system permitting the effective management of air quality.

So far the air quality management has been restricted to the installation of instruments recording meteorological and air quality data, and to simple elaboration of these data [1-5]. In fact, advanced methodologies already developed (i.e., suitable techniques for data base organisation and handling; statistical and diffusion models; etc.) have not yet been made accessible to all the people involved in the air pollution problem. The present study proposes a possible organisation of a Computerised Air Quality Management System, hereafter referred to as CAQMS, combining the techniques of data management specifically designed for environmental data with statistic and deterministic codes elaborated for application to air pollution. The organisation here proposed is foreseen to be implemented in an interactive computer environment such as, for example APL/CMS. CAQMS is intended to be a fundamental help both to people who must take decisions for controlling air quality and to scientists who want to develop and test methodologies for a better understanding of the problem.

GOALS OF CAQMS

The current way of approaching the air quality management is generally based on data collection, studies of transport and diffusion of pollutants by mathematical models, and statistical anlysis of measured and simulated data (see for example [6,7]). In the same line as above, some techniques limited to the control of large industrial sources (see for example [8,9]) have been developed, including criteria for an emission reduction strategy. All these studies are carried out by using computer facilities, but they have not yet been framed in an organic software structure allowing the users to apply the above techniques according to their particular needs. This goal could be achieved provided that CAQMS were both totally computerised and designed in an interactive environment such as the one provided by APL/CMS.

The performances required to CAQMS derive from the needs of its general user, who may be concerned with the investigation of the features of his atmospheric environment (analysis), decisions on which action must be undertaken either in order to minimise damages by temporarily modifying emissions (control), or to optimise future developments of the area (planning). In addition, CAQMS must include suitable techniques for the data management, as shown in Fig.1, where the general structure of CAQMS and its general utilization is presented.

From a preliminary analysis concerning the different aspects of the problem, a decision follows on the information which must be gathered to provide the input for the air quality management. Once the data have been reduced to a form accessible by the computer, the different performances of CAQMS can be exploited. Results can be displayed on the user's terminal (on-line), on different devices (off-line), or, when representing essential acquired knowledge to be used in further investigations, they can be included in the Data Base (resident). The location of CAQMS in Fig.1 is the most

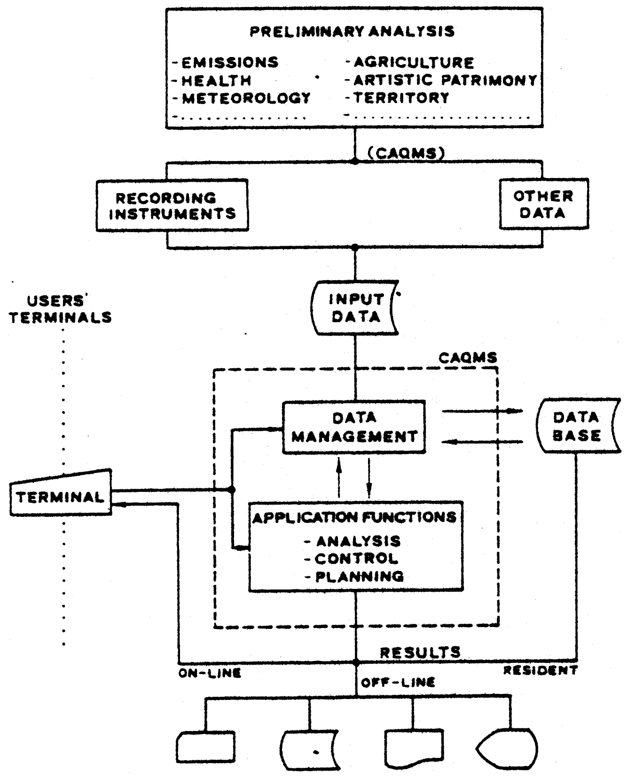

Fig.1 - Schematic representation of CAQMS structure and usage.

common one; however CAQMS can be applied also during the preliminary analysis, provided that suitable data are available.

In particular, the installation of a network of recording instruments, which is the result of the preliminary analysis, can be done by following two different lines. A simple approach is based on a qualitative identification of the monitoring locations by estimating the most damaged area. On the contrary, the use of CAQMS, indicated in parentheses in Fig.1, can provide, by means of different models, a more detailed evaluation of the concentration field in the area and identify both the most frequently and the most seriously polluted areas. In addition, the use of suitable techniques available in the literature [10,11] provides an optimisation of both number and location of monitoring stations. In a similar way, CAQMS can provide a management of the emission inventory by means of suitable techniques [12]. Finally, the structure of CAQMS must be such that any user can integrate it by adding techniques designed for special application, not originally included in the system.

In conclusion, an effective use of CAQMS requires that it be interactive (in the sense that the user can not only access data and techniques but also exert direct action on every stage of the computation), flexible (in that it can be applied to a large variety of problems related to air pollution and that it can be utilised by users having different backgrounds and needs), and extensible (since the users can integrate it in case of necessity).

STRUCTURE OF CAQMS

As already shown in Fig.1, CAQMS is composed of two blocks: the Data Management Block (DMB) and the Application Functions Block (AFB). The first one is designed on the basis of a relational data base organisation. The second one consists of a series of subprograms, hereafter called functions according to the APL terminology, which can be executed by the user with the aim of performing the activities of analysis, control, and planning. These functions, which are either provided by the system or included in it by the user, can be used individually or can be linked together according to the user's needs. In addition, the Application Functions Block includes a set of functions describing, on the user's request, how to operate the system

Data Management Block (DMB)

On the basis of the variety of possible CAQMS users and o[f] its applications above outlined, DMB must be such that an user having no specific background in data eleborations ca[n] handle his data base without being obliged to learn comple[x] languages and data base access methods. In addition, DMB must allow not preplanned transactions and the use of standard pre-existing programs. The above requirements can b[e] met by using MIDA (Multipurpose Interactive Data Access), which has been developed as a joint project by the IBM Scientific Centers of Pisa and Venice [13,14] .

As can be seen in Fig.2, MIDA consists essentially of XR[M] which is a relational access method developed at IBM Cambridge Scientific Center [15], XL [13] which is a high lev[el] query language, and an interpreter of MIDA command language. The host operating system is VM/CMS whose commands can be executed by MIDA. CMS is the Conversationa[l] Monitoring System, i.e., an interactive Operating System running in the virtual machine environment provided by VM/370 [16] . By means of MIDA the user can organise th[e] file of collected data in a relational data base, from which he can select data according to his needs. He can also perform simple computations (e.g., averages, standard deviations, etc.) on the data extracted and finally he can transfer subsets of data, formatted on user's specifications, to any computer storage device and, in particular, to Application Functions Block (AFB).

Application Functions Block (AFB)

As already pointed out, this block consists of a set of functions enabling the user to perform analysis, control, and planning of air quality.

Analysis The scope of analysis is the evaluation of air qua[lity] characteristics as a function of local meteorology, geography, and source distribution as well as the identificatio[n] of the models providing the best description (fitting) of th[e] phenomenon. To this purpose AFB must include: a set of functions for graphical display of measured and simulated data, univariate functions for basic statistical computations (e.g., averages, variances, histograms, distribution analysis, auto-spectral analysis, etc.) and for fitting techniques with ARIMA and/or cyclo-stationary (CS) models [17,18] .

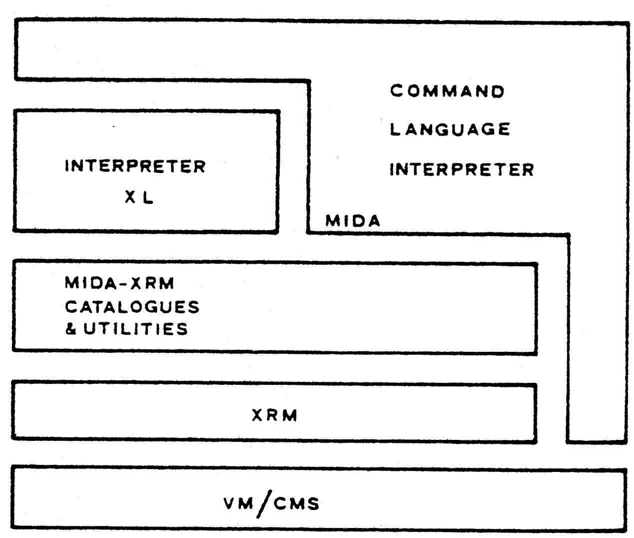

Fig.2 - Schematic representation of MIDA structure.

bivariate functions similar to the previous ones, but operating on two different series of data (e.g. concentration and meteorological data) [17,19] , and multivariate functions operating on different series of data (e.g., concentration, meteorology and emissions). The last ones should include diffusion models [20,21] , planetary boundary layer models [22] , and statistical multivariate analysis [23,24] .

A possible utilisation of CAQMS in analysing the air pollution problem is shown in Fig.3, in which both the statistical and the deterministic approach are illustrated. Furthermore statistical and deterministic approaches can be combined together to improve the simulation of the phenomenon. Substantially, the analysis should lead the user to understand the basic characteristics of the problem and to identify the most suitable modelling techniques and related parameters to be used in control and planning activities.

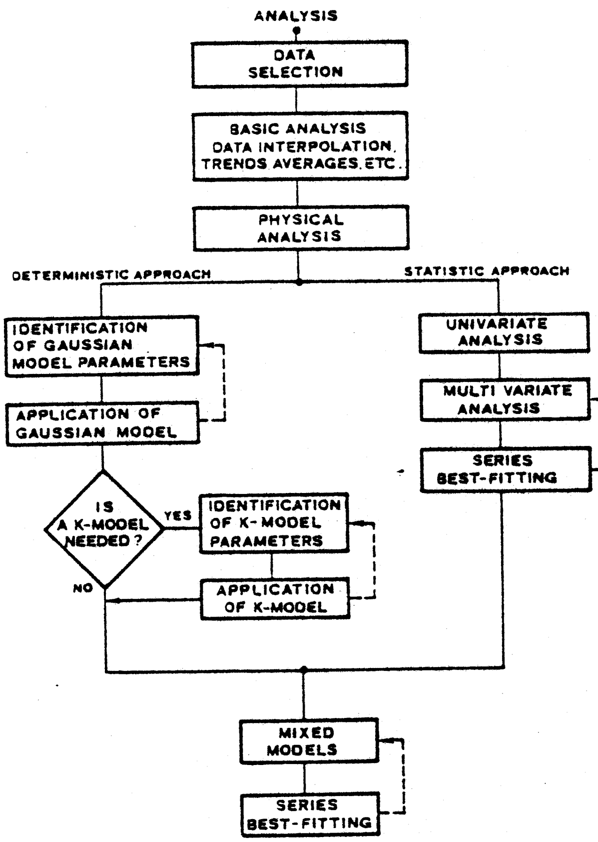

Fig.3 - General use of CAQMS for analysis of an air pollution problem.

<u>Control</u> CAQMS provides a series of functions allowing a real time control of air pollution episodes . This activity requires a series of steps, the first of which consists of air quality and, if necessary, meteorological prediction, to be carried out by using the models considered in the analysis stage. In particular, since real-time prediction is needed, the fastest techniques provided (semi-empirical deterministic models and/or statistical algorithms) by CAQMS should be preferred. The predicted concentration field makes it possible to evaluate by suitable functions the damages produced with respect to different parameters, i.e., public health, agriculture, artistic patrimony, etc.. Every time the short-term forecast damages exceed the prefixed standards, CAQMS functions must provide an emission reduction strategy, which both minimises the total cost of intervention and assures, within a certain level of confidence, that standards are not exceeded. It must be pointed out that, if deterministic models are used in the predictive step, the evaluation of the contribution of each source to pollution level is straightforward, while use of statistical models requires that the evaluation of the above contributions, classified according to different meteorological situations, be made in advance in the analysis stage. The logic of the control activity is shown in Fig.4. Applications of optimisation techniques to air quality control problems have been already developed by several authors [25,26] .

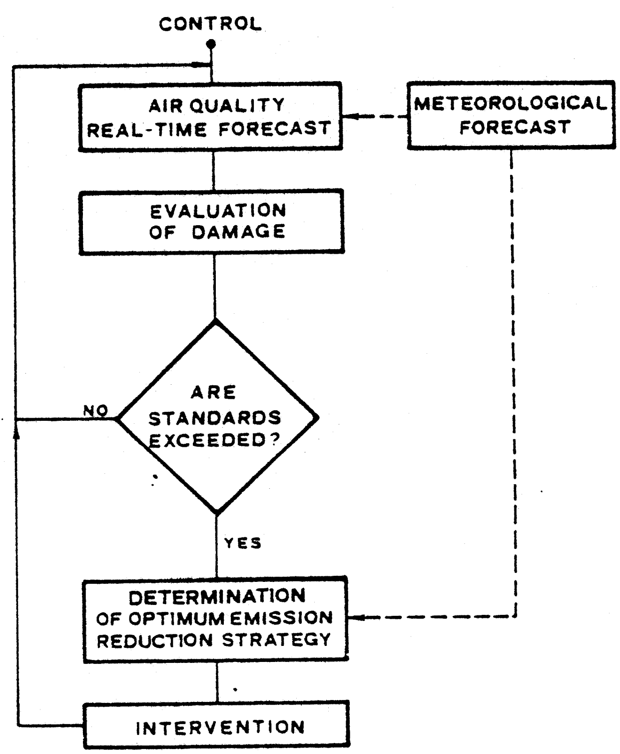

Fig.4 - Control of air pollution episodes by using CAQMS.

<u>Planning</u> The planning activity concerns those situations in which a permanent modification of source distribution and emission rates must be optimised. This activity must be performed not only in case of preplanned development of an industrial and/or urban area, but also when the real-time control of pollution episodes becomes too expensive or when the long term average concentration needs to be reduced. The models used in this planning step are the same used in analysis and control, except that they work in conjunction with optimisation techniques slightly different from those used in control [27-31] . In practice, there is a noticeable similarity between control and planning activities. In the present study, however, they have been considered separately since planning, unlike control, does not require prediction of meteorological conditions, while it needs detailed information on the territory (e.g., land use and social and economical aspects related to the development of the area). In addition, when planning is oriented to a development of a urban and/or industrial area, sophisticated techniques, such as K-models and planetary boundary layer models, may be required in order to get an evaluation as accurate as possible of the contribution of new sources to the pre-existing pollution level.

PRESENT STATE OF WORK

On the basis of the above stated concepts, some techniques, which can already be included in CAQMS, have been developed at Venice IBM Scientific Center. This is the case of MIDA, which has been mentioned in the paragraph dealing

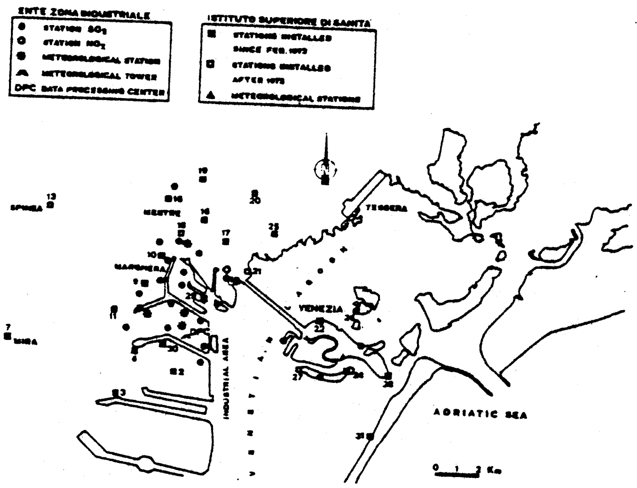

Fig.5 - Venetian Area and its air quality networks.

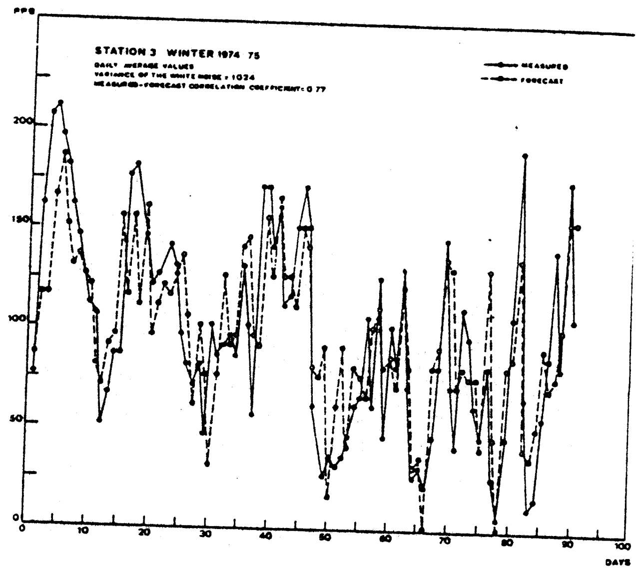

Fig.7 - Measured and predicted daily average SO_2 conce tion in winter 1974-75. Prediction is achieved by multipl regression between SO_2 and meteorological parameters.

with DMB. As to AFB, some techniques briefly described in the following have been developed with the purpose of testing their applicability to a real air pollution problem. Some of these techniques have already been translated into a set of functions programmed in APL. Other techniques, i.e. diffusion models, have still to be programmed as APL functions, while the implementation of optimisation techniques, to be used in planning and control, has not yet been undertaken.

An example of application of the available material to the task of identifying some aspects of a real air pollution problem is reported in the following . It refers to Venice area (shown in Fig.5), where a consistent data set is available and where the pollution problem is also relevant for its effects on the decay of the artistic patrimony of the city. In addition to that, the industrial area is still in expansion, thus urgently requiring a management of the problem. For the above reasons two networks of altogether 45 stations monitoring SO_2 concentration and 5 stations measuring meteorological parameters have been installed in the area. By using data of these networks it is shown below how available functions and techniques can identify the cycles of the phenomenon (Fig.6), can predict the temporal evolution of SO_2 pollution levels at a given station (Fig.7), and, finally, can simulate the long term SO_2 averages in the area (Fig.8).

The results in Fig.7 are obtained as follows:

- MIDA selects [13,14] from the data set the series of S data to be elaborated, by using the command:
  find (year,month,day,hour,minute,ppb)/exdata fror (year,month,day,hour,minute,ppb,station)/SO where ST/SO2='29' & year/SO2='74' & (month/ SO2>='06' & month/SO2<='08')
- The data selected are transferred to a file accessible t APL by the command:
  scan exdata newfile data
- The above time series is analysed by the function 'MISSING' which intrepolates the missing values, then the interpolated series is processed by the function 'AUTOCOR', whose results are displayed by 'PLOT' as shown in Fig.6.

In a similar way, by using a suitable series of functions, is possible to get the results shown in fig.7 [24] , while the results in Fig.8 [20] show the capability of a climatolo gical Gaussian diffusion model to simulate long term averag SO_2 concentration in the Venetian area.

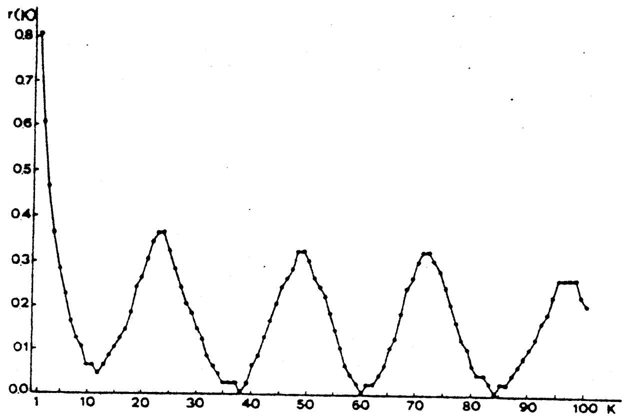

Fig.6 - Autocorrelation function of logarithms of hourly average SO_2 concentration measured at Station 29 (ISS) in Summer 1974.

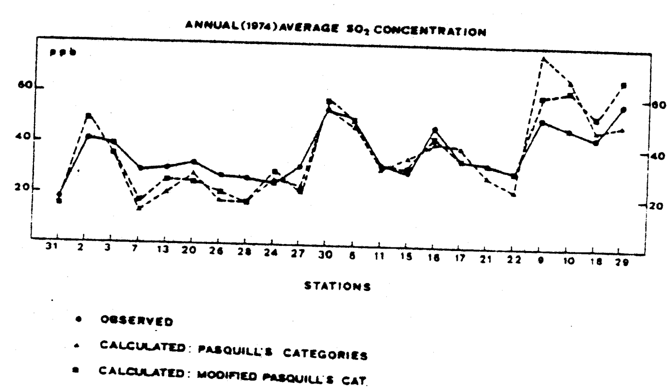

Fig.8 - Simulation of yearly (1974) average SO_2 concentration by using a multiple-source climatological Gaussian model.

CONCLUSIONS

The gravity and the complexity of the air pollution problem make it urgent to develop a practical tool for its management. A possible attempt to answer this demand has been developed in the present study by outlining the characteristics and the structure of a Computerised Air Quality Management System (CAQMS). It has been shown that CAQMS must be totally computerised and interactive in order to make accessible the necessary techniques to the different people, ranging from technicians to politicians, involved in the management of air quality. A possible way of fulfilling the above requirement is to develop the system in APL/CMS environment and to organise CAQMS in two main sections: the Data Management Block (DMB) and the Application Functions Block (AFB). As to the first one, a great flexibility in handling large data base, as those encountered in environmental problems, is allowed by the use of relational data base organisation, for which software tools (e.g.,MIDA: Multipurpose Interactive Data Access) are already available. An outline has also been given, on the basis of the techniques available in the literature, of the concepts to be followed in the design of AFB, enabling the user to perform the activities of analysis, control, and planning. The user must also be given the possibility of integrating AFB by new functions, solving his particular problems, not originally included in CAQMS.

Finally, in some practical examples both the applicability and the reliability of some of the proposed techniques have been shown. As a final statement, the authors want to point out that the implementation of CAQMS would be not only a great help to people facing the problem of air pollution, but also a step toward a global treatment of environmental problems, in that it represents a part of a more general ecological system.

Acknowledgements
The authors are grateful to Dr. G. Marini of the IBM Scientific Center of Venice for his helpful discussions and suggestions. Appreciation is also expressed to the Istituto Superiore di Sanità (National Department for Health) and to the Ente Zona Industriale di Porto Marghera (Local Industrial Committee) for providing the data used in the application of the techniques presented in this paper.

REFERENCES

1. Istituto Superiore di Sanità-Ente Nazionale Idrocarburi, "Rilevamento dell'Inquinamento Atmosferico nella Zona di Venezia", Technical Report, 1973.

2. Sekikawa, S., Naganawa, H., Murakami, H. Ozawa, K., and Koike, H., "Air Pollution Monitoring System Utilising Minicomputer", NEC RESEARCH & DEVELOPMENT, No.24, pp.32-47, January, 1972

3. Mantero, J., "Design of an Air Monitoring Network for the Control of Air Pollution in Bilbao", Technical Report SCR-03.74, IBM Madrid Scientific Center, September, 1974.

4. Zilio-Grandi, F., "Ricerche sulla Qualità dell'Aria della Zona di P. Marghera, Mestre, Venezia", Ambiente e Risorse, 2^Meeting, University of Padua,1975.

5. Dittrich, W., Brown, W., Hallman, G., and Nelson, E., "Automated Data Handling for Small Authorities", JOURNAL OF THE APCA, Vol.21, No.9, pp.555-558, September, 1971.

6. Feldstein M., Macomber, R., Harawitz, H., Mead, R., Norris, A., and Thuillier, R., "Air Quality Modeling for Land Use Planning and Control Applications. An Interdisciplinary Approach", Technical Report No.73-187, Bay Area Air Pollution Control District, San Francisco, Ca., 1973.

7. Roberts, J.J., Croke, E.J., Kennedy, A.S., Norco, J.E., and Conley, L.A., "Chicago Air Pollution System Analysis Program", Technical Report ANL/ES-CC-007, Argonne National Laboratory, May 1970.

8. Egan, B.A., Modeling for Supplementary Control Systems", 5^Meeting NATO/CCMS, Roskilde, Denmark, 1974.

9. Croke, K.J., and Kennedy, A.S., "An Air Quality Control Program for Large Industrial Sources in the City of Chicago", Technical Report No.69-71, Argonne National Laboratory, 1969.

10. Seinfeld, J.H., "Optimal Locations of Pollutant Monitoring Stations in an Airshed", ATMOSPHERIC ENVIRONMENT, Vol.6, pp.847-856, 1972.

11. Darby, W.P., Ossenbruggen, P.J., and Gregory, C. J., "Optimisation of Urban Air Monitoring Network", JOURNAL OF THE ENVIRONMENT ENGINEERING DIVISION, pp.577-591, June, 1974.

12. Runca, E., Zannetti, P., and Melli, P., "Computerised Emissions Inventory Procedure (CEIP) for Urban and Industrial Sources, with Application to Venice, Italy", Submitted to the JOURNAL OF THE APCA.

13. Casazza, I., Faedo, C., and Marini, G., "XL: the Query Language for the MIDA Project", Technical Report CSP029, Pisa IBM Scientific Center, March, 1975.

14. Casazza, I., and Marini, G.,"MIDA: a Relational System for Data Management Architecture and User's Guide", Venice IBM Scientific Center Technical Report (in press).

15. Lorie, R.A., "XRM: an Extended (n-ary) Relational Memory", IBM Cambridge Scientific Center Technical Report, No.320-2096, January, 1974.

16. "Virtual Machine/370-Introduction", IBM Manual GC20-1800.

17. Box, G.P., and Jenkins, G.M., "Time Series Analysis forecasting and control", Holden-Day, San Francisco, 1970.

18. Zannetti, P., Finzi, G., Fronza, G., and Rinaldi, S., "Time Series Analysis of Venice Air Quality Data", IFAC Symposium on Environmental Systems Planning, Design, and Control, Kyoto, Japan, 1977.

19. Trivikrama, S.R., Samson, P.J., and Peddada, A.R., "Spectral Analysis Approach to the Dynamics of Air Pollutants", ATMOSPHERIC ENVIRONMENT, Vol.19, pp. 375-379, 1976.

20. Runca, E., Melli, P., and Zannetti, P., "Computation of Long-Term Average SO_2 Concentration in the Venetian Area", APPLIED MATHEMATICAL MODELLING, Vol.1, pp.9-15, June, 1976.

21. Shir, C.C., and Shieh, L.J., "A Generalised Urban Air Pollution Model and its Application to the Study of SO_2 Distributions in the St. Louis Metropolitan Area", IBM San José Research Center Technical Report RJ1227, Ca., 1973.

22. Bornstein, R.D., "The Two-Dimensional URBMET Urban Boundary Layer Model", JOURNAL OF APPLIED METEOROLOGY, Vol.14, No.8, pp.1459-1477, 1975.

23. Chock, D.P., Terrell, T.R., and Levitt, S.B., "Time Series Analysis of Riverside, California Air Quality Data", ATMOSPHERIC ENVIRONMENT, Vol.9, pp.978-989, 1975.

24. Zannetti, P., "Modelling and Forecasting SO_2 Air Pollution Levels: a Statistical Approach", International Conference on Applied Numerical Modelling, University of Southampton, 1977.

25. Kyan, C.P.,and Seinfeld, J.H., "Real-Time Control of Air Pollution", AIChE JOURNAL, pp.579-589, Vol. 14, No.3, May, 1973.

26. Chu, K., Jamshidi, M., and Levitan, R.E., "An Approach to on-Line Power Dispatch with Ambient Air

Pollution Constraints", IBM Thomas J. Watson Research Center Technical Report RC 5997, 1976.

27. Seinfeld, J.H., and Kyan, C.P., "Determination of Optimal Air Pollution Control Strategies", SOCIO-ECON. PLANN. SCI., Vol.5, pp.173-190,1971.

28. Seinfeld, J.H., and Chen, W.H., "Optimal Distribution of Air Pollution Sources", ATMOSPHERIC ENVIRONMENT, Vol.7, pp.87-99, 1973.

29. Kyan, C.P., and Seinfeld, J.H., "Determination of Optimal Multiyear Aar Pollution Control Policies", JOURNAL OF DYNAMICS SYSTEMS, MEASUREMENTS AND CONTROL, September, 1972.

30. Gustafson, S.-A., "Optimisation Problems in Air Quality Control", METHODS OF OPERATIONS RESEARCH, XXI, August, 1974.

31. Gustafson, S.A., and Kortanek, K.O., "On the Calculation of Optimal Long-Term Air Pollution Abatment Strategies for Multiple-Source Areas", International Conference on Mathematical Models for Environmental Problems, University of Southampton, 1976.