AMBIENT AIR MONITORING FOR HIGHWAY ENVIRONMENTAL ANALYSIS

F. L. Palmieri, Air Quality Analysis Unit, New York State Department of Transportation

The ever-increasing demands for accurate analysis of air quality impacts of highway proposals have caused ambient air quality monitoring to become a topic of substantial concern to transportation analysts. The data acquired through ambient air monitoring are an essential input to the mathematical models used for highway air pollution forecasting, both for the determination of ambient background levels and for the validation and calibration of the models themselves. Despite its importance, however, a standardized body of procedure and good practice for this type of data acquisition has developed slowly. Because of the substantial differences between this type of ambient monitoring and that done routinely by state environmental agencies for their urban-area air quality surveillance programs, the techniques for highway ambient monitoring have largely grown out of the efforts and experimentation of the state and federal transportation agencies themselves. This paper presents some of the considerations and results of such an effort by the New York State Department of Transportation, which has had an active and extensive program in this field since 1972.

USES OF AMBIENT AIR DATA

Because the uses to which the data will be put have a great influence on the data collection process, the 2 primary purposes of the ambient monitoring effort should be briefly reviewed.

First, and most straightforward, is the acquisition of ambient data for the purpose of estimation of background concentration. Most of the standard mathematical models in use for highway analysis provide forecasts only of the pollution contribution from the highway; to this must be added an estimate of future contributions from other sources. A standard procedure for doing this is first to measure present-day background levels in the vicinity of the proposed project site and then to adjust these measurements to provide future forecasts by some sort of "rollback" analysis making use of the estimates of future areawide emission levels to be found in the state air quality implementation plan.

A more subtle and complicated use for ambient data is in the validation and calibration of the predictive models themselves. Most highway departments currently involved in this kind of analysis make use of Gaussian-diffusion models, such as the FHWA and California Division of Highways TLINE and CALINE or the U.S. Environmental Protection Agency HIWAY. The direct usefulness of these models is limited. They are derived for a certain set of specific and limiting assumptions, including constant vertical wind-speed distribution, constant wind direction, uniform wind flow field upwind of the highway section, no obstructions off the highway or sharply sloped cuts or fills adjacent to it, no aerodynamic effects of flow about supporting structures, and so forth. As a result, predictions made by use of these models are only applicable—without further calibration—to the case of a rural, at-grade highway. For any more complex situation, including the important urban situations of cut sections, elevated sections, and street canyons, a calibration of the model should be done. This allows correction of the model for violations of the input assumptions, which would otherwise be unaccounted for and could introduce serious errors.

Lately there has been increasing use of the new generation of numerical or conservation-of-mass models. These, even more than the Gaussian models, require extensive programs of ambient data acquisition to successfully validate and calibrate them.

It must be kept in mind that, when we speak of calibration of a model, we are perforce talking about a more complex monitoring effort than would be required simply for the determination of ambient background concentrations. To provide a valid calibration requires that concentration measurements be obtained at 2 points at least on each side of the roadway at a given cross section of interest. The calibration analysis then becomes an effort to determine the single calibration constant that gives the best "averaged" predictive curve matching the 4 (or more) measured points. Obviously a true calibration cannot be made with only a single measurement point since the calibration constant would only ensure a match between the model and observed reality at this 1 point, with no assurance of acceptable predictive accuracy anywhere else.

APPROACHES TO DATA ACQUISITION

There are obviously several approaches by which the necessary data may be gathered. If the primary object is to determine ambient background concentration data, using some existing source of this information may suffice. The most common source is the ambient data taken in each urban area as a part of each state's ambient air quality surveillance system. Although originally intended for the purpose of measuring progress toward achievement of the National Ambient Air Quality Standards and providing the data input necessary for an air quality emergency episode warning system, these urban networks (sometimes referred to as continuous air monitoring systems or CAMS) can provide useful data to the transportation planner. The most serious weakness of CAMS as sources of ambient data is that generally the funding available for the network limits it to a small number of monitoring stations, and these are generally located to observe the most serious concentrations of stationary pollution sources in the area. These locations may or may not be at all suitable with respect to providing meaningful data for the transportation corridor under study. Nevertheless, CAMS should certainly be among the first data sources considered by the transportation planner not having his or her own monitoring capability.

Similarly, it may be found that there exist other sources of ambient data that were gathered for other special purposes. For example, under state indirect source control regulations, developers of major commercial enterprises may be required to do ambient monitoring in support of the air quality impact analysis that must accompany the indirect source permit application. Or, a local university may conduct air quality monitoring for academic or research purposes. A good starting point for attempting to identify significant sources of existing ambient data is the U.S. Environmental Protection Agency data bank (storage and retrieval of aerometric data, or SAROAD). SAROAD receives data from a variety of sources, codes them by geographic location, and tabulates them in a standard format for easy retrieval. It can often provide clues to the existence of ambient data that would otherwise go unnoticed.

Should secondary sources such as CAMS and SAROAD fail to provide suitable data, the transportation agency faces the necessity of performing a special monitoring study. This may often arise when ambient background estimates are prepared, and is virtually inevitable when one is involved in the calibration of mathematical models. Again, the agency has several possible approaches: It may have the data gathered for it by some outside group under contract, by another governmental agency, or by a private consultant; or it may choose to establish its own monitoring program. Many transportation agencies whose monitoring needs are limited will choose the consultant-contract option. This approach, however, has distinct advantages and disadvantages that should be clearly understood in advance.

The basic administrative advantage of using a private consultant is, of course, the saving in time and administrative effort compared to that required for the agency to establish its own monitoring program. Especially now, when widespread fiscal crises and consequent austerity programs affect many state governments, the establishment of an in-house monitoring program, with its attendant problems of civil service staffing procedures and equipment purchase justifications, may simply be unfeasible from an administrative point of view. In such a case, consultants who can provide their own equipment and technicians and who furnish as a final product ready-to-use, edited tabulations of the necessary data, will seem attractive. This is especially true if the data are needed quickly; even in the best of times, the cumbersome budgetary procedures of most state governments would require at least 1 to 2 years of lead time to establish an in-house program.

On the other hand, the use of consultants may be a foolish choice to the agency whose program will clearly require a large-scale, continuing monitoring effort in support of a steady stream of environmental impact statements (EIS). The costs involved in consultant production of data have, in our experience, ranged from 2 to 4 times the unit cost of producing the same data via an in-house program. Such costs can quickly become unbearable if the overall scale of the program is large.

The transportation agency facing the need for a monitoring program of such magnitude may choose to contract for the data acquisition by another government agency, rather than try to establish its own program. Because of the air-surveillance requirements of the Clean Air Act Amendments of 1970, each state and many regional or local environmental agencies are now deeply involved in ambient data collection. Administratively, it is quite possible for the least cost and least effort solution to the transportation monitoring requirement to be the establishment of a special monitoring program, catering to the highway EIS requirement, within the environmental agency's overall monitoring effort. There are many obvious advantages of such an approach, including centralized management responsibility, use of established personnel pools, avoidance of the need for separate and duplicative maintenance and repair facilities and spares inventories, and acquisition and editing of the data to uniform, national EPA standards of quality assurance by personnel experienced in proper procedures.

In fact, this was the approach adopted by the New York State Department of Transportation (NYSDOT), which in early 1973 established such a joint program with the New York State Department of Environmental Conservation (NYSDEC). Initially, NYSDOT provided full funding for the acquisition of 5 fully equipped mobile laboratories and ancillary equipment (totaling about $250,000), and NYSDEC provided personnel, expendable supplies, and computer facilities for data tabulation. In subsequent years, NYSDOT has furnished lower levels of funding sufficient to cover equipment and material expenses and a proportion of the personnel costs. The joint program has been highly successful overall, producing good data at a much lower cost than had been estimated for a fully in-house NYSDOT program.

It may, of course, be that an individual transportation agency finds that such an option is not open to it. The appropriate environmental agency may find its resources already committed to such an extent that it has no interest in assuming additional responsibilities, even if partly or wholly funded by the transportation agency. Or, in some states, the environmental agency may have delegated the monitoring responsibility to local agencies who prove uncooperative for a variety of reasons. In such a circumstance, the transportation agency will have little choice (if the scope of its program precludes use of private consultants) but to establish its own in-house monitoring effort. The remainder of this paper will be devoted to a discussion of some of the considerations central to the establishment of such a program, on either a joint or fully in-house basis.

PERSONNEL FOR THE MONITORING PROGRAM

One of the more difficult problems that must be faced is the acquisition of appropriately skilled personnel. Ambient air monitoring is a highly specialized branch of physical chemistry, demanding personnel possessing training and skills not usually available in the typical transportation department. These personnel will fall into 4 general categories: monitoring program managers, instrumentation operators, maintenance and repair technicians, and data editing, processing, and tabulation specialists.

The monitoring program manager must be a highly skilled jack-of-all-trades. He or she must have extensive background in the theory and practice of monitoring instrument operation while also having a familiarity with basic transportation planning procedures and with the requirements of the mathematical modeling of pollutant dispersion that will affect technical decisions on the monitoring (e.g., site selection and location of probes). Personality and ability to work well with associates of widely varying backgrounds will be of great importance since he or she will be a personal bridge between the transportation planners, usually highway planners and designers, and personnel whose whole training and orientation are toward environmental studies, which in some cases will have developed in them a definite antagonism toward the whole highway program. Under such circumstances, considerable diplomatic abilities are a necessity.

The equipment and mobile laboratory operators will generally be junior scientists, generally having an environmental-studies background and a fairly recent bachelor's degree. They must be capable of operating all the equipment and evaluating the validity of data on a real-time basis to detect malfunctions as early as possible and be trained to perform basic service and repair work. One of the more difficult problems associated with the use of such personnel is the difficulty in retaining them in a job that is an endless round of physical moves, with little time at any permanent home. For this reason, experience indicates that the young unmarried person best fills this sort of position; however, one may have to be resigned to, and prepare to deal with via vigorous recruitment, a rather higher job-turnover rate than is customary in government agencies. An advantage of the cooperative-program approach discussed above is that within the environmental agency will probably be a number of advancement opportunities open to the laboratory operator, thus tending to ameliorate his or her growing unrest with the unsettled nature of the job. Opportunities for career advancement for a person of such a background are generally much rarer in a transportation agency; therefore, the employee may come to think of the job as merely a waystop on the way to better things elsewhere. Obviously such an attitude is not conducive to high productivity.

The electronics technician may pose far fewer problems for the transportation agency. Generally some personnel of such a background will already have been retained for use in servicing traffic-count and other programs already making use of sophisticated electronic equipment. Therefore, the agency may find it easiest to build on its existing management and workshop capability, adding a small number of suitably trained workers as necessary. Specialized training in the maintenance of monitoring instruments is often available from the manufacturers; the EPA Institute for Air Pollution Training also offers introductory-level courses in instrumentation that can be highly useful in the basic indoctrination of skilled personnel.

Similarly, most transportation planning agencies will already have substantial in-house capability for data processing and tabulation by computer. Again, the EPA institute courses provide a useful introduction to the specifics of air quality data handling.

SELECTION OF EQUIPMENT

Equipment selection is the next crucial problem facing the monitoring program manager. If he or she is to be successful in equipping the unit to carry out its responsibilities within the typically insufficient budget, careful attention must be paid to some preliminary considerations.

First is the question of selecting the pollutants to be monitored. Obviously, carbon monoxide is the first and most important choice. Generally, whenever any monitoring at all is required in connection with a transportation EIS, carbon monoxide will be the most important—and often only—concern. Beyond CO, however, the monitoring program manager should proceed cautiously.

Certainly nitrogen oxides and nonmethane hydrocarbons are transportation-related pollutants that must be discussed in the air quality analysis of any major transportation project. However, monitoring for these pollutants is not automatically justified. At the present, there are no widely accepted photochemical models for the dispersion of these pollutants. Therefore, they are normally treated in an EIS on a mesoscale basis; that is, any concentration calculations are normally based on simplistic box or rollback models. It may, therefore, be argued with considerable logic that the acquisition of extensive NO_x and HC data, specific to the proposed highway location, is not justified. The alternative would be to make use of CAMS or other existing data, arguing that it will provide an area-average estimate of existing concentrations that is conceptually consistent with the crude, areawide model used for these pollutants. I feel that, if such data are available from other sources and do seem to be usable within such a philosophical framework, the transportation agency may be much better off to put its money into acquiring additional CO monitoring instruments, thus allowing the measurement of CO at several points in space at a given cross section and allowing better model calibration.

Another question requiring an early answer relates to the necessary extent of meteorological monitoring. If the agency is confining itself to the use of the simplest Gaussian-diffusion models, applied in cross-sectional geometries consistent with their assumptions, and dealing with an environmental review agency that will accept the use of an uncalibrated model, little meteorological monitoring may be required. The agency may be able to confine its acquisition of meteorological equipment to a small number of self-contained wind speed-direction units, such as the well-known MRI mechanical weather station. At the other extreme, in a major project in a heavily polluted urban area and in the presence of complex geometries of cross sections and obstructions, a sophisticated, calibrated model is a necessity. Under such circumstances the meteorological equipment inventory will be larger both in number of instruments (due to the need to monitor more points in space at a given cross section) and in sophistication (due to the need for esoteric data such as 3-axis wind components and vertical and horizontal stability parameters).

In the latter case careful attention will have to be paid to specific choice of equipment since many of the most useful instruments on the market, in terms of their sensitivity and range of output parameters, are designed primarily as research tools and do not possess the durability required for long-term monitoring at exposed sites under all weather conditions.

Having arrived at the requisite decisions regarding the scope of his or her program, the monitoring program manager must next proceed to choose field instrumentation. In this, there is really no substitute for long experience; some equipment may exceed every specification and expectation, while other equipment may exhibit only the most tenuous relation between catalog claims and actual field performance. If the program manager has limited experience in the field, he or she ought to seek available expert opinions from environmental agencies, local academic institutions, or any other handy source. For further guidance, a few general principles might be stated at this point.

The longevity in business and the service record of the manufacturer should be considered. The air monitoring equipment field, especially in the last few years, has seen numerous small manufacturers come into existence, place equipment in service, and then disappear into mergers and bankruptcies, leaving customers with expensive inventories of "orphan" instruments for which parts and service are no longer available.

Cost, therefore, should not be allowed to be the paramount consideration since most often the marginal producer will be able to quote a somewhat lower price than the large manufacturer whose quoted price must include a fair share of corporate overhead costs. This is certainly not to say that one should avoid the small manufacturer and deal only with the giants of the industry. But the purchaser should clearly understand the possibilities of the situation. Of course, the small manufacturer may quote a price on the basic instrument and an adequate inventory of spares that in total is still lower than the larger company's instrument price alone. Then, as long as the purchaser is confident of his or her in-house service capability, there is no reason not to take advantage of the cost break.

Those agencies whose monitoring unit personnel will be thinly stretched will want to carefully investigate the newer generation of instruments that provide a self-calibration capability. In combination with a data telemetry system and some automatic checks for validity as the data are fed into the computerized tabulation system so as to quickly identify equipment failures, these self-calibrating instruments may greatly reduce or eliminate the need to have an operator physically present. Instead, the mobile laboratory or instrument installation may simply be set up in a secure place, protected from vandals, and merely visited periodically by a technician performing routine preventive maintenance. Or, if necessary, an operator may be able to divide his or her time between several installations in the same general area.

SPECIFIC TYPES OF INSTRUMENTATION

Although it is not appropriate here to discourse at length on the various types of instrumentation available, agencies only now beginning to build a monitoring capability may perhaps benefit from a brief discussion of the experiences of the New York Department of Transportation with the various specific units now in use for the production of data to support highway EIS preparation.

For carbon monoxide, we at first made the same choice as a number of other agencies and acquired a substantial number of electrochemical CO analyzers, primarily for their great cost advantage over other types of CO monitors. However, it must be candidly stated that in the long-term continuous monitoring application these units did not work out well and have been superseded by other instruments. The basic problem was simply that they were not originally designed or intended for long-term continuous operation and, therefore, constantly had difficulties of component durability and calibration drift. Used for their designed purpose—short-term, spot monitoring, with frequent calibration and no extended on-cycles—they can be quite useful. But in the continuous monitoring application, they were not equal to the demands placed on them. Many agencies have purchased these units or are currently considering their purchase, primarily because of their potentially tremendous cost savings (they are about one-third the cost of an infrared spectrometer), but I feel strongly that their acquisition should be accompanied by a clear understanding of their strengths and weaknesses. Also, in fairness to the manufacturer, I should point out that since our purchase considerable development work has taken place on the instrument and late models may exhibit substantially improved durability.

In our mobile laboratories, until recently the primary instrument for both carbon monoxide and hydrocarbons was the gas chromatograph/flame ionization detector (GC/FID). These units performed well, but at the cost of high personnel demands for servicing and calibration. The other inherent disadvantages of the GC/FID, including the need for highly flammable hydrogen fuel and extremely high cost, are well-known and need not be belabored here. Nevertheless, they were significant enough that, when a decision was made to discontinue acquisition of HC data as a routine practice, we decided to replace them with infrared photometers for CO.

The nondispersive infrared photometer (NDIR) is, of course, the classic method of CO determination and is the original EPA-approved reference method for this pollutant. We originally shied away from NDIR equipment largely because of the bad experiences of other agencies with interferences and calibration drift when this type of instrument was used for long-term, unattended operation. However, an evaluation of the latest generation of self-calibrating NDIRs convinced us that these problems appear to have been reduced to manageable proportions in a properly installed instrument, and we now use these exclusively for CO measurement. We have not had them on hand long enough to say anything definitive about long-term durability, but the results of the evaluation tests performed for us by the service personnel of the Department of Environmental Conservation certainly seem promising.

The comments above on the gas chromatograph for CO determination apply equally well to its use for hydrocarbons. It is the only practical instrumental method currently available. Although it produces good data, the operational difficulties associated with using it in a mobile field application are serious enough to warrant second thoughts about whether the HC data acquisition is really necessary and justified.

The original EPA-approved reference method for nitrogen oxides is the modified Saltzmann method, a wet-chemistry technique. Although perhaps suited to laboratory use, I know no one actively engaged in a transportation monitoring program from mobile laboratories who seriously considers it a practical method. Further, of course, the accuracy of the method has been under serious challenge, and EPA has withdrawn it as a reference method. EPA has subsequently proposed alternative wet-chemistry methods that eliminate the accuracy problem, but all have the basic impracticality of dealing with glassware and reagents in a field operation, compared with the use of an electronic instrument. Therefore, the use of instruments operating on the chemiluminescent principle is almost universal for highway monitoring. These have performed well for us, given proper installation and service. Particular attention must be paid to proper control of the ethylene, which these instruments use as a working fluid. A leak in the exhaust plumbing or placement of the exhaust outlet too close to the intakes for other instruments, can create serious interferences, especially with the gas chromatograph, which determines nonmethane hydrocarbons by first making a total hydrocarbon measurement, which would include the spurious ethylene as well as ambient hydrocarbons.

We originally equipped our mobile laboratories for determining ozone but the data have proved to be of only limited usefulness, and we have effectively discontinued regular O_x monitoring. Similarly, our HiVol particulate samplers have seen only limited use because of the limited emphasis placed on particulates from transportation sources by our environmental review agencies.

HOUSING THE EQUIPMENT

There are 3 common approaches to housing the equipment: use of existing local buildings, use of special small shelters, and use of mobile laboratories. Each has some particular advantages and disadvantages for the monitoring program manager to consider before selecting the approach.

The use of local buildings may be attractive when suitable structures are available in appropriate locations. The obvious advantages will be low (or no) cost and, usually, ready availability of utilities. On the other hand, security from vandalism may be a problem. Tenants of the building may object to noise from the instruments. The explosive gases required for GC or chemiluminescent equipment may constitute a violation of local fire regulations. Owners of private buildings may insist on payment for electricity and other utilities (if drawn from existing building circuits) and on prearrangement for liability indemnification in the event of an accident. Most important, a suitable building simply may not be available at the desired monitoring site. Nevertheless, despite these potential problems, the program manager is always well-advised to look for a building location first.

If a suitable building is not available, use may be made of some sort of small, easily erected and removed shelter—usually a small metal hut just big enough to comfortably enclose the equipment. If the study is to be of extended duration and the equipment is self-calibrating and does not require constant attendance, this may be the most cost-effective solution. However, it may be a poor choice (in the absence of a security system) at high-security-risk locations since such a structure is usually rather flimsy and presents little challenge to the vandal determined to break in. Also, the precise control of environmental factors such as temperature and humidity, which are crucial to the proper operation of some instruments, may be difficult to achieve in such an unsophisticated structure. Despite these problems, its very low cost makes the small shelter an attractive alternative, especially to the agency whose overall monitoring program is of limited or uncertain scope.

The mobile laboratory is an approach that has been adopted in a number of states. The laboratory offers good opportunity for environmental control; adequate interior space for multiple instrumentation as used in a sophisticated calibration study; provision for an on-the-spot maintenance and repair capability; and great flexibility in location. It also permits the use of instruments that require the constant presence of an operator; or, alternatively, the headquarters space may be used for real-time monitoring of the data, or even for a security guard. In the latter context, also, the laboratory (especially if it is a towed trailer) can be much more sturdily built than the small shelter. If security is a consideration from the beginning of its design, it can be made reasonably invulnerable to casual vandalism.

The laboratory may provide surprising protection to its valuable cargo of instruments in an accident situation. We discovered this when one of our laboratory trailers came adrift from its tow hitch at 55 mph (88 km/h) on the New York State Thruway. The trailer left the road and was thoroughly demolished, but the solidly mounted equipment suffered only relatively minor damage and was soon repaired.

A major decision in considering the mobile laboratory approach centers around the question of whether the unit should be self-propelled and self-powered or towed and dependent on external utility hookups. There are trade-offs involved in all aspects of this decision. The self-propelled laboratory will be much more mobile; but, if it is to move only once every few months, is the mobility worth the cost? On the other hand, in security-risk areas, the mobility may pay for itself many times over if vandalism is avoided by withdrawing the unit to a safer location each night. The self-powered laboratory is far more flexible in terms of where it can be installed, but it may be far more expensive to operate, and the generator exhaust may affect the instrumentation.

Balancing all these considerations, we chose an externally powered, towed configuration; however, varying conditions of use could equally validly lead monitoring program managers in other states to different choices. The most important part of the decision-making process will always be a careful evaluation of the operational conditions under which a laboratory will be used, with no preconceptions as to the type or configuration of vehicle. The application should generate the specifications.

CONCLUSION

This paper can only introduce an exceedingly complex topic. It presents an array of information and advice to those who are new to ambient monitoring. For that reason, it is appropriate to close by repeating a statement made several times previously: Monitoring is definitely a field in which experience is the best teacher. The wise monitoring program manager, especially a neophyte, will keep open all possible lines of communication with agencies and individuals already working in the field. This includes EPA, state and local environmental agencies, appropriate academic groups, and other state transportation agencies.