

Integrated Program on Urban, Regional, and Global Air Pollution

Exploratory Field Measurement Campaign in the MCMA

Now in its second phase, the Mexico City Program has moved from assessment to an active measurement phase. A major activity of the program's second phase involves field measurement campaigns to update and improve the MCMA emissions inventory, and to improve current knowledge of the chemistry, and dispersion and transport processes of pollutants emitted to the MCMA atmosphere.

A series of exploratory mobile and fixed-site field measurements, funded by the Comisión Ambiental Metropolitana (CAM) and coordinated by Dr. Luisa Molina, were performed during February 2002, and an intensive five-week field measurement campaign is scheduled to run from late March through early May of 2003. The campaign was conducted utilizing a mobile laboratory developed at Aerodyne Research, Inc. (ARI) and equipped with a range of realtime particle and trace gas diagnostics, as well as various other instruments from Washington State University (WSU), Montana State University (MSU), and the Massachusetts Institute of Technology. The Mexican field measurement team included scientists from the Mexican Petroleum Institute (IMP), National University of Mexico (UNAM), Metropolitan University (UAM-I, UAM-A), National Institute of Public Health (INSP), as well as investigators from Mexican government agencies involved in air quality in the MCMA-Federal Ministry of the Environment and National Resources (SEMARNAT), Secretary of the Environment of the Government of the Federal District (SMA-GDF), and the Secretary of Ecology of the State of Mexico.



Table of Contents

| MCP measurement campaign 1 |
|--|
| Integrated assessment redefined . 3 |
| Risk reduction: benefits vs. costs . 4 |
| Mid-career workshop 5 |
| Water properties of soot 8 |
| Monterrey case study 10 |
| Taxi drivers in MCMA 11 |
| |

The layout for the ARI Mobile Laboratory, as deployed in Mexico City last February, is shown in Figure 1. Realtime measurements of selected trace gases were provided by ARI's tunable infrared laser differential absorption spectroscopy (TILDAS) instruments using lead salt diode lasers. Fast response fine aerosol size distributions (40-2000 nm) and non-refrac-



Figure 1. Configuration of the Mobile Laboratory for the February-2002 Exploratory MCMA Field Campaign.

tory chemical composition were measured with a novel aerosol mass spectrometer (AMS) designed and built at ARI. Fixed site rapid response measurements of selected aromatic and partially oxygenated VOCs were provided by a proton transfer reaction mass spectrometer (PTR-MS) operated by MSU. A commercial LICOR non-dispersive infrared (NDIR) unit provides realtime CO₂ measurements and a commercial TSI condensation particle counter (CPC) provides realtime total number densities for particles with diameters between 10 and 1000 nm. Commercial air quality monitors for NO/NO₂, CO and O₃ supplied by WSU were also included. Ultraviolet (UV) solar flux was recorded by an Epply total UV radiometer. WSU collected VOC whole air samples at selected sampling points within the urban area using portable canister samplers.

During the exploratory field measurement campaign the mobile lab operated in three modes: First, stationary deployments at selected RAMA monitoring sites were used to measure diurnal pollution levels in various sectors of the MCMA and to provide high time resolution research instrument data for selected pollutants to help validate and amplify data from the monitoring instruments. Second, mobile measurements were made through selected city sectors to map ambient pollutant levels, and sample and characterize mobile and fixed site emission plumes. Finally, dedicated chase experiments were mounted to better characterize gaseous and particulate emissions from selected classes of vehicles, including heavyduty diesel trucks, buses, and colectivos. While detailed analysis of the February 2002 data is ongoing, a sampling of findings is presented here to indicate the quality and import of the data.



Figure 2. Mobile laboratory measurements of diurnal gaseous pollutant and fine aerosol species concentrations at Pedregal, Feb. 15-16, 2002.

Figure 2 shows a sampling of diurnal, fixed site data taken at the RAMA station on the grounds of an elementary school in Pedregal. Situated in the southwest portion of the Federal District, Pedregal receives a pollutant flow when the normal wind pattern blows southwest from the metropolitan and industrial areas. Even though the weather was not unusually hot or sunny, tremendous photochemical activity can be observed, with ozone levels exceeding 250 ppbv on the afternoon of Feb. 15, and 200 ppbv on the afternoon of Feb. 16 (gray trace in second panel from top). One key to this photochemical activity are the high levels of formaldehyde (green trace in center panel, measured with the TILDAS instrument); HCHO levels of 20 to 40 ppbv build up in the morning, preceding the photochemical oxidant peaks by several hours. Data from the core urban and industrial areas to the northwest show even higher morning HCHO buildups, even on completely cloudy mornings with no appreciable photochemical activity (in general the weather during the Feb. 2002 campaign was unusually cloudy, rainy and cool), demonstrating large emission sources for this key photochemical trigger species.

Finally, the top panel of AMS data shows a photochemical "bloom" of fine (mode peak at 400-500 nm) secondary aerosols composed primarily of ammonium nitrate, ammonium sulfate, and partially oxidized VOCs. The simultaneous early afternoon production of large concentrations of photochemical oxidants (ozone, nitrogen dioxide, organic nitrates) and secondary fine aerosol particles demonstrates how closely connected the photochemical oxidant and fine aerosol problems are in the MCMA, and suggests they will have to be dealt with in concert, not as separate issues.

Data taken during transverse MCMA "mapping" activities with the mobile laboratory confirms that a significant emission source of HCHO is present and persistent. Using the fast response (1s) TILDAS and NDIR measurements, the amount of HCHO present when the mobile laboratory samples a transient CO_2 plume, predominantly from mobile vehicle sources, can be evaluated. Figure 3 shows the correlation (in blue) between the concentration of CO_2 and HCHO in MCMA transient plumes during one transect, while the same correlation for metropolitan Boston traffic in mid-March 2002 is shown in red. The average HCHO/ CO_2 ratio in the MCMA plumes is 0.0002. The exploratory MCMA field campaign also showed the utility of using the mobile laboratory in "chase" mode, where classes of motor vehicles of interest can be specifically sampled to better quantify their emissions characteristics as a function of driving cycles. In this mode a target vehicle of the desired type is followed as the mobile laboratory's sampling probe moves in and out of its exhaust plume.

MCMA-2003 Field Campaign

The MIT/CAM MCMA experimental team has committed to an intensive, five-week field campaign in the spring of 2003. The campaign's field measurement phase is planned to extend from late March to early May and is designed to cover the height of the annual photochemical season just prior to the onset of the rainy season. This period will include measurements taken before, during, and after Holy Week (April 14-20, 2003), when vehicular traffic is historically reduced as city residents leave for the holiday. By taking measurements before, during and after this period, it is likely that a better assessment of the vehicular emissions contribution to the air quality reduction in this megacity can be assessed with regard to oxidant and aerosol levels.

Unlike the February 2002 exploratory field campaign that focused primarily on mobile laboratory measurements, the 2003 campaign will also involve a highly instrumented "supersite" located at the field campaign headquarters at the National Center for Environmental Research and Training (Centro Nacional de Investigación y Capacitación Ambiental or CENICA). The fixed supersite will be enhanced by the deployment of one or two research grade differential optical analysis spectroscopy (DOAS) instruments and a research LIDAR. It will also host collaborative measurement campaigns by several US research groups, including Drs. Jeffrey Gaffney and Nancy Marley of the US Department of Energy's (DOE) Argonne National Laboratory, and Drs. Janet Arey and Roger Atkinson of the University of California at Riverside. In addition, similar to February 2002 exploratory campaign, extensive meteorological data as well as a wide range of fixed site chemical data will be available from collaborating Mexican research groups.



Figure 3. Comparison of transient mobile source exhaust plume: $HCHO/CO_2$ correlations from traffic in the MCMA (02/02) and metropolitan Boston (03/02).

The Mexico City Program redefines "Integrated Assessment" to put local needs and decision-makers first

Contributed by Stephen R. Connors and the MIT Scenarios Team

Improving air quality in the Mexico City Metropolitan Area (MCMA) is a daunting task. To help local decision makers achieve this goal, the Mexico City Program's mix of Bostonand Mexico-based researchers have redefined the approach and scope of "integrated assessments" commonly used to provide such guidance.

For the last decade, climate researchers have been touting integrated assessments as a way to determine the costs and benefits associated with alternative ways to address climate change. By comparing the cost to reduce (mitigate) greenhouse gases, as well as the cost to adapt to climatic changes, against the anticipated damages that climate change may bring, they hope to inform governments, industry, and the public about what society should do. Both complexity and controversy apply to the determination of those costs and impacts. And, the level of guidance that can be provided under those circumstances remains suspect. Due to the size and complexity of the effort, computational models tend to be global in nature, and treat the economic and societal aspects in a top-down, aggregated manner. More sophisticated models group nations and regions into economic zones, and with luck look at the positive and negative feedbacks among greenhouse gases, atmospheric aerosols, terrestrial ecosystems, oceans, and economic activity.

How much guidance can such approaches offer local decision-makers regarding what "to do?" Furthermore, how high on the priority list of things needing attention is air quality in general, and climate change, given all the other challenges facing the MCMA? These are tough questions. The Mexico City Program has turned integrated assessment approach on its head, defining it from the decision-maker's perspective, rather than the modeler's. This means looking at issues from a local and regional perspective first, and doing the analysis on a bottom-up, versus top-down basis. The goal is to be "prescriptive," taking into account that the future is very uncertain, and that local decision-makers often have numerous and competing goals.

To be informative, both the analysis and discussion of "assessment" results must address three levels of "feasibility," the first two primarily computational, and the third process oriented. These three "feasibility screens" are:

1. Technical Feasibility

To realize an improvement in air quality, measures must achieve sufficient reductions in the "right" emissions. Depending on whether the issue is ozone or particulate concentrations, this might mean the right pollutant reductions at the right time and location in the city. How effective in improving air quality are the arsenal of PROAIRE measures? Are the improvements short-term, or can they be sustained over many years or decades?

2. Economic Feasibility

Second, of those measures that are "effective," which are "affordable?" Are they "cost-effective" on a narrow accounting basis, or in a broader economic, social and environmental context? What direct and indirect "policy options" promote the "technology options" via technical analysis? How might such policy options be designed to be even more effective? Which are more amenable to market-based versus commandand-control approaches?

3. Political and Institutional Feasibility

Just because quantitative analysis indicates that certain measures are effective from the perspective of economics or emissions reduction, does not mean than politicians can back them or that the business community and the public will accept them. Nor does it mean that the current structure of the MCMA's environmental, transportation, urban planning, and economic development agencies can easily implement them. As we look at longer-term solutions, greater coordination among these agencies will likely be needed. How can they act in the near and long-term to implement the most technically and economically feasible options, including monitoring, enforcement and refinement of those options?

With all these factors in mind, the Mexico City Program has combined several methodological approaches to address these needs. Using the best available information and models, the program has combined Royal Dutch Shell's top-down scenario approach with MIT's fact-finding, scenario-based tradeoff analysis. This synthesis allows researchers to retain the prescriptive capabilities of bottom-up tradeoff analysis of transportation, industry and other end-use focused emissions reduction options, and couple it with the alternative long-term changes in the MCMA's population and economy—including level of affluence and motorization, and urban form. This approach allows the Mexico City Program research team to identify robust, long-term, cost-effective, and, hopefully, implementable combinations of options.

Research to date has focused on the technical and economic feasibility of the various measures. In order to refine and make the analysis more useful, the dialogue phase—to further inform decision makers and vet the better solutions—needs to be further pursued. As the Program advances, improved linkages among the bottom-up emissions modeling, the calculation of changes in pollutant concentrations, and their associated exposure and health impacts are being developed. At the Sixth Workshop on Mexico City Air Quality in January 2003, the MIT Scenarios Team will present the current research, and invites all attendees to make suggestions on how to refine and improve the integrated assessment.

Stephen Connors is coordinator of the MIT Scenarios Team of the Integrated Program on Urban, Regional, and Global Air Pollution. This work is supported with funds from Comisión Ambiental Metropolitana, US National Science Foundation, and MIT/AGS.

Estimating the economic value of reducing health risks by improving air quality in Mexico City

Contributed by James Hammitt and Maria E. Ibarrarán

Environmental regulations aim at reducing mortality and morbidity risks for the population. To determine if the benefits of regulations exceed the costs, it is necessary to estimate the level of expenditure society is willing to pay to prevent an expected fatality within a time period, the so-called "value per statistical life." We report preliminary estimates of the value of reducing several health effects (mortality, chronic bronchitis, cold) in the Mexico City Metropolitan Area. Estimates were obtained using both contingent valuation and hedonic wage methods. Data were collected by personal interview of 1000 respondents in the metropolitan area, 40% in households and 60% at the work place. The estimated value of a statistical life in Mexico City ranges from US\$150–500,000. These results are consistent with the small number of estimates for developing countries found in the literature.

This note is divided into three sections. The first one shows preliminary results of using the contingent valuation method to determine the value of a statistical life (VSL) for adults, the value of a statistical case of chronic bronchitis, and the VSL for children¹. The second part shows preliminary results for the VSL and the value of a statistical injury using the hedonic wage approach. In both sections an econometric analysis is performed to determine what individual characteristics help to explain willingness to pay to reduce health risks. The final section offers some concluding remarks.

1. Results from the Contingent Valuation Study

The main objective is to estimate the value of reducing health risks by improving air quality in the Mexico City Metropolitan Area. We use the contingent valuation (CV) method to find the willingness to pay (WTP) of the individuals for risk reductions. WTP is the amount of money that an average inhabitant will pay to reduce his or her chance of dying in the next year by a specified amount. Dividing the mean WTP by the average risk reduction gives the value per statistical life (VSL), which is the total amount that the inhabitants would be willing to pay to prevent one unidentified, random fatality in the next year. A risk-risk trade-off is also used to test for consistency between the estimated VSL and value per statistical case of bronchitis (Viscusi, 1991). This question asks respondents the maximum risk of an allergic fatal reaction to medicine they are willing to accept to reduce the risk of getting chronic bronchitis.

The mean WTP to prevent a minor illness (cold) is US\$28, the value of a statistical case of chronic bronchitis is US\$30,000 with a WTP to reduce the risk of getting chronic bronchitis of US\$106. The mean WTP to reduce mortality risk for one year

is US\$181; dividing this by the risk reduction, we obtained that the VSL in Mexico City is US\$500,000. This value is in the range of values estimated by extrapolating from US estimates of VSL to Mexico by adjusting for the average difference in income (Evans *et al.*, 2002).

We analyze the main factors that help explain WTP to reduce cold, chronic bronchitis, and adult and child mortality using separate regressions in each case. The general model used for the econometric analyses was:

LnWTP=
$$\beta_0 + \beta_1 C + \beta_2 S + \beta_3 CP + \varepsilon$$

where C are the control variables, S the perceived health variables and CP the personal and economic characteristics of individuals. ε is the error term.

We find that WTP to reduce health risk varies with individual characteristics. To prevent mortality, results suggest WTP increases with family income and is larger for males and younger respondents. WTP to prevent a cold also increases with family income and youth, and is larger for people with a chronic illness and high expenditures on medicines and medical visits. WTP to prevent chronic bronchitis increases with age for young people and decreases for older people.

VSL for children (both infants and teenagers) was higher than that for adults. The VSL for children does not seem to differ between younger and older children, and is estimated as about US\$1 million. WTP to reduce child mortality risk increases with the education of the parents and decreases with parents' age. It is larger for single parents.

2. Results from the Hedonic Wage Study

We examine the relationship between wages and perceived occupational health risks for blue-collar workers in Mexico. We estimate hedonic wage functions to compare workers' wages to their perceived risks for fatal and non-fatal accidents.

We specified the traditional hedonic wage function as:

lnHWAGE = f(RISK, H, W, P) + u

where lnHWAGE is the natural logarithm of the *i*th worker's wage rate, RISK are the perceived risk variables, H describes human capital variables, W are the work environment variables, P includes personal characteristics variables, and u is a random error term assumed to be independently and identically distributed across workers.

Results indicate that workers in relatively risky jobs receive a compensating wage differential, after controlling for human capital, work environment, and personal characteristics.

The estimated coefficients on the perceived fatal- and nonfatal-injury risk variables are not statistically significant when both are included in the regression model, because the two risks are highly correlated across workers. To estimate the VSL and value per statistical injury, we use the results of regression models using only the corresponding risk variable. The estimated VSL is US\$150,000 and value per non-fatal injury is US\$7,300. These estimates are likely to be biased upward, because the additional wages compensate workers for both fatal and non-fatal risks. The estimated VSL is toward the

James Hammittis a professor of Economics at the Harvard School of Public Health; Maria E. Ibarrarán is a professor of Economics at the Universidad de las Américas. ¹ Children were separated into those less than 4 years old (infants) and 4 to 18 years old (teenagers).

lower end of the range extrapolated by Evans et al. (2002) and the value per non-fatal injury is consistent with estimates for other countries and with the cost of treatment estimated by Instituto Mexicano del Seguro Social.

3. Final Remarks

To compare the health benefits of programs to reduce air pollution in Mexico City with the costs of implementing these programs, it is useful to have estimates of the monetary value of reductions in health risk. By surveying Mexico City residents, we can obtain direct estimates of the values they place on reduced health risk. Such direct estimates may be more useful than estimates obtained by extrapolation from other countries, because they account for economic conditions, cultural factors, and preferences of the Mexican people themselves. In future work, we hope to refine the preliminary estimates presented here by critical evaluation and improvement of the econometric models used.

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Report from the MCP's 2nd Mid-Career Workshop

Contributed by Jed Horne

Hotel Vista Hermosa, Tequesquitengo, Mexico. August in Tequesquitengo can be a scorcher, and the clear blue of the swimming pool at this Conquista-era resort looked mighty inviting. Despite a few furtive glances, however, participants at the second workshop for mid-career professionals resisted temptation and quickly got down to brass tacks. The participants, coming from universities, government,

environmental NGOs, and industry, were here to learn. The Hotel Vista Hermosa's ample and luxurious amenities were of secondary importance.

The workshop was organized by the Integrated Program on Urban, Regional and Global Air Pollution: Mexico City Case Study (Mexico City Program) as part of its education activities and was sponsored by the Comisión Ambiental Metropolitana. The week's schedule was divided into two three-day workshops, given by world-class educators in their respective fields. Dr. John Evans, of the Harvard Center for Risk Analysis, began the week with a discussion of risk analysis – a tool for communicating scientific investigations to concerned stakeholders. Dr. Lawrence Susskind, from the Department of Urban Studies and Planning at MIT, led a highly interactive forum on negotiation and conflict resolution—a key component of environmental decision-making, and an area that often draws on risk assessment analysis.

Bleary eyed and still stuffed from the welcome dinner on Sunday night, the participants filed into the hotel's majestic

conference room at 8:30 on Monday morning, eager and prepared for the week ahead.

Introduction to Risk Assessment (August 12–14, 2002)

After brief welcoming remarks from the CAM officials and opening remarks by workshop organizer, Dr. Luisa Molina of MIT, Professor Mario Molina introduced Dr. Evans, who began his presentation by asking three focal questions: What is risk? Can it be studied? And, if it can, how do we use existing evidence to evaluate it?

Noting the diverse background of the workshop's 60-odd participants, Dr. Evans asked them how they would define the "ideal" background for risk assessment. Everyone quickly realized that risk assessment, like the broader problem of air pollution, is truly a multidisciplinary endeavor, one that requires the expertise of chemists, doctors, statisticians, and epidemiologists - fortunately, groups well represented in this extraordinary gathering of people.

Risk assessment, Dr. Evans argued, is an important tool for communicating between these disciplines, streamlining research goals, and facilitating decision making among concerned parties. Of particular relevance to the organizations



Opening plenary session of the Integrated Program's second mid-career workshop.

Jed Horne is an undergraduate research assistant who has worked with the MIT Integrated Program on Air Pollution for the past two years.



Workshop participants learned negotiation techniques at several simulation exercises.

represented in the room, risk assessment can aid decision making in air-pollution management, adding credibility and breadth to cost-benefit analyses that otherwise might lack political backing. Risk assessment also provides a framework to evaluate what assumptions were made behind a particular decision. It is often these assumptions, rather than hard science, that guide policymaking.

There are four stages of risk assessment in public health: hazard identification, exposure assessment, dose-response assessment, and risk characterization. Again, it is often how hazards are labeled, rather than the actual risk they represent, that guides public reaction and, in turn, policy responses.

Dr. Evans continued the workshop by describing the differences between cancer and non-cancer risk assessment. Cancer risk assessment generally assumes a linear relationship between dose and risk. Non-cancer assessment uses a threshold-type dose response curve. Non-cancer risk assessors compute what is known as the NOAEL (no observed adverse effect level) or the LOAEL (lowest observed adverse effect level). These numbers give an indication of a minimum threshold exposure to certain pollutants or toxins, and are used to compute the reference dose (RfD), a value used in policy making to denote maximum accepted values of that chemical. The workshop continued with a thorough and technical discussion of both cancer and non-caner assessment, including methods for low-dose and inter-species extrapolation for bioassays. Epidemiological evidence was also analyzed, and participants learned about the famous "six cities" study showing a relationship between



Drs. Basilio Verduzco Chávez (left) and Lawrence Susskind.

mortality and air pollution in the US.

Following Dr. Evans' introduction to the topic, Paulina Serrano, a doctoral student at Harvard School of Public Health, presented her research on volatile organic compound (VOC) risk assessment in Mexico City. During the course of her research, she collected data from twelve sites around the city. Her presentation generated considerable interest, and a little controversy—not surprising given the participants' expertise and the immediacy of Ms. Serrano's research to the problem at hand.

Ms. Serrano also discussed her research on exposure assessment in the city, again, an area of controversy. The possibility that indoor air pollution is a primary source of exposure to VOCs was raised, questioning some of the assumptions of air pollution control and challenging decision makers to look at microenvironment pollution controls

Roberto Muñoz (subdirector de analisis e información, Secretaria de Medio Ambiente, GDF) also presented the work he had done in the area of public health and estimation of health impacts. The relevance of his specific topic and the controversial nature of his area of research generated methodological and theoretical discussions about valuation, costing, and social perception of control strategies.

Dr. Evans concluded his course by presenting his work in value of information analysis. While it is always true that better information will lead to better decision-making, it is often the case that the cost of obtaining that information and the requisite delay in decision making may outweigh any benefits to acquiring it. Depending on the discount rate, for example, a delay in enacting restrictions on fine particle emissions, created by overly cautious environmental policy, may hurt society rather than help it. Value of information analysis is an important tool for establishing research priorities.

Negotiation and Conflict Resolution (August 15–17, 2002)

On Thursday, Professor Mario Molina was called upon again for an introduction. Dr. Susskind, the Ford Professor of Urban and Environmental Planning at MIT and president of the multinational consulting firm Consensus Building, was joined by Dr. Basilio Verduzco Chávez, a professor in the Department of Regional Studies at the University of Guadalajara.

Professor Susskind began by emphasizing the increasing importance of negotiation and conflict resolution, particularly in contentious disputes where the courts can become involved in the absence of an amicable solution. Dr. Verduzco drew on his immediate experience in Mexico, and commented on the country's rapidly changing political climate. With the emergence of a three-party democratic system, it is now almost impossible to impose a decision without conflict, and negotiation is an increasingly important tool for policy makers and politicians to iron out differences.

The main emphasis of the next three days was three negotiation games, simulating environmental disputes and introducing important concepts in conflict resolution.

In the first simulation, two fictitious countries, Alba and Batia, competed by selling oil to a third, richer country, Capita. Participants were divided into 12 groups, split between Alba and Batia. Each country set prices for what they thought would be maximum benefit given imperfect information about how the other group was making the same decision. After a few rounds, the warring parties were allowed to meet and negotiate fixed prices for maximum benefit.

Of course, many of the agreements were not perfect. Miscommunication, betrayal, and cutthroat decision-making tainted some negotiations, dragging down the gains of both parties.

The conclusion was that the most important characteristics of a successful negotiator in the first game were provocability, forgiveness, and clarity. It is important to punish betrayal or departure from agreements, but it is equally important to forgive sincere retractions of mistakes. A muddled or ambiguous strategy simply leaves the other team at a loss, making agreement nearly impossible.

Dr. Susskind described a "mutual gains" approach to decision-making — a four step process. The first, and perhaps most important step, is preparation. The second is to create value before the division of benefits has been discussed, by making a "larger pie" to compete for. The third is to distribute the value generated during the second step. The final step, often ignored by decision makers, is follow through and enforcement.

Competing parties are looking at the bottom line – what is their best alternative to no negotiation (BATNA)? Here the most important question to ask is "what if?" – with a little imagination, the players will often realize they have more to offer each other than they first realized, probably considerably more than their respective BATNA's. The three aspects of good negotiation – forgiveness, clarity, and provocability, still apply. It is also necessary to be prepared for any unexpected events or surprises that may occur during the negotiation itself or during the final implementation.

To build up to the most important game of the workshop, participants were then divided into groups of three to compete in a small three-party negotiation of the second game, where not all three players had equal bargaining power. The key to success in this second game was coalition building – an important skill during the third, and much more complex, multi-party negotiation game known as Pablo Burford.

In the Pablo Burford simulation, participants were divided into groups of ten. Players were assigned roles as representatives of different government agencies, NGOs, and lobby groups. Together, they were charged with ironing out environmental disputes between a developing country, Pablo, and its developed neighbor, Burford. Participants reported favorable reactions to the game, and appeared to have learned quite a bit by the earlier games and theoretical discussions.

Dong-Young Kim, a PhD candidate under Dr. Susskind's supervision and research assistant with the Mexico City Program, was pleased with the results. "Because I was in charge of filming the workshop, I kept a close eye on the participants. Even with the sizzling heat and long schedules, I didn't catch anybody napping. People took the Pablo-Burford game so seriously they didn't even talk over the enchiladas at lunch," he noted.

Dr. Susskind was equally impressed, commenting, "They committed themselves to often unfamiliar assigned roles and played their parts with skill and passion. I think the skills of negotiation taught in the seminar will be of great importance to many of the participants in their professional roles."

On Sunday, August 18th, the participants had to leave their role as students and return to their real jobs as engineers, lawyers, scientists, and government officials. The conference had been an overwhelming success, and everyone seemed in a good mood on the way out. Maybe it was everything they had learned, but it could have been that a few of the participants had done more than glance at the pool – only in the evenings, of course. Armed with new tools, everyone involved left the serenity of Vista Hermosa better prepared for the considerable challenges ahead.

Acknowledgement. Special thanks to Professor Gerardo Mejia of ITESM, Professor Larry Susskind of MIT, and Dong-Young Kim for contributing to this article.



Workshop participants enjoy lunch in the pleasant gardens of the Hotel Vista Hermosa.

Impact of Soot on Cloud Formation

Contributed by Rosario Guzman, Gustavo Sosa, and Abel Toribio

Why are we paying attention to the properties of soot that involve water? This question sounds trivial: health and visibility problems related to high concentration of soot are familiar enough. However, there is a process associated with soot's geometry that has defied our intuition.

Soot is a black carbonaceous substance produced during incomplete combustion of coal, wood, oil, etc., rising in fine particles that adhere to and blacken surfaces on contact. It is hydrophobic (that is, it does not absorb water). In fact, the soot-water contact angle is around 80°. Contact angle measures "how much a substance wets a surface," thus a small contact angle reflects hydrophilic (strong affinity for water) surfaces, while a large contact angle indicates a hydrophobic surface.

Until recently, soot was modeled as a sphere having properties equivalent to those of the real particle. This model confirmed our intuitive idea with respect to the amount of water able to condense on soot's surface: it was insignificant, and increasing this amount required extremely supersaturated air. Let us not forget though that these conclusions depend strongly on the model used, and that soot is far from having a spherical contour.

In 1996, Xie and Marlow from Texas A&M University investigated the effect of substrate surface curvature on water equilibrium vapor pressure. Figuring out what they called "complex aerosols" (two to four identical spheres stuck together, fixed in ten different configurations), they determined the water volume content as a function of relative humidity. In order to do this, they used "Surface Evolver," a free access program available in the Internet. Evolver is a program that minimizes the energy of a system subject to forces and restrictions specified by the user. In this way, Xie



Figure 1. Soot aerosol particle. Left, experimental photograph. Right, MIT-CAM team's simulation: fractal aggregate of 64 primary particles and fractal dimension 1.7.

R. Guzmán, A. Toribio, Escuela Superior de Ingeniería Química e Industrias Extractivas del IPN; G. Sosa, Programa de Investigación en Medio Ambiente y Seguridad, Instituto Mexicano del Petróleo. Figure 2. Water uptake in a fourprimary-particle a g g r e g a t e . Here we show one of the 10 geometrical configurations studied by Xie. The MIT-CAM team simulated water condensation over a substrate of contact angle 60° using Surface Evolver.



and Marlow determined the equilibrium thermodynamic conditions for an air-water-substrate system subject to waterair surface tension. The results revealed strong sensitivity of vapor pressure with regards to surface geometry; one of the more relevant results can be understood as soot able to absorb limitless water amounts.

In 1979, Forrest and Witten noticed the fractal nature of several aerosol particles such as metals, metal oxides, silicon dioxide and soot, which are formed by aggregation of small, nearby spherical particles (that we will call "primary particles"). A fractal is a mathematical concept that "qualitatively can be described as a rough object such that its roughness appears at any scale" (Jullien and Botet, 1987). This quality can be accounted for by a quantity called fractal dimension, "which do not have any reason to be an integer" (contrary to the dimension of a smooth curve or surface, Figures 1 and 2 respectively). Although perfect fractals do not exist in nature, irregular fractal-like shapes do. Such is the case of fractured surfaces, ecological systems, cloud profiles, "the intricate arrangement of flying-bird-wing feathers" (Stoyan and Stoyan, 1994), and fresh soot. This last has a fractal dimension between 1.7 and 1.9.

In 1996, Thouy and Jullien proposed an algorithm to generate fractals of fractal dimension between 1 and 2.55, and an arbitrary number of primary particles. In nature, particles stick together in different ways, such as one particle to another, a particle to an aggregate, or an aggregate to another aggregate. Thouy and Jullien used the aggregate-aggregate mechanism as it better reflects soot's aggregation processes.

In 2002, Toribio and Guzman developed an aerosol simulation system based on Thouy and Jullien's algorithm. Once this simulation system was available, Sosa (2002) and Guzman *et al.* (2002) investigated if Xie's aerosols appear in "real" fractal-like soot aerosol particles and if they do, how frequent they are. The answer was "yes, several of those 10 geometrical configurations are present." As some may know, cloud condensation nuclei (CCN) must be available in the atmosphere for clouds to grow. Traditionally, CCN were considered to be hydrophilic particles. Nevertheless, after their findings, Guzman *et al.* predict that soot is able to become CCN, and they provide an estimated value for the relative humidity necessary. Therefore, we come to important conclusions: thanks to its roughness, soot absorbs more water than we thought; moreover, it has the capability to form clouds under conditions commonly encountered in the atmosphere. (Geometrical properties "against" physical properties).

What properties do these "new" clouds possess? What effect do they have on Earth's energy budget? If soot absorbs water, it probably absorbs other substances too. Does this property affect people's health? Does it influence particle chemistry? These and other questions are being investigated as part of the MIT-CAM Project.

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Master Program on Environmental and Health Management for Mid-Career Pro-

fessionals (Right) The Master Program on Environmental and Health Management, a joint initiative of Mexico's Ministry of the Environment and Natural Resources (SEMARNAT), MIT's Integrated Program on Air Pollution, and the Harvard School of Public Health, officially began in the summer of 2002. Three students are presently enrolled: Araceli Vargas and Armando Yanez from INE, and Antonio Perez (right) from the Ministry of Energy.





Juan-Pablo Montero (below), Professor of Economics from the Department of Economics at the Catholic University of Chile, presented the inaugural lecture of the joint Mexico City Program and MIT-Harvard Seminar Series on Environmental Management. The title of his lecture was, "Market-Based Environmental Policies to Control Air Pollution in Santiago-Chile: Experience and future directions."



GURME Expert Workshop on Air Quality Forecasting (Left) On October 24-26, 2002, the Integrated Program hosted the GAW Urban Research Meteorology and Environment (GURME) Expert Workshop on Air Quality Forecasting. Twenty-five participants from eleven countries attended the three-day workshop, held in Cuernavaca, Mexico. WMO/ GURME and NOAA co-sponsored the event.



Integrated Air Quality Study of Monterrey Metropolitan Area: Planning Workshop

Contributed by Gerardo M. Mejía Velázquez

Introduction

A planning workshop for the Integrated Air Quality Study of the Monterrey Metropolitan Area (MMA) was held on 13 November 2002 at the Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM). Thirty-five people participated in the day-long event, which was jointly organized by the MIT-based Integrated Program on Urban, Regional and Global Air Pollution, under the direction of Drs. Mario and Luisa Molina, and by ITESM, under the direction of Dr. Gerardo Mejía.

Drs. Molina and a group of Mexican and US researchers are currently studying the air quality in the Mexico City Metropolitan Area (MCMA) as a case study of the Integrated Program. This Program is the first to employ an integrated assessment methodology, bringing researchers from diverse fields together to develop a coordinated air quality strategy that takes into account technical, economic, social and political issues. Specific areas of study include: scientific issues related to monitoring efforts and pollutant characterization, emission inventories, health assessment studies, air quality models, evaluation procedures for control strategies, social and policy issues, and education and outreach efforts. The objective is to identify the most promising and robust strategies, considering cost-benefit criteria and flexibility of implementation and operation under various environmental and economic conditions, in such a way that guidelines and recommendations can be given to decision makers to prevent and control air pollution.

The Integrated Program on Air Pollution is now expanding its area of research beyond Mexico City to other regions of Mexico, with the Monterrey airshed scheduled to become the next focus of research. Workshop participants included Drs. Molina and researchers from ITESM and the Universidad Autónoma de Nuevo León, representatives from SEMARNAT, the Subsecretaría de Ecología of the Government of Nuevo Léon, and individual municipalities within the MMA (Monterrey, Santa Catarina, San Pedro Garza García, Guadalupe, Apodaca, Escobedo, and San Nicolás de los Garza), as well as research assistants and a representative of CEMEX.

Workshop Presentations

Dr. Alberto Bustani Adem, Rector of ITESM, formally opened the proceedings, followed by Julián de la Garza Casto, Subminister of Ecology of the Government of the State of Nuevo León.

The Subsecretaría de Ecología presented an overview and led a general discussion on air quality issues in the MMA. Next, Dr. Mario Molina discussed the ongoing MCMA case study, answering questions regarding the integrated assessment methodology, the purpose of the MCMA study, and its applicability to the MMA airshed. Several presentations on health issues then correlated air pollution levels with hospital visits, toxicology, and effects of biogenic pollutants.

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Other presentations focused on the physical and chemical characterization of pollutants, air quality modelling, data management and visualization, and health and modelling data integration and their link to economic studies to estimate cost and benefits of proposed strategies. In the closing session, economic evaluation tools, environmental legislation, and environmental education issues were discussed. The need to develop environmental education material and programs was emphasized, in order to reach the general public and build awareness of the air quality problem in the MMA. Finally, initial research priorities were identified, including particle characterization, hydrocarbon speciation, pollutant monitoring, emission inventory actualisation, air quality modelling, health effects studies, design and development of databases and information management, economic evaluation of air pollution impacts, legal mechanisms and economic incentives, and social communication and educational material development for different segments of society.

Next steps for the MMA include a report on the workshops results and advocacy to federal and state authorities to include the MMA study in its environmental agenda. A follow-up meeting will be organized with members of the working group to identify potential funding sources and set research priorities for the next several years.

The MMA Airshed

Since the implementation of the Sistema Integral de Monitoreo Ambiental (SIMA) in 1993, when air quality in the MMA first began to be monitored at five automatic monitoring stations, data has indicated that the MMA has PM10 and ozone air pollution problems. Annual average PM10 concentrations have exceeded standard concentrations of 50 µg/m³ for each year except 1997, when an average of $42 \,\mu g/m^3$ was reported. However, this is an average value for the MMA; areas exist with both higher and lower average concentrations. For 2001 and 2002, the SIMA reports that the average annual concentration values rose incrementally, reaching 59 and $120 \,\mu g/m^3$. This may represent serious chronic problems in vulnerable populations, particularly children. From 1993 to 2001, the daily PM10 average standard of 150 μ g/m³ was exceeded 30 to 90 days per year. In the case of ozone, the hourly air quality standard of 0.11 ppm was exceeded for ~10% of the years from 1993 to 2001. Over the last three years, the MMA has shown a dramatic increase in the size of its vehicle fleet, and significant industrial and population growth. It is important to study the MMA airshed and take corrective actions before the problem becomes worse. The MCMA case study shows that improving air quality is a complex and expensive effort. The MMA can forestall a worsening crisis by means of an appropriate administration of the air shed. The development of this project will generate the necessary information to support adequate decisions to prevent major air quality problems.

As part of the workshop's outreach efforts, Dr. Mario Molina gave a presentation on "Impact of Human Activities in the Atmosphere," sponsored by the ITESM-SEMARNAT Program on Sustainable Development. The presentation was held in ITESM's Sala Mayor de Rectoría and was transmitted by the Virtual University of ITESM to other locations in Mexico.

Labor Conditions for Taxi Drivers in **Mexico City**

Contributed by Luis Arturo Rivas Tovar and Jorge Esteban Rocha

Although efforts to introduce public transportation in Mexico City started as early as the colonial period, large-scale programs date only to the second half of the 19th century, when the government granted a concession to build a tramline from Mexico to Tacubaya. Taxi service is even more recent, beginning in 1915 when vehicles for hire first became widespread in the city.

With the disappearance of trams, other means of transport took their place, including buses, trolleys, and peseros, which came out in the 1960s. At the end of the 1960s, the construction of the first line of the Metro subway system offered some hope that large-scale public transportation had indeed started in Mexico City. In 1971, big taxis were replaced with the first 500 units of the popular vochos, giving birth to the minitaxis that substituted for the well-known crocodiles of the 1950s.

Public transportation in Mexico City, however, was weakened during the administration of President Zedillo with the elimination of Ruta 100, a metropolitan bus network introduced in 1982. Although it captured about 25% of total demand, the elimination of Ruta 100 favored the expansion of low-capacity transport, which now accounts for roughly 75% of total trips.

Currently, following the administrations of two governments led by the Partido de la Revolución Democrática (PRD), little significant progress has been made regarding problems of disorganization, corruption, and patronage that have left associations of taxis and independent taxi drivers hostage to diverse political groups.

According to research carried out in E.S.C.A Santo Tomás at the Instituto Politécnico Nacional de México (IPN), the authors of this paper learned that there are 104,694 legal and 22,000 illegal taxis (pirates) in Mexico City, creating the largest fleet of taxis in the world. By comparison, just 16,000 taxis are licensed to operate in Madrid.

The above-mentioned research used the ethno-biographical method and interviews within a sample of 185 taxi drivers. This allowed us to draw a socio-demographic profile of taxi drivers in Mexico City:

Taking all this into consideration, it is possible to draw a profile of an average taxi driver in the city of Mexico.

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México (I.P.N.), and Invited Professor at Universidad Politécnica de Madrid. Jorge Esteban Rocha is a professor at the Instituto Politécnico Nacional de México (IPN); his research has focused on megalopolis administration.

- 56% are the sole source of income for their family
- 69% contribute to the family expenditure with an amount that ranges from 100 pesos (10 US\$) to 200 pesos (20 US\$) a day

Taxi driver profile

- A 42-year-old man, born in Mexico City, who has been working for 10 years as a taxi driver, has secondary studies and is married with two children. He works 10 hours a day, works split shifts, and earns the equivalent of three minimum wages. His family depends on him economically and he contributes 200 pesos per day to family expenses. He does not trust public authorities and believes they do not do enough to face the problem of illegal or pirate taxi drivers.
- His social origins, his means, and his living standard place him within the lower-middle class.

This work demonstrates that urgent, vigorous actions are needed to reorganize public transport in Mexico City, particularly within the taxi sector. Further research is required to confront the dilemma of these workers in their different categories: free, limited to particular places, pirates, etc. All are subject to levels of insecurity, exploitation, and working and living conditions that should be intolerable in a country respectful of the rights of its citizens.



Socio-demographic profile

- 25% have been working from 5 to 10 years as taxi drivers
- 78% are married
- 44% have primary and secondary education •
- 70% work from 5 to 10 hours a day
- 58% do mixed shift work
- 70% do not have social security
- 58% are not entitled to a pension
- 74% lack paid holidays
- 78% do not receive Christmas gifts
- 36% are between 36 and 49 years old
- 99% are men
- 94% were born in the Federal District
- 86% have their residence in the Federal District
- 52% have a monthly income 1 to 3 times the minimum wage (about 42 pesos)
- 53% are financially responsible for at least one dependent
- 51% own their taxi

[•]



Loading dock of truck terminal.

Re-Inauguration of IM Laboratory

(Left) Dr. Claudia Sheinbaum, Secretary of the Environment for the Federal District, together with Drs. Mario and Luisa Molina and personnel of the IM-240 Laboratory for Vehicle Emissions, during the lab's re-inauguration on September 27, 2002.

(Bottom) Lab personnel demonstrating testing vehicle procedures.

Comparative Study of Diesel Exposure in North America

Another activity of the Integrated Program Mexico City Case Study involves a pilot study of diesel exhaust exposure in the Mexico City area, to investigate if the incidence of lung cancer in trucking company employees can be linked to their personal exposures to diesel exhaust. This MIT-HSPH pilot study, with collaboration from RAMA, is an extension of an HSPH project being conducted in clusters of both large and small trucking terminals and related truck routes in many locations throughout the United States, as well as in some terminals in Canada. It is sponsored by the North American Commission on Environmental Cooperation and MIT/AGS.



Cabs of diesel truck going on delivery routes.

The Program plans to extend this pilot study to assess the feasibility of developing a national database of physical exam results for transportation workers who are exposed to diesel exhaust, and to relate this database to various health outcomes (mortality, health care utilization, etc.) This study will involve the participation of Mexican health experts from several institutions as well as the collaboration of the Secretariat of Communications and Transportation (SCT), the trucking industry, and the Social Security Administration.





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