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Mexico City Air Quality Research Initiative

Volume V
Strategic Evaluation

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MASTER

Volume V
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ACRONYM LIST

BAR	Bureau of Automotive Repair
CC	Catalytic Converter Option
CFE	Comisión Federal de Electricidad (Federal Electricity Commission)
CNG	compressed natural gas
DDF	Departamento del Distrito Federal (Federal District Department—Mexico City Government)
DF	Distrito Federal (Federal District)
EdoMex	Estado de México (State of New Mexico)
EKMA	empirical kinetic modeling approach
FOM	figure of merit
GAS	Natural Gas Option
HOTMAC	computer program for air flow
IM	inspection and maintenance
IMECA	Indice Metropolitano de Calidad del Aire (Metropolitan Air Quality Index)
IMP	Instituto Mexicano del Petróleo (Mexican Petroleum Institute)
JICA	Japan International Cooperation Agency
LANL	Los Alamos National Laboratory
LP	linear program
LPG	liquified petroleum gas
MADT	Multi-Attribute Decision Theory
MARI	Mexico City Air Quality Research Institute
MCMA	Mexico City Metropolitan Area
MTBE	methyltertiarybutyl ether
OECD	Organization for Economic Cooperation and Development
PEMEX	Petróleos Mexicanos (Mexican Petroleum Company)
PICCA	Programa Integral Contra la Contaminación Atmosférica (Integrated Program Against Atmospheric Contamination)
RVP	Reid vapor pressure
SCAQMD	South Coast Air Quality Management District
SEDESOL	Secretaría de Desarollo Social (Secretariat for Social Development)
SOGELERG	French consulting firm
SSA	Secretaría de Salud (Secretariat for Health)
STE	Electric Transport Service
WAG	weighted average grade

A. INTRODUCTION

Members of the Task III (Strategic Evaluation) team were responsible for the development of a methodology to evaluate policies designed to alleviate air pollution in Mexico City. This methodology utilizes information from various reports that examined ways to reduce pollutant emissions, results from models that calculate the improvement in air quality due to a reduction in pollutant emissions, and the opinions of experts as to the requirements and trade-offs that are involved in developing a program to address the air pollution problem in Mexico City. The methodology combines these data to produce comparisons between different approaches to improving Mexico City's air quality. These comparisons take into account not only objective factors such as the air quality improvement or cost of the different approaches, but also subjective factors such as public acceptance or political attractiveness of the different approaches. The end result of the process is a ranking of the different approaches and, more importantly, the process provides insights into the implications of implementing a particular approach or policy.

The methodology accomplishes the comparison by modeling the initial stages of the process that occur when a general policy statement is converted into a specific set of laws, regulations, etc. designed to carry out the stated policy (Figure A.1). For example, if a government policy was issued that stated overall air pollution must be reduced by 50% before the year 2000, the first step toward implementation of the policy would involve developing a series of regulations, proposed laws, etc. If these measures were enacted, it would be anticipated that they would reduce the pollution to the desired level. The next step in the procedure would involve sending this package of measures, laws, etc., to cognizant organizations for review and comment. In actual practice, this would start an iterative process where, based on comments, the package would be modified until the various groups reached a consensus. Because our task was to develop a tool that could be used by appropriate officials to determine the implications of implementing a particular policy rather than a tool that gives a specific recommendation as to which options to use, the model does not include the process of reaching a consensus.

The Task III team used the linear program (LP) method to model the process of selecting a group of options to carry out a policy. This group of selected options was then defined as a strategy. The selection process was represented in the LP method as an optimization problem subject to a series of constraints. For example, the LP process would select a group of options that would minimize some total attribute of the strategy such as total cost, subject to the requirement that the pollution levels be reduced to a specified point. This modeled the real life process where a staff would select a series of measures to implement a policy based on the cost-effectiveness of each option. The next step in the methodology was to use decision analysis to evaluate the policy by examining relevant issues such as cost, air quality improvement, political acceptability, technical feasibility, etc. Decision analysis can be compared to circulating a policy package for review. The decision analysis framework developed by the Mexico City Air Quality Research Initiative (MARI) team evaluates the policies based on the effect on imports, implementation requirements, cost distribution between the various economic sectors, cost, air

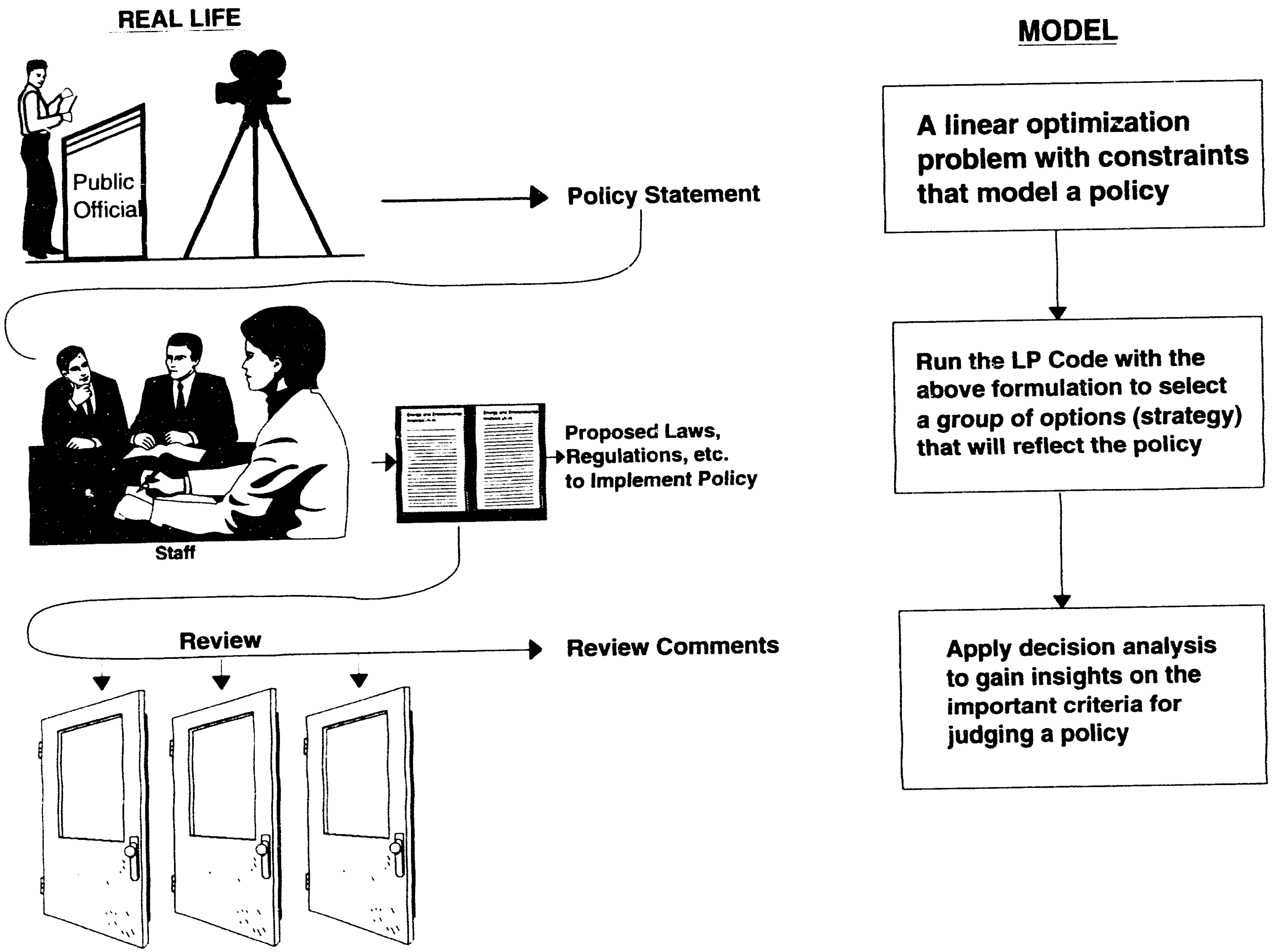

Figure A.1. A schematic illustration of the approach taken in the strategic evaluation task. The methodology that was developed (described on the left-hand side) models the "real life" process (shown on the right) of developing measures to implement policy.

quality improvement, etc. MARI's decision analysis framework also involves examining subjective factors such as political and public acceptance of a policy, the administrative capability required to implement the policy, etc. A full description of the issues or criteria that are evaluated in the MARI decision analysis appears in the decision analysis section (Section H).

Strategic evaluation is a mechanism for comparing hypothetical policies without requiring a staff to select measures to implement the hypothetical policy. This allows a larger number of policies to be evaluated without the lengthy and costly procedure of a staff selecting measures for each policy. The methodology also provides accountability because all the steps involved use clearly stated rules and procedures. Thus, the reason a particular result was obtained can be traced back through the methodology. This methodology will not, of course, reproduce exactly the results that would be obtained in a real life situation, but it does produce a specific group of options or a strategy that has many of the same attributes that the measures in an actual policy implementation would have.

The limiting factor in the application of the methodology is the lack of complete data, a common problem in situations where air pollution problems are being addressed. Sufficient data do exist to begin the analysis of different approaches to improving air quality in Mexico City, but there can be increasing confidence in the results as better data become available and if information on additional options is available. Data from sources other than Mexico City will also need to be refined for specific Mexico City conditions. The examples given in this report are based upon a sample case designed to illustrate the methodology.

B. EVALUATION PROCESS

1. Process Flow

Figure B.1 presents a picture of the information flow through the strategic evaluation process. The starting point in the process is a list of options gathered from reports that examine ways to improve air quality in Mexico City. Associated with each option is the cost of implementation and a projected reduction in pollutant emissions obtained from the above mentioned reports. The emission reduction information is used in the air quality models to determine the air quality improvement that will result from the reduction of emissions.

The list of options, associated cost of implementation, and air quality improvements are utilized by the LP analysis to develop groups of options or strategies. The choice of options is based on the formulation of a particular policy as an optimization problem subject to a series of constraints. The group of options (defined as a strategy) selected are specific actions that could be implemented to carry out a hypothetical policy.

The strategies are compared with each other using decision analysis. A decision analysis tree, which is the structure for proceeding through the decision analysis process, contains the criteria for scoring the various strategies with a weight that is the indicator of the importance of the various criteria. During the decision analysis process all factors; technical, economic, environmental, and social/political are considered in the evaluation. The estimated air quality improvement from implementing the strategies was calculated using 3-D air quality analysis codes. Subjective factors were determined using a panel of experts from various organizations charged with improving air quality in Mexico City. Organizations represented on this panel include the following: Instituto Mexicano del Petróleo (IMP), Departmento del Distrito Federal (DDF), Petróleos Mexicanos (PEMEX), Comisión Federal de Electricidad (CFE), Estado de México (EdoMex), Secretaría de Desarrollo Social (SEDESOL), Secretaría de Salud (SSA), and Los Alamos National Laboratory (LANL).

The panel of experts (Table B.1) attended a series of meetings to develop, refine, and apply the decision analysis methodology. The initial meetings generated the decision tree by establishing the important criteria that should be used to judge the various strategies and the weight or importance that should be assigned to each criteria. Two options were then evaluated using the established decision tree to test whether methods to measure the different criteria were practical and whether the assigned weights reflected the consensus of the panel of experts. After this test, the panel revised parts of the decision tree. The panel was used again in the final analysis to assign values for the various criteria for the strategies being evaluated.

The end result of the strategic evaluation is a comparison of strategies that gives the rank of each strategy and compares the different criteria for each strategy. Thus the strategic evaluation provides insight into the implications for implementing a particular policy for improving air quality.

2. Options and Data Collection

The first step in the evaluation process was to identify as many options for reducing pollutant emissions in Mexico City as possible. These

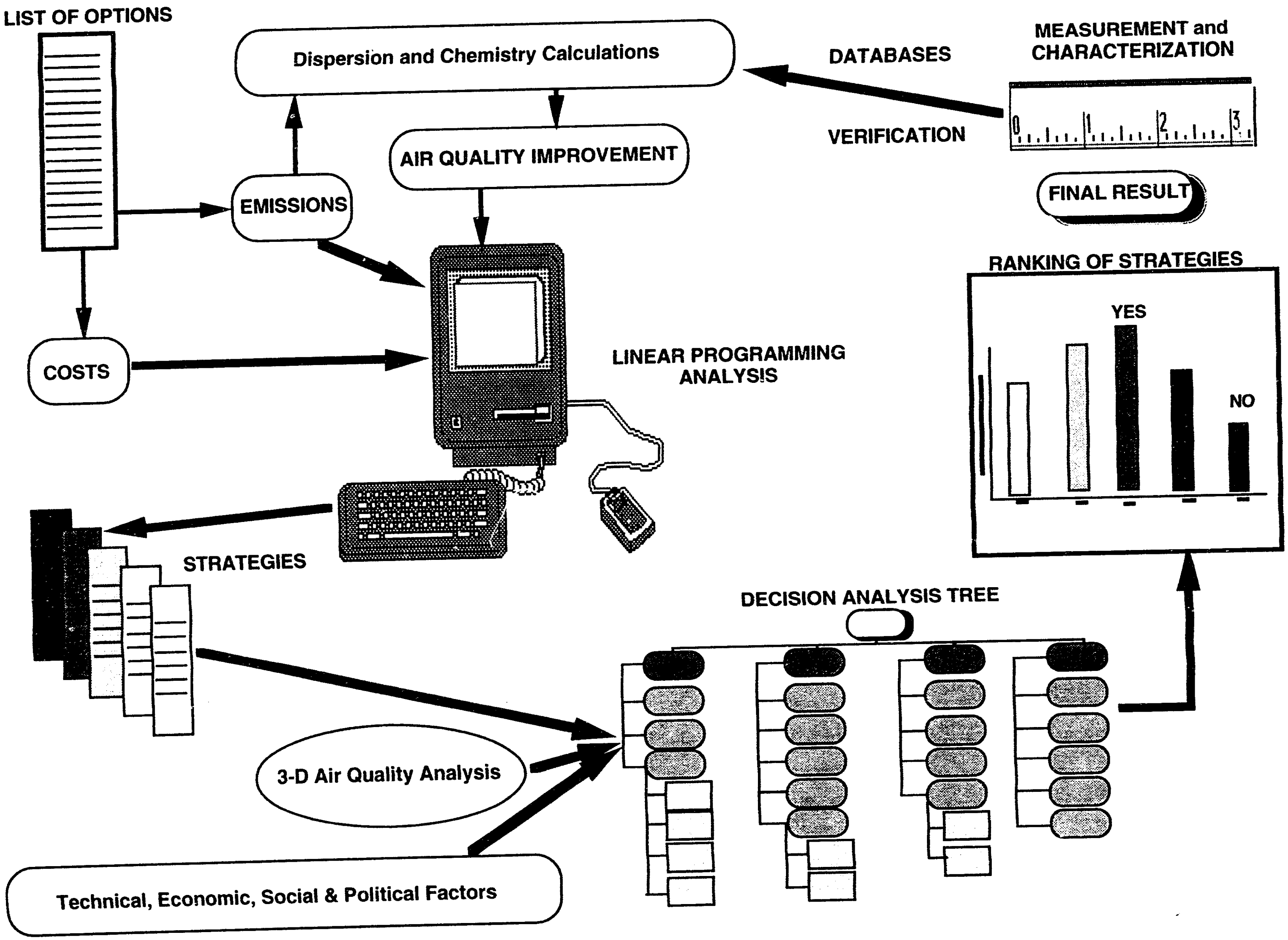

Figure B.1. Schematic illustrating the information utilized in the strategic evaluation and its flow through the methodology and the results obtained from different parts of the methodology

TABLE B.1 List of Personnel that Attended Meeting of Experts

Organ.	Name	Organ.	Name
CFE	Fis. Alberto Carlos	IMP	Ing. José Manuel Olivares
DDF	M. en C. Porfirio Aldana Torres	IMP	M. en C. Bulmaro Valdés P.
DDF	M. en C. Martha Barbiaux	LANL	Dr. Gary Thayer
DDF	Ing. Francisco Bueno Zirion	LANL	Ing. R. Wayne Hardie
DDF	Ing. Rodolfo Lacy T.	PEMEX	Ing. Cutberto Azuara Pavón
DDF	Srta. Ma. Angélica Muñoz López	PEMEX	Ing. Rey Carpio Guerrero
DDF	Ing. Hipólito Pérez	PEMEX	Biol. Mari Cruz Rosas
DDF	Lic. Agustín Sánchez Guevara	PEMEX	Biol. Rosa Ma. Fernández
DDF	Sr. José Antonio Ortega	PEMEX	Ing. Jesús Gamboa Rodríguez
EDOMEX	Lic. Ivico Ahumada Lobo	PEMEX	Ing. Juan Carlos García G.
EDOMEX	Ing. Modesto Fernández Gutiérrez	PEMEX	Ing. Ignacio Abdiel Garduño
EDOMEX	Ing. Antonieta Martínez Velasco	PEMEX	Ing. Ana de Gortari
IMP	Dr. Adrián Barrera Roldán	PEMEX	Ing. Artemio Juárez Martínez
IMP	Ing. Ignacio Cahue López	PEMEX	Ing. Héctor López Guerrero
IMP	Ing. Angel Cerezo Moreno	PEMEX	Dr. Luis Macías Chapa
IMP	Ing. Fernando Fuentes	PEMEX	Biol. Laura Moreno Rivera
IMP	Ing. Armando Galindo	PEMEX	Ing. Michelle Mouret Zuazua
IMP	Ing. Leopoldo Gómez Díaz	PEMEX	Ing. Ricardo Torres Villalobos
IMP	Ing. Emanuel González	SEDESOL	Arq. René Altamirano
IMP	Dr. Francisco Guzmán	SEDESOL	Dra. Cristina Cortinas
IMP	Ing. Delfino Guzmán Villanueva	SEDESOL	Dr. Xavier Garzón Cárdenas
IMP	Lic. Angel Juárez Garrido	SEDESOL	Ing. Mariano Montes González
IMP	Lic. Roberto Lañas Mollinedo	SEDESOL	Dr. Víctor Hugo Páramo
IMP	Ing. Abraham de Luna Q.	SEDESOL	Ing. Gabriel Pérez Zaguilan
IMP	Ing. Moisés Magdaleno Molina	SEDESOL	M. en C. Carlos Sánchez
IMP	Arq. Ma. Esther Medel Ortega	SEDESOL	Lic. Francisco Valadez Morales
IMP	Ing. Jorge Pérez Munguía	SSA	Dr. Bonfilio Muñoz
IMP	Ing. Claudio Santos Núñez		

options were obtained from reports from DDF (PICCA 1990 & AQMP 1991), the World Bank (World Bank 1992), and the Japanese (JICA 1991). Also options that were being considered by the South Coast Air Quality Management District (SCAQMD) in California U.S. that were appropriate for Mexico City were included in the possible list of options. (See SCAQMD 1989 and 1991 IV-A.) The list of options considered for this project is listed in Table B.2.

Once a list of the options had been generated, data on the costs and the emissions reductions associated with the options were obtained for as many of the options as possible. Again the information for the costs and emissions reductions was primarily obtained from the reports that analyzed the various options. Additional information was obtained from SCAQMD analyses and consultation with other experts in the field. The cost data were normalized by calculating an annualized cost for the options. This consisted of adding the annual operating cost to the annualized capital cost. The annualized capital cost was assumed to be the annual payments necessary to pay back an initial loan equal to the initial costs for the option. The payback period

TABLE B.2 Options Identified for Improving Air Quality in Mexico City

OPTIONS FROM PROGRAMA INTEGRAL (PICCA 1990)

1. Produce gasoline conforming to international standards
2. Produce low sulfur diesel
3. Produce low sulfur fuel oil and gasoleo (combination of fuel oil and diesel)
4. Expand Ruta 100 (Mexico City's public bus system)
5. Authorize expanded bus routes
6. Continue day-without-a-car program
7. Expand the verification program for gasoline and diesel vehicles
8. Convert public vehicles and delivery trucks to LP gas and install catalytic converters
9. Retrofit catalytic converters on minibuses
10. Require recent model taxis (newer than 84) and combi's * (newer than 80)
11. Substitute natural gas for fuel oil in industry
12. Clean and/or relocate the foundries in the Valley of Mexico
13. Improve combustion and install control equipment on small boilers
14. Substitute natural gas for fuel oil in Mexico City and the Mexico Valley power plants
15. Implement a program to reforest Mexico City and the Mexico Valley

DDF PROGRAMS (AQMP 1991)

16. Remove very obviously polluting cars and prevent them from entering city
17. Reduce electricity production in the Mexico Valley by 30%
18. Prohibit all open burning
19. Limit use of paints and finishes in industries that don't control vapors
20. Limit operation of closed trash burners to optimum time of day
21. Relocate polluting industries
22. Install vapor recovery systems in filling stations (both storage and delivery)
23. Reduce circulation of official vehicles by 30%
24. Prohibit parking on selected streets
25. Eliminate restrictions on operating hours for some commercial companies
26. Extend the operating hours of Ruta 100
27. Encourage nighttime deliveries
28. Require private enterprises to maintain their fleets
29. Require private enterprises to promote environmental programs with employees
30. Promote the use of bicycles

SOGELERG SUGGESTIONS (AQMP 1991)

31. Coordinate traffic lights to speed flow of traffic
32. Implement information system on traffic conditions
33. Construct and police parking lots next to public transportation stations
34. Improve taxi efficiencies by use of taxi stands
35. Create toll streets and roads for single passenger vehicles
36. Control and increase fees on parking lots
37. Construct Line 8 of the Metro
38. Improve electric transport (trolleys)
39. Improve public transportation image
40. New assessment on the advantages of public transportation
41. Better organization of traffic and parking in the Central Historical District
42. Political support for financial support of public transportation

*Taxis are cars with taxi license plates and generally with distinctive paint schemes. Combis are cars, minivans, vans or other vehicles licensed to carry fare-paying passengers. The numbers of both are restricted by the government.

TABLE B.2 Options Identified for Improving Air Quality in Mexico City (Cont.)

SCAQMD OPTIONS
43. Reduce emissions from metal cleaning and degreasing
44. Require radial tires on light duty trucks
45. Reduce emissions from dry cleaning
46. Control emissions from commercial charbroiling
47. Control emissions from woodworking operations
48. Control emissions from utility equipment (lawn & garden, etc.)
49. Control emissions from large commercial bakeries
50. Control emissions from livestock waste
51. Control fugitive emissions from construction of roads & buildings

ADDITIONAL OPTIONS
52. Use of "feebate" system for taxing new cars
53. Purchase of old polluting cars
54. Continue to require catalytic converters on automobiles
55. Convert gasoline trucks to compressed natural gas (CNG)
56. Require gasoline trucks to conform to 1993 standards
57. Replace gasoline trucks not suitable for conversion to CNG or liquified petroleum gas (LPG)
58. Pave roads

LEVEL 1 EMERGENCY MEASURES
59. Suspend use of 50% of official vehicles
60. Suspend services (public baths, dry cleaning, and painting)
61. Use policemen to speed traffic flow
62. Suspend street maintenance and official construction
63. Suspend asphalt production
64. Promote the non-use of badly polluting autos

LEVEL 2 EMERGENCY MEASURES
65. Suspend activities in non-essential commerce and entertainment
66. Add a second day without a car
67. Suspend all construction and demolition activities and construction material transport

was assumed to be the particular lifetime of the option. The annualized capital costs were calculated using a real (actual rate minus inflation rate) interest rate of 5%. Since the annual operating costs are assumed to be constant and the annualized capital cost does not consider inflation, the annualized cost given for the options is the cost per year, in constant dollars, that would be required to implement an option. This is an approximate way of determining the cost impact for the options. However, this approximation is only used in the screening process to generate a group of options. Once a group of options has been considered, the impacts of capital versus operating costs, economic sector that pays, etc. are evaluated in the decision analysis segment of the methodology.

Information in Table B.2 formed the database for the Linear Program and Decision Analysis exercises. We were not able to obtain the required information for all the options because of a lack of published data or emission information. Thus, effort is needed to generate a option list complete with the associated data (a more detailed description of the data collection process is given in Section F). Appendix A contains a summary of the derivations of the cost and emission reduction information for each option that had information available. A list of the options for which we were able to obtain usable data is given in Table B.3. These options formed the base we used in the selection and analyses of strategies.

3. Linear Programming (LP) Analyses

The LP method selects a specific group of options to represent a policy that could be used in attacking the air pollution problem in Mexico City. The initial step is to state the policy in terms of an optimization problem and then decide on the restrictions that apply in the particular case. This puts the problem in a form that can be coded in the LP. In the example presented in the introduction, reduce pollution by 50% before the year 2000, the problem would be formulated subject to constraints. This would be done by requiring the LP program to minimize cost by selecting the least costly set of options. This selection would be subject to the constraint that the concentration for each pollutant be reduced to one-half of its initial value. This assumes that the data given for emissions reductions is the amount of reduction that can be achieved by the year 2000.

The LP allows the user to model many different policies and methods for selecting groups of options. Factors other than cost could be used to select the groups of options. For example, the problem could be formulated to select the options that would reduce pollution the fastest, subject to a constraint on the amount of funds available, or the formulation could select a group of options that produce the maximum political attractiveness, again subject to cost constraints. An example of the equations used to select the most cost-effective options is shown in Figure B.2.

The next step is to run the LP using the above criteria to select a group of options which will be a potential strategy. In the above example, we assume that the least costly set of options would represent the package of measures, proposed laws, etc., that would be developed by a staff charged with implementing the proposed policy. We assume for this case that the staff starts by selecting those measures that are the most cost-effective and continues down the list until the desired reduction in pollutants is achieved. If the staff decided to preferentially reduce emissions from industrial sources, this could also be modeled using the LP and a different strategy or set of options would be obtained that would model this bias.

We have assumed in the modeling of these various policies that the options can be ranked according to their cost-effectiveness in reducing ozone levels in Mexico City. A cost-optimized policy is modeled by selecting the options starting with the most cost-effective option and proceeding to options with larger cost/benefit ratios until the group of options will succeed in reducing the pollution to a specified level. The effectiveness of each option or the amount each option would improve the air quality was estimated assuming that it was part of a total package that was implemented. This is especially important for examining ozone effects because ozone reductions are not linear with respect to emissions reductions. If the reduction in ozone was calculated simply for a single option, the effect would probably be very small. However, when the option is part of a total package to

TABLE B.3 Options where Enough Data were Available for Timely Consideration in this Project

PRESENT OPTIONS FROM PICCA 1990

1. Produce gasoline conforming to international standards
2. Produce low sulfur diesel
3. Produce low sulfur fuel oil and gasoleo
4. Expand Ruta 100
5. Authorize expanded bus routes
7. Expand the verification program for gasoline and diesel vehicles
8. *Convert public vehicles and delivery trucks to LP gas and install catalytic converters*
9. Retrofit catalytic converters on minibuses
10. Require recent model taxis (newer than 84) and combi's (newer than 80)
11. Substitute natural gas for fuel oil in industry
12. Clean and/or relocate the foundries in the Valley of Mexico
13. Improve combustion and install control equipment on small boilers
14. *Substitute natural gas for fuel oil in Mexico City and the Mexico Valley power plants*
15. *Implement a program to reforest Mexico City and the Mexico Valley*

DDF PROGRAMS

16. Remove very obviously polluting cars and prevent them from entering city
17. Prohibit all open burning
18. Limit use of paints and finishes in industries that don't control vapors
19. Limit operation of closed trash burners to optimum time of day
20. *Install vapor recovery systems in filling stations (both storage and delivery)*
21. Reduce circulation of official vehicles by 30%

SOGELERG SUGGESTIONS

31. Coordinate traffic lights to speed flow of traffic
32. Implement information system on traffic conditions
33. Construct and police parking lots next to public transportation stations
34. Improve taxi efficiencies by use of taxi stands
35. Create toll streets and roads for single passenger vehicles
36. Control and increase fees on parking lots
37. Construct Line 8 of the Metro
38. Improve electric transport (trolleys)
41. Better organization of traffic and parking in the Central Historical District

SCAQMD OPTIONS

43. Reduce emissions from metal cleaning and degreasing
45. Reduce emissions from dry cleaning

ADDITIONAL OPTIONS

53. *Purchase and scrap old, polluting cars*
54. *Continue to require catalytic converters on automobiles*
55. Convert gasoline trucks to CNG
56. Require gasoline trucks to conform to 1993 standards
57. Replace gasoline trucks not suitable for conversion to CNG or LPG
58. Pave roads

Options analyzed in detail by IMP

Minimize:

$$\sum_{\text{All Options}}^{i=1} N_i * C_i$$

Subject to:

$$\sum_{\text{All Options}}^{i=1} N_i * E_{ij} > \mu_j$$

For all pollutants j

Where:

N_i is 0 or 1 depending on whether the option is implemented,

C_i is the cost of implementing an option,

E_{ij} is the air quality improvement for pollutant j for each option (in % of maximum value), and

μ_j is the total air quality improvement desired for pollutant j (in % of maximum value).
For the example this would be set to 50%.

Figure B.2. An example of the equations used in the LP method. This example is for the case where the LP is used to select the most cost-effective group of options to achieve a specified improvement in air quality.

reduce emissions, its contributions to the reduction in ozone are much greater. Spatial effects of emissions are also not taken into account in the LP model; therefore, once the total emissions are obtained for each strategy, a detailed calculation, taking into account total emissions reductions and spatial effects, is run to obtain a better estimate of the improvement of the air quality that would be achieved if a particular policy were followed.

For a policy that stresses reduction of a particular source of emissions, such as industrial or mobile sources, the options that represented mobile or industrial sources can be weighted to make them appear more cost-effective depending on which source is being emphasized. The weighting factor for the sample case of emphasizing industrial sources was to decrease the annual cost of the options related to reducing industrial emissions by one-half. The LP program was then used to select a strategy consisting of the most cost-effective way to reduce pollution to a selected level using the appropriate weighted rankings. The expected emissions reductions were calculated for each strategy and the annual cost (using the non-weighted annual cost figures) was determined for each strategy. The expected emissions reductions, along with their spatial effects, were then used as input to the air quality models, and an estimate of the air quality improvement for each strategy was obtained. These sets of options or strategies formed the basis for the analysis to be performed using decision analysis.

4. Decision Theory

In the example given in the introduction, the decision analysis process is equivalent to sending the package of measures, etc., out for review and comment by various organizations. The decision analysis uses a set of criteria that include all the important aspects that should be considered to conduct an evaluation of the policy. These criteria include items such as the political acceptance of a strategy, effects on import of goods, public acceptance, etc. The criteria are arranged into a decision tree (Figure B.3) and each criteria is given weights. Individual scores (from 0 to 1) for each criteria and for each strategy are assigned using a utility function. The utility functions are described in more detail in Section H. Because some criteria are more important than others, each criteria is assigned a weight, denoting its individual importance. This weight is multiplied times the score from the utility function to obtain a weighted score for each criteria and strategy. The weighted scores of the criteria are then combined to obtain a figure of merit (FOM) for each strategy (see Section H.3). The figures of merit for the strategies can then be compared, considering all important aspects, to determine which strategy is optimum.

The decision tree that was used in the analysis of the strategies was set up by a panel of experts from the various organizations that had responsibility for policy on improving air quality in Mexico City. The organizations that participated in the panel of experts are listed in Table B.1 and more detail on the process is presented in Section H.2.

In general, the most important result from using decision theory is not the final FOM number, but that each strategy has been evaluated in a consistent manner and that all important factors, as represented by the decision tree, have been taken into account for each option. The results of the decision analysis can also be used to explain why one strategy is preferred over another. The strategy score for each criterion gives an indication of the strengths and weaknesses of each strategy. Thus, applying the decision theory provides insight into what is involved if a particular strategy is implemented or a if a particular approach to improving air quality is followed.

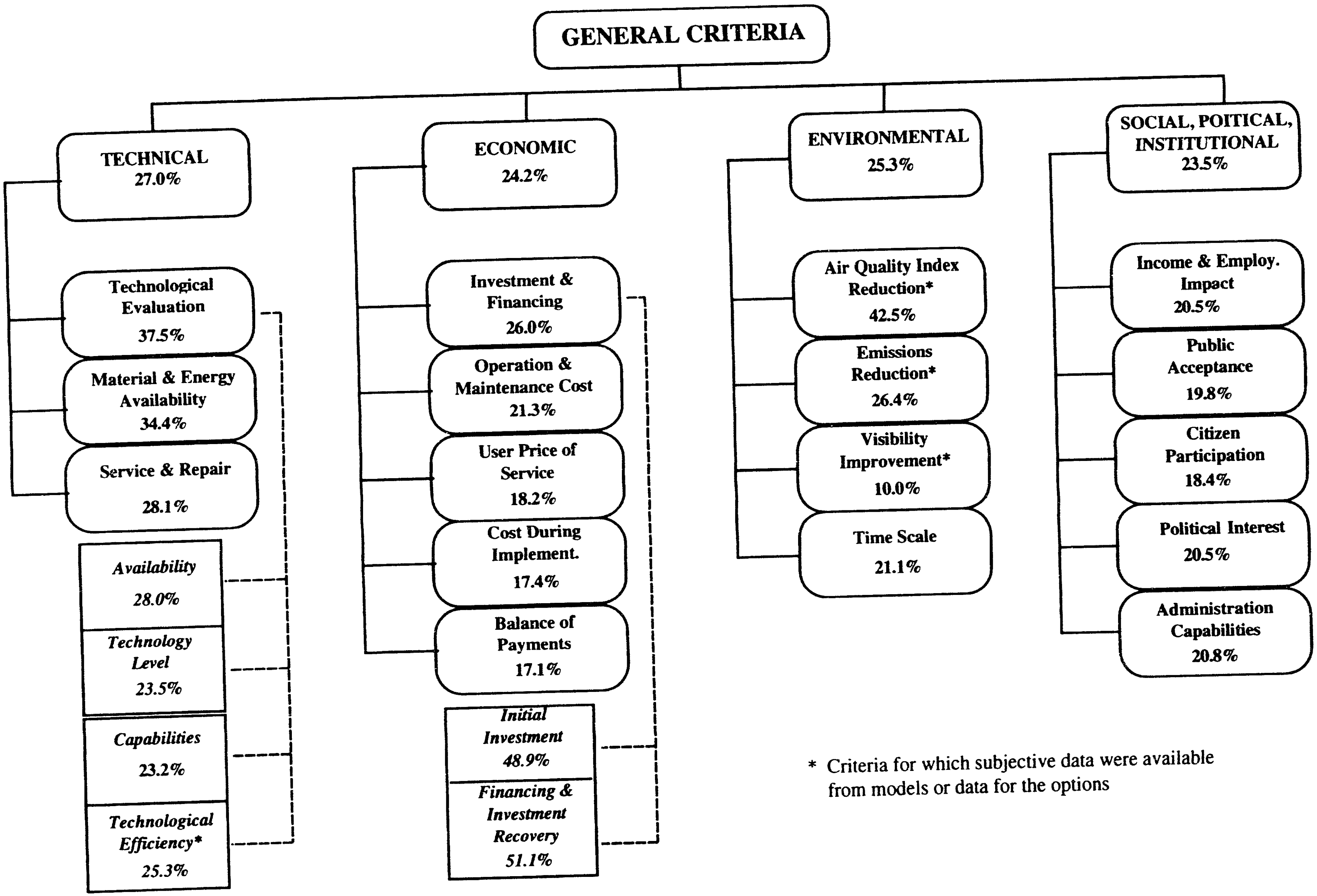

Figure B.3. The decision tree developed for the Mexico City project. The criteria and weights were selected by a panel of experts consisting of personnel from the organizations in Mexico City responsible for setting policy on air quality.

C. EMISSIONS DATA

1. Base Case Emissions Data

The same database described in Section D.4.d. of Volume III was used for the source database information.

2. Modifications of Source Database

The emissions database was modified to reflect the total impact of a strategy on the reductions of emissions for Mexico City. The spatial effects of the emissions reductions were also included. Simulations with these reduced emissions made using the various three-dimensional models. These simulations provide an estimate of the air quality improvement that would have been obtained if that strategy had been implemented.

The emissions reductions only included a reduction in the total emissions of a pollutant, not in the characteristics of the pollutant. Thus, when hydrocarbons were reduced, total hydrocarbon emissions were reduced taking into account spatial effects, but the changes in the hydrocarbon species being emitted were not considered, except that two different mixtures of hydrocarbons were in the emissions database, one for mobile sources and the other for fixed sources. As mobile emissions were reduced, the hydrocarbon species represented by mobile sources would be preferentially reduced, and the same would be true for the total fixed sources.

The emissions database was divided into a number of categories for mobile sources and fixed sources. Therefore, the emissions reductions were apportioned to these categories. Where it was possible, spatial effects other than those incorporated in the division of the emissions database into mobile and fixed sources were considered. Thus, if an option would reduce traffic preferentially in one part of Mexico City, this was taken into account by changing the spatial distribution of the appropriate mobile sources in the database. Similarly, if emissions reductions from a particular industry were being considered, an attempt was made to determine the sections of the city where that industry was concentrated and the emissions reductions were concentrated in those areas. Occasionally the database emissions from a sector were not large enough to account for all the emissions reductions estimated for that sector. In that case, the emissions of a particular pollutant in the sector were reduced to zero and the remaining emissions reductions applied arbitrarily to adjacent sectors.

When the emissions reductions from all the options were summed, the total possible emissions reductions are obtained. These total possible emissions reductions for each component of the emissions database are given in Table C.1 and C.2. The possible emissions reductions for some pollutants for some of the components are larger than the total estimated emissions for those pollutants because of two reasons. The first is that the emissions reductions were obtained from a number of different emission databases and these databases had a different base case than what was used in this project. Secondly, there is some double counting of emissions reductions when the reduction from all the options are summed. This double counting is subsequently eliminated by the LP.

TABLE C.1 Percent of Total Emissions Removed by Implementing All Options, Separated into Emission Database Categories

	CO	HC	NO_X	Part	SO_2
Mobile 1	49%	21%	10%	2%	2%
Mobile 2	14%	6%	3%	0%	1%
Mobile 3	8%	3%	1%	0%	0%
Mobile 4	2%	1%	0%	0%	0%
Mobile 5	1%	1%	0%	0%	0%
Mobile 6	0%	0%	0%	0%	0%
Mobile 7	0%	0%	0%	0%	0%
Mobile 8	0%	0%	0%	0%	0%
Mobile 9	0%	0%	0%	0%	0%
Mobile 10	34%	14%	10%	1%	2%
Mobile 11	0%	0%	0%	0%	0%
Mobile 12	0%	0%	0%	0%	0%
Mobile 13	0%	0%	0%	0%	0%
All Mobile	108%	45%	25%	4%	4%
Stationary 1	0%	0%	5%	1%	44%
Stationary 2	0%	0%	1%	0%	1%
Stationary 3	0%	0%	0%	1%	0%
Stationary 4	1%	1%	0%	2%	0%
Stationary 5	0%	5%	0%	0%	0%
Stationary 6	0%	0%	2%	11%	55%
Stationary 7	0%	3%	0%	69%	0%
Stationary 8	0%	0%	0%	0%	0%
Stationary 9	0%	0%	0%	0%	0%
All Stationary	1%	9%	7%	84%	100%
Total for all Options	109%	54%	33%	88%	104%

TABLE C.2 Fraction of the Emissions for Each Emission Category Removed by Implementing All Options

	CO	HC	NO_X	Part	SO_2
Mobile 1	110%	86%	46%	139%	104%
Mobile 2	137%	102%	63%	154%	153%
Mobile 3	91%	68%	24%	107%	57%
Mobile 4	91%	68%	24%	107%	57%
Mobile 5	52%	45%	18%	193%	34%
Mobile 6	0%	0%	0%	0%	0%
Mobile 7	52%	45%	18%	193%	34%
Mobile 8	17%	12%	2%	84%	0%
Mobile 9	17%	12%	2%	84%	0%
Mobile 10	130%	118%	111%	239%	113%
Mobile 11	1%	0%	1%	85%	12%
Mobile 12	0%	0%	0%	84%	0%
Mobile 13	0%	0%	0%	84%	0%
Total Mobile	113%	87%	35%	139%	31%
Stationary 1	0%	0%	37%	86%	112%
Stationary 2	0%	0%	24%	84%	47%
Stationary 3	30%	44%	31%	120%	0%
Stationary 4	30%	44%	31%	120%	0%
Stationary 5	0%	39%	0%	84%	0%
Stationary 6	11%	0%	17%	89%	123%
Stationary 7	0%	25%	37%	86%	112%
Stationary 8	0%	0%	0%	84%	0%
Stationary 9	0%	0%	0%	84%	0%
Total Stationary	20%	19%	26%	87%	116%
Total	109%	54%	33%	88%	104%

D. CALCULATION OF THE INDICE METROPOLITANO DE CALIDAD DEL AIRE (IMECA) VALUES

1. Background

The IMECA was established in Mexico City to provide a consistent, easily understood method for reporting air pollution. Values for the IMECA are reported by the city for six pollutants: ozone, CO, NO_2, SO_2, and particulates (both total particles and particles under 10 microns). In all cases, an IMECA value of 100 is the standard established in Mexico City for the particular pollutant. The IMECA value is calculated from the values of pollutant concentration measured by the automatic pollutant measuring network of 26 sites established in Mexico City. The IMECA value reported in Mexico City is a peak value figure and represents the maximum value for one day and each sector for the index. For reporting purposes, Mexico City is divided into five sectors: central northwest, northeast, southeast, and southwest (Figure D.1).

2. Calculation of IMECA Values

Calculations of IMECA values greater than 100 compensate for the differences in toxicity of the various pollutants at concentrations higher than the standard. This compensation is accomplished using curves that have two linear sections, one from 0 to 100 and the other for IMECA values greater than 100.

The standards for the pollutants are time averages and each pollutant has a different time interval for the average. The definition of the IMECA values also takes into account the time interval for averaging the concentration. It was not clear from the information obtained for the calculation of the IMECA values exactly how the index is calculated in practice, and attempts to duplicate the calculation of the IMECA values from the record of the pollutant concentrations were not entirely successful. In this project, where IMECA values were calculated for comparing model results, the "official" method for calculating the IMECA values was used. The method used for the calculation of the IMECA or this project is given in Table D.1.

The reported IMECA values are grouped into five sectors, and the reported values represent the maximum value for each sector. The exact grouping of the monitoring sites into sectors, used in the reporting of the IMECA values, was never clear. Attempts to reproduce the reported IMECA values using the measurements from the stations were not successful. The grouping of monitoring sites into sectors that was used in this report for reporting purposes is given in Table D.2.

3. Use of the Calculated IMECA Values

The IMECA calculations were used in this project to compare the results of the base case model calculations with the emission reduction calculations. Therefore, even though we were not able to consistently reproduce the reported IMECA values using the reported measurements from the monitoring network, the IMECA values, used in comparing the model results for the base case with the strategies were calculated using a consistent method. Also, the method used in this project corresponds to the "official" method as defined by the organizations responsible for reporting IMECA values.

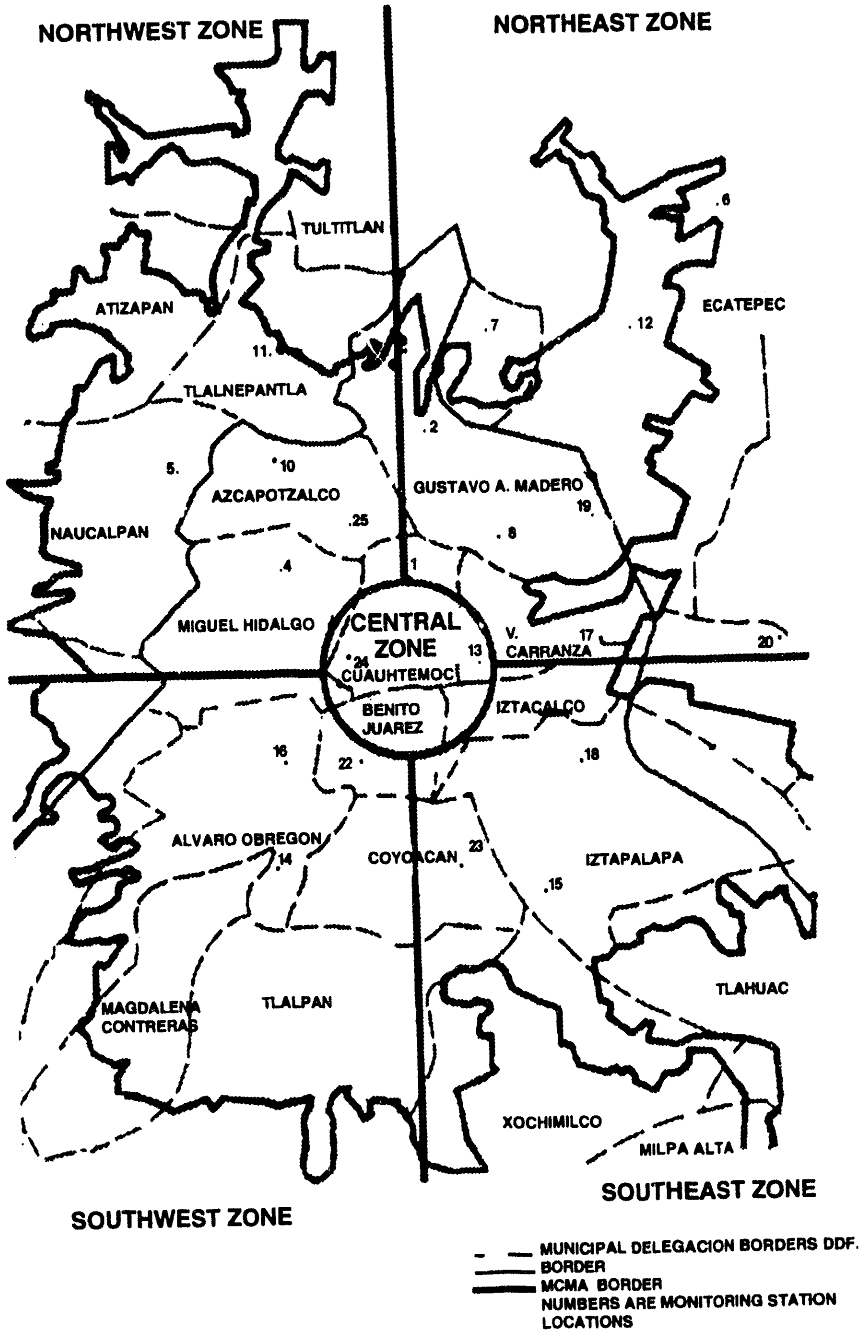

Figure D.1. The division of Mexico City into five sectors for the purpose of public reporting of air quality information. The reported air quality index values would be the maximum value recorded at any monitoring station in each sector.

TABLE D.1 Methods of Calculating IMECA Values for the Pollutants

Pollutant	Time Interval and Determination of Maximum IMECA Values	Concentration Interval	Equation
Particulates (Pst)	Average over 24 hours 1900 to 1800 next day	0–275 μg/M^3 275–1000 μg/M^3	IMECA = 0.36363636*C(Pst) IMECA = .55172413*C(Pst) – 51.72413
SO_2	Average over 24 hours 1900 to 1800 next day	0–0.13 PPM 0.13–1 PPM	IMECA = 769.230769*C(CO_2) IMECA = 459.770114*C (SO_2) + 40.22989
CO	Maximum of 3 daily 8 hour averages 1900 to 200 300 to 1000 1000 to 1800	0–13 PPM 13–50 PPM	IMECA = 7.69230768*C(CO) IMECA = 10.8108108*C(CO) – 40.5405
NO_2	Maximum 1 hour Average from 1900 to 1800	0–0.21 PPM 0.21–2 PPM	IMECA = 476.190476*C(NO_2) IMECA = 223.463687*C (NO_2) + 53.07264
O_3	Maximum 1 hour Average from 1900 to 1800	0–0.11 PPM 0.11–0.6 PPM	IMECA = 909.090909*C(O_3) + 5 IMECA = 816.326350*C(O_3) + 10.20409

*Where: C(x) is the concentration of the pollutant averaged as indicated.

TABLE D.2 Sector Grouping of Monitoring Stations

Station Name	Letter Designation	Sector
CUITLAHUAC	A	NORTHWEST
TACUBA	B	NORTHWEST
AZCAPOTZALCO	C	NORTHWEST
IMP	D	NORTHWEST
VALLEJO	E	NORTHWEST
TLALNEPANTLA	F	NORTHWEST
ACATLAN	G	NORTHWEST
LA PRESA	H	NORTHEAST
LA VILLA	J	NORTHEAST
ARAGON	K	NORTHEAST
XALOSTOC	L	NORTHEAST
LOS LAURELES	M	NORTHEAST
SAN AGUSTIN	N	NORTHEAST
NEZAHUALCOYOTL	O	NORTHEAST
IZTAPALAPA	P	SOUTHEAST
C. ESTRELLA	Q	SOUTHEAST
TAXQUEÑA	R	SOUTHEAST
SANTA URSULA	S	SOUTHWEST
PEDREGAL	T	SOUTHWEST
PLATEROS	U	SOUTHWEST
INSURGENTES	V	CENTRAL
BENITO JUAREZ	W	CENTRAL
MERCED	X	CENTRAL
HANGARES	Y	CENTRAL
LAGUNILLA	Z	CENTRAL

E. POLLUTANT WEIGHTING FACTORS

The decision analysis tree (Section H.3) requires a way to compare the behavior of different pollutants. A method was designed to assign weighting factors to the atmospheric pollutants. Only four pollutants were considered in this study because of a lack of information on others and because these are the pollutants that are of most interest for Mexico City at the present time. The four pollutants considered were ozone, carbon monoxide, nitrogen dioxide and sulfur dioxide. Although particulates and hydrocarbons were not included in the analyses, the results of this work do provide a necessary method for assigning weighting factors.

The method considers four characteristics of the pollutants and their statistics: health effects (IMECA), frequency above the Mexican standards, intensity above the Mexican standards, and trends. In order to take health effects into account, we used the definition of the IMECA value for all the statistical handling of data. The IMECA value definition is based on international standards that were defined in terms of health effects produced by pollutants.

The frequency above the Mexican standard for each pollutant was defined as:

$$\frac{\text{\#of days above the standard in the year considered}}{\text{365 days}}$$

and the numbers obtained were normalized with respect to the smallest one.

Intensity above the Mexican standard for each pollutant was defined as:

The absolute maximum in the year considered

And once again the numbers obtained were normalized with respect to the smallest one.

The trends for each pollutant are defined in Figure E.1, using the following formula:

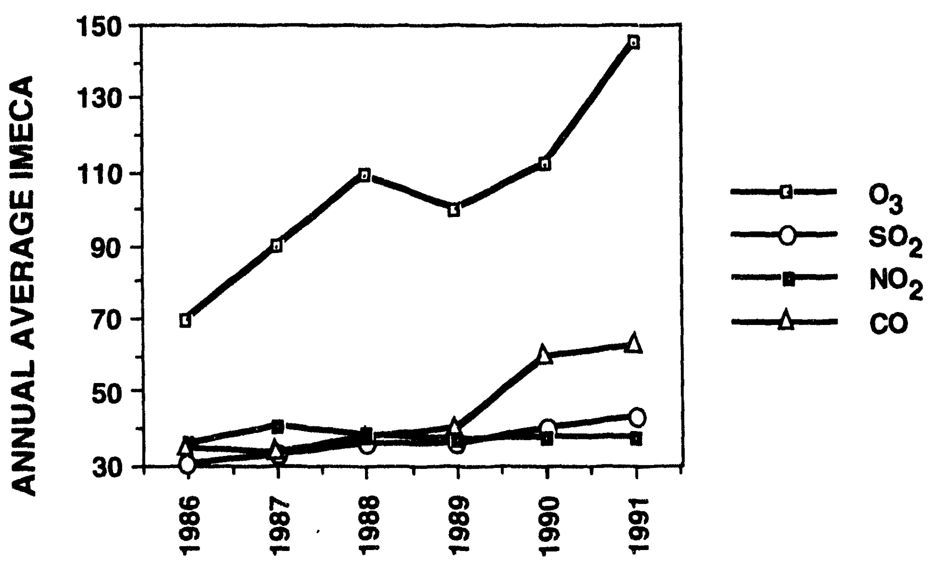

Figure E.1. The trend of the pollutant levels in Mexico City using an Annual Average IMECA value as an indicator of the pollution levels that existed for the year.

$$\frac{1}{i_L - i_0 - 1} \sum_{i=i_0}^{i_L} \left[AVE_i - AVE_{i-1} \right]$$

where

i_L is the latest year,
i_0 is the second oldest year, and
AVE_i is the IMECA value annual average for the i-year.

For the calculation we considered the period 1986 - 1991 because that was the period for which data were available.

Finally the numbers obtained were normalized with respect to the smallest one, and the weighting factors for each of the four pollutants considered for the Valley of Mexico were obtained (Figure E.2).

The weighting factors for each pollutant in the Mexico City Metropolitan Area (MCMA) were obtained as the average of the three criteria:

- Frequency above the Mexican standards,
- Intensity above the Mexican standards, and
- Trends.

For each of the five sectors defined by the IMECA a weighting factor was defined. The weighting factor for a sector was defined as the sum of the non-normalized pollutant weighting factors for that zone (Figure E.3).

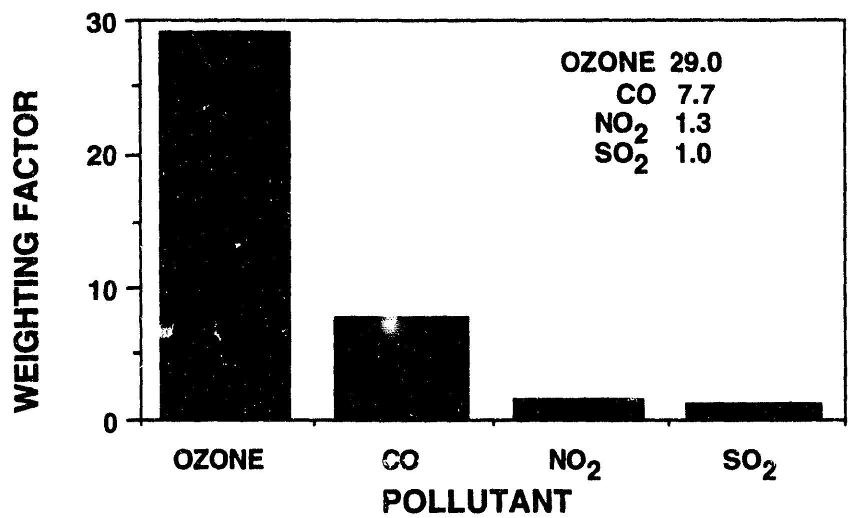

Figure E.2. The weighting factors for four pollutants. These weighting factors give the relative importance for Mexico City of controlling each particular pollutant.

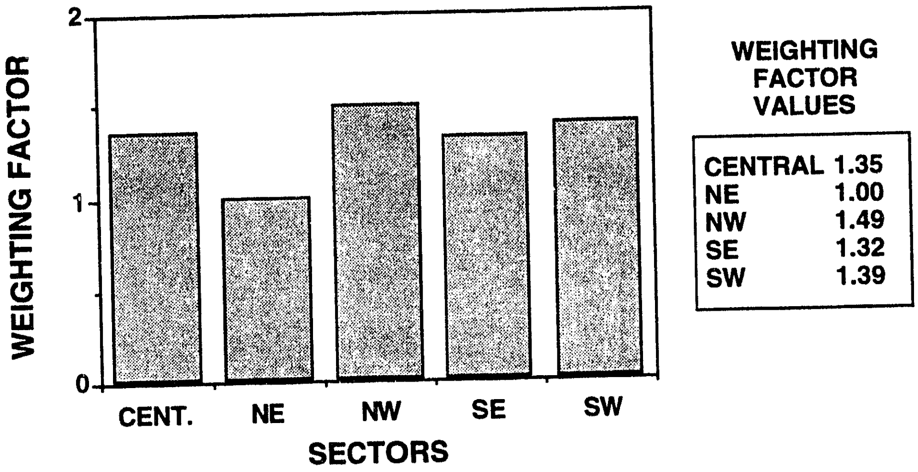

Figure E.3. The weighting factor for the five sectors in Mexico City. These factors give the relative importance of controlling pollution in the different sectors of Mexico City.

F. OPTIONS DATA

1. Options Considered

The list of options that were considered in this project previously appeared in Table B.3. The team attempted to use as many sources of information as possible in selecting the options. The options were chosen so that control measures for the different types of pollutant emitters were represented. Thus, options appear for:

- reformulating or changing fuels for fixed industrial installations,
- controlling emissions from industrial combustion sources,
- controlling evaporative emissions,
- controlling vehicular emissions,
- reduction of vehicular traffic, and
- controlling particulate emissions.

Not all the options were considered in the development of strategies. There were a number of reasons for this. Some of the options were completely implemented during the lifetime of the project and therefore no longer needed be considered. For other options, data were not available on the cost or emissions reductions that would be realized if the option were implemented. This is especially true of the options that promoted alternatives to automobile travel, for example, promotion of the metro. These options were considered to be general suggestions and no analysis was done to compare the expected pollution reduction results versus the amount of money spent on the promotion. Another class of options that was not considered in the final LP analysis was options that involved changing the time of emissions to a more favorable part of the day when their impact would be less significant. Obtaining any information on the effects of implementing these options would have required extensive analysis using the 3-D codes that were not available early enough in the project to perform the calculations. A study of the effect of varying the time of emissions would be a useful additional study for Mexico City.

Sometimes there were several ways an option could be implemented. For example in the reduction of emissions from degreasing operations, changes could be made to the system used to degrease parts, or a recycling program could be established for the solvent. In these cases, the Task III team tried to pick a reasonable program to address specific Mexico City conditions and emissions problems. The process of choosing what should be done to reduce a particular emission ideally involves trade-offs and dialogue between the government and the population that will be impacted by the regulations designed to reduce the emissions. Thus, the options list should contain options that have emerged successfully from a review in Mexico City. However, consensus is a lengthy process and as a practical matter, an option list will usually contain options that are more speculative.

The options that are used in the analysis should be practical to implement. Having an option on the list that is impractical for any reason would cause considerable problems because it would cause a whole strategy (which consists of a number of options) to be eliminated simply because of the one option. Therefore, it remains with the cognizant authorities to assure that only options that are practical and possible to implement appear on the options list. Once a strategy is formed the summation of all the effects of a strategy may mean that the strategy becomes impractical. For example, it may be entirely practical for one option to reduce traffic in Mexico City by 10%, but if a strategy includes eight options, each of which is designed to reduce traffic by 10%, the 80% reduction in traffic proposed by the strategy may not be practical or politically acceptable. This is one reason for examining a strategy as a whole, rather than viewing the individual options.

The option data that were used for analysis appears in Appendix A.

2. Sources for Option Data

The primary sources for options and their data on costs and emissions reductions data were existing reports that examined ways of reducing the emissions of pollutants in Mexico City. A number of comprehensive studies on options to improve air quality in Mexico City have been issued. The data supplied by these reports were used in the analysis, resulting in considerable time and cost savings by not having MARI "reinvent the wheel" and by being able to leverage the excellent work that had already been done. Reports reviewed for options to be included in the option's list were from the DDF, through the Programa Integral (PICCA 1990), and through the programs suggested by DDF (Comisión 1992). Additional options were obtained from SOGELERG (AQMP 1991), who did a study examining options for reducing emissions from mobile sources. Options were also obtained from SCAQMD. A few options were identified and added by Los Alamos and IMP as they worked on the project and became familiar with the many aspects of the issue.

The data for the options were also obtained from a number of sources. The primary sources for the data for mobile emissions were the analysis done for the PICCA (PICCA 1990 & AQMP 1991) and the World Bank Study on mobile emissions in Mexico City (World Bank 1992). Information on emissions reductions from fixed sources was primarily obtained from a study done by the Japanese (JICA 1991) that examined the fixed source emissions in Mexico City. The third external source of information for cost and emissions reductions for the various options was from the analyses done by SCAQMD for methods of reducing emissions in the Los Angeles basin. These analyses were adapted to the Mexico City situation.

Five options: requiring catalytic converters on automobiles, converting power plants to natural gas, reforestation, purchase of old polluting cars, and conversion of collectives to LPG were examined in detail by IMP. The options that were selected by IMP for more detailed study were those that were given a high priority by the city government and those significant options where there were little or no data available (reforestation and purchase of old vehicles). The detailed studies on these options appear in Appendix A.

3. Caveats for Options

As one would expect when analyzing proposed actions, the costs and emissions reductions estimates for the various options generally have a large uncertainty associated with them. The cost information was normalized by calculation of an annualized cost using a real interest rate of 5%. This is an approximate method of determining the cost of an option and does not include information on the portion of this annualized cost that is initial costs and the information on who pays (government, private individuals, companies). These factors were considered, however, in the decision analysis portion of the methodology.

Most of the information for the emission reduction effects come from U.S. sources, primarily the EPA emission factors (EPA 1989) and the Mobile 4 Code (EPA 1989), modified slightly to reflect the distribution of the Mexico City vehicle fleet. Due to lack of availability, emission factors based on actual measurements of Mexico City emissions are not incorporated extensively in the data presented here. However, the JICA study (JICA 1991) was based on actual measurements of fixed source emissions in Mexico City, and this information has been incorporated into the results presented in this report.

One of the main problems encountered in normalizing the data from the various sources was that different emission databases were used for different studies. This is especially important when ozone effects are being considered because different studies assumed a different ratio of emissions of hydrocarbons and NO_X from the mobile fleet. This different ratio affected the calculation of the ozone reductions expected for the options as described below. The different databases also meant that the total emissions reductions for all options for CO exceeded the total estimated CO emission estimates for Mexico City. With the creation of a reference emission database some of the problems may be reduced, but as long as different studies base results on different emissions assumptions, some discrepancies will result.

4. Determination of Ozone Reductions Produced by HC and NO_X Reductions

When hydrocarbon and NO_X emissions are reduced, there is not a linear relationship between those reductions and the reduction in ozone. In fact, small reductions in hydrocarbon or NO_X emissions may actually cause the ozone concentration to increase. This occurs because of the complicated air chemistry involved in the production of ozone and because of spatial effects. Therefore, because the data for the options only included estimates of hydrocarbon and NO_X emissions reductions, it was difficult to obtain estimates of the ozone reduction that would result from the emissions reductions.

It is not possible to calculate the ozone reduction for each individual option and add these reductions to obtain the total ozone reduction for a strategy or group of options. Because of the non-linearity of the ozone process, the contribution of each option's emissions reductions to the ozone reduction depended on the total emissions reductions for the group of options. Therefore, the first step in the procedure for estimating ozone reductions was to estimate what the final total emissions reductions would be. An Empirical Kinetic Modeling Approach (EKMA) calculation was performed to determine what the ozone reduction would be for two points near the expected total HC and NOx reductions. Next an equation was generated for a plane formed by the points corresponding to the initial HC and NO_X concentrations and the two points near to the expected final HC and NO_X concentrations. The new ozone level was calculated in the LP model by choosing a value for the HC and NO_X

reductions and finding the ozone level from the equation for the plane. The LP program requires a linear relationship between the HC and NO_X reductions and the ozone level, and by using the method presented here, the ozone levels could be estimated with the linear relationship of the plane.

This procedure was an attempt to make a non-linear process into a linear one, and therefore numerous uncertainties are inherent in the process. First, the relationship between the ozone concentration and the emissions reductions was very dependent on the total emissions reductions at the endpoints that defined the plane. The LP model is designed to find the optimum end points, but since the data input into the LP model would change for different end points, we cannot insure that the LP model has actually given an optimum solution to the reduction of ozone. Also, because different endpoints of total emissions reductions are obtained for the different strategies, the LP estimates of the ozone reduction for the different strategies are not accurate. A separate 3-D calculation using the specific emissions reductions for each strategy was done to reduce the uncertainty in this portion of the process. In addition to the above problems, the EKMA calculation used as the basis for the ozone reductions has many approximations involved in it. When further work is done on determining projected ozone reductions, it would be better if 3-D calculations were used to calculate the ozone level at the estimated end points of the emissions reductions. But this is a time consuming process and was not done because of the time limitations on this project. This process to determine ozone level reduction was only used to develop strategies. Once a strategy was created, the ozone reduction was calculated from the 3-D models and this value was used in subsequent analysis. Thus although there were a number of approximations in determining ozone levels for the LP analysis, the ozone reduction values for the decision analysis were based on more detailed and accurate 3-D models.

5. Final Values Used for Options

The linear relationship for the calculation of ozone levels was obtained by forming a plane through the three points on the isopleth shown on Figure F.1. The exact values for the points are given in Table F.1. The isopleth was calculated using the EKMA trajectory model and was for conditions existing on February 22, 1991. The calculation of the isopleth is described in more detail in Volume III, Section D.5.a.

The points represent the base case hydrocarbon and NO concentrations and two points that bracket the expected hydrocarbon and NO concentrations that are projected to exist when all the emissions reductions in a strategy have been achieved. The final equation for the calculation of ozone was

$$\mathbf{Oz = NO_X \times 0.126 + HC \times 0.095 + 0.029}$$

where

Oz is the ozone concentration,
NO_X is the NO_2 concentration, and
HC is the HC concentration.

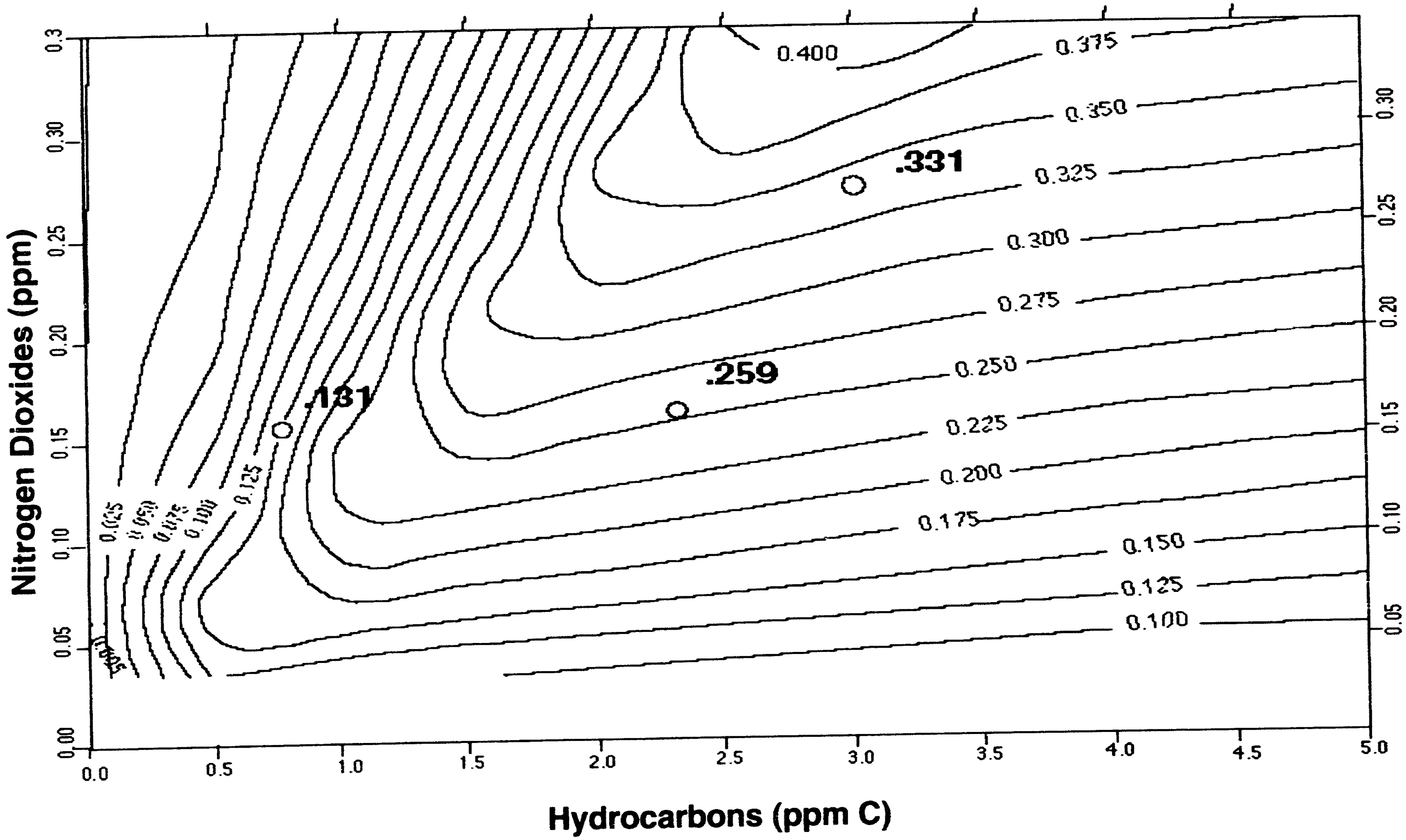

Figure F.1. Isopleth showing the relationship between the HC and NO_X concentrations and the resulting peak ozone concentrations. The isopleth was created for conditions existing on February 22, 1991. Points indicating base conditions and conditions existing with two estimates of emission reductions are shown.

Table F.1 Points and Results of Calculation of the Plane for Determining Ozone

Points from Isopleth

NO_X	HC	Ozone
0.275	2.827	0.331
0.179	2.2	0.2595
0.179	0.848	0.1314
Coefficients of the Plane		
0.126	0.095	0.029

The emissions reductions in tons per year for each option and the annualized cost for implementing the options that were used in this project are given in Table F.2. These numbers do not include the change in emissions reductions for reducing traffic when vehicles are equipped with catalytic converters nor the multiplication of the hydrocarbon emissions by 4 (for more detail see Section G.3). Table F.2 also indicates whether an option must be implemented as a unit, or if only a fraction of an option can be implemented. Table F.3 gives the percentage each option reduces the total emissions assuming that no vehicles are equipped with catalytic converters. Table F.4 presents the same information except that it is assumed that except for option 54, (catalytic converters required for private vehicles and taxis) all vehicles are equipped with catalytic converters. Tables F.5 & F.6 present the expected reduction in pollutant levels (including ozone reduction) in IMECA values that are projected if the option is implemented. The ozone reduction was calculated using the above formula. Table F.5. is the reduction without catalytic converters, and Table F.6. is the reduction with private autos and taxis equipped with catalytic converters.

TABLE F.2 Summary of the Cost and Emissions Reduction Data for the Options (Assumes No Vehicles are Equipped with Catalytic Converters)

Option # (see Table B.2)	Description	Integer ?	Annual Cost (million $)	Emissions Reduction (ton/y) CO	HC	NO_X	SO_2	Part
1	Prod. Int. Stand. Gas	Y	195.	461 000	133 200			
2	Prod. Low S Diesel	Y	16.6			290	10 600	500
3	Prod. Low S Fuel Oil	Y	50.8			1 200	80 000	880
4	Ruta 100 Expand	Y	34.	17 000	5 600	-88		
5	Auth. Bus Routes	Y	7.9	60 600	16 800	620		
7	Expand Verification	Y	29.	166 000	126 400			312
8	LP Gas Conv. & CC's	Y	39.3	236 000	67 200	2 600	754	1 400
9	CC's on Collectivos	N	12.6	103 000	27 200	224		
10	Repl. Taxi & Combi	N	410.	260 000	68 800	3 800	790	410
11	Sub NG for FO in Ind.	N	28.8			6 400	110 000	4 100
12	Foundries	Y	0.86	6 670	0	83	455	1 279
13	Tune Boilers	Y	7.	270	600	11 400	1 960	2 042
14	NG Power Plants	N	1.			-3 539	45 123	
15	Reforestation	N	35.		–1			300 000
16	Remove Poll. Veh.	N	0.8	3 400	5 600			
18	Open Burning	Y	0.23	20 349	25 600	700		3 200
19	Paints & Finishes	Y	52.7		49 200			
20	Reg. Trash Burners	Y	0.07		0			
22	Vapor Recov. Sys.	Y	–4.5		73 200			
23	Offic. Veh. Reduce	N	0.9	2 545	712	58	31.5	7
31	Corrd. Traffic Lights	Y	3.	10 600	3 200	200		
32	Traffic Info.	N	0.7	5 340	1 228	29		
33	Park-N-Ride	Y	4.5	67 280	189 20	1 530	250	181
34	Taxi Stands	Y	–0.35	283	100	4		
35	Urban Tolls	Y	3.	31 400	11 200	200	159	86
36	Parking Org.	Y	39.	5 900	2 612	123		
37	Line 8 Metro	Y	60.	23 820	9 608	1 087		
38	Electric Trolley	Y	0.2	4 847	2 612	668		
41	Hist. Dist. Park	Y	60.	30 000	10 000	780	133	117
43	Metal Cleaning	Y	–1.6		62 000			
45	Dry Cleaning	Y	2		15 600			
53	Purchase Old Cars	N	1.6	34 66	1 405	82.4		
54	CC's autos	Y	466.	1 300 000	393 600	21 000	4 000	2 500
55	Conv. Trucks to CNG	N	–19.6	315 000	88 000	1 900	1 000	90
56	Req. 1993 Truck Std.	N	55.	904 000	220 000	9 900	1 700	250
57	Rpl. Gas Trucks	N	76.	317 000	76 000	3 500	580	800
58	Pave Rds.	N	0.0088					7.52
	Total Emission Reductions			4 355 771	1 516 196	64 751	257536	318 154

Table F.3 Percent Each Option Reduces the Total Emissions of Five Pollutants (Assumes No Vehicles are Equipped with Catalytic Converters)

Option # (see Table B.2)	Description	Annual Cost (million $)	Emissions Reduction (% of Total)				
			CO	HC	NO_X	SO_2	Part
1	Prod. Int. Stand. Gas	195.	13.69%	6.58%	0.00%	0.00%	0.00%
2	Prod. Low S Diesel	16.6	0.00%	0.00%	0.16%	5.19%	0.11%
3	Prod. Low S Fuel Oil	50.8	0.00%	0.00%	0.68%	39.14%	0.20%
4	Ruta 100 Expand	34.	0.50%	0.28%	–0.05%	0.00%	0.00%
5	Auth. Bus Routes	7.9	1.80%	0.83%	0.35%	0.00%	0.00%
7	Expand Verification	29.	4.93%	6.24%	0.00%	0.00%	0.07%
8	LP Gas Conv. & CC's	39.3	7.01%	3.32%	1.47%	0.37%	0.31%
9	CC's on Collectivos	12.6	3.06%	1.34%	0.13%	0.00%	0.00%
10	Repl. Taxi & Combi	410.	7.72%	3.40%	2.15%	0.39%	0.09%
11	Sub NG for FO in Ind.	28.8	0.00%	0.00%	3.63%	53.82%	0.91%
12	Foundries	0.86	0.20%	0.00%	0.05%	0.22%	0.28%
13	Tune Boilers	7.	0.01%	0.03%	6.46%	0.96%	0.45%
14	NG Power Plants	1.	0.00%	0.00%	–2.00%	22.08%	0.00%
15	Reforestation	35.	0.00%	0.00%	0.00%	0.00%	66.62%
16	Remove Poll. Veh.	0.8	0.10%	0.28%	0.00%	0.00%	0.00%
18	Open Burning	0.23	0.60%	1.26%	0.40%	0.00%	0.71%
19	Paints & Finishes	52.7	0.00%	2.43%	0.00%	0.00%	0.00%
20	Reg. Trash Burners	0.07	0.00%	0.00%	0.00%	0.00%	0.00%
22	Vapor Recov. Sys.	–4.5	0.00%	3.61%	0.00%	0.00%	0.00%
23	Offic. Veh. Reduce	0.9	0.08%	0.04%	0.03%	0.02%	0.00%
31	Corrd. Traffic Lights	3.	0.31%	0.16%	0.11%	0.00%	0.00%
32	Traffic Info.	0.7	0.16%	0.06%	0.02%	0.00%	0.00%
33	Park-N-Ride	4.5	2.00%	0.93%	0.87%	0.12%	0.04%
34	Taxi Stands	–0.35	0.01%	0.00%	0.00%	0.00%	0.00%
35	Urban Tolls	3.	0.93%	0.55%	0.11%	0.08%	0.02%
36	Parking Org.	39.	0.18%	0.13%	0.07%	0.00%	0.00%
37	Line 8 Metro	60.	0.71%	0.47%	0.62%	0.00%	0.00%
38	Electric Trolley	0.2	0.14%	0.13%	0.38%	0.00%	0.00%
41	Hist. Dist. Park	60.	0.89%	0.49%	0.44%	0.07%	0.03%
43	Metal Cleaning	–1.6	0.00%	3.06%	0.00%	0.00%	0.00%
45	Dry Cleaning	2	0.00%	0.77%	0.00%	0.00%	0.00%
53	Purchase Old Cars	1.6	0.10%	0.07%	0.05%	0.00%	0.00%
54	CC's autos	466.	38.62%	19.43%	11.90%	1.96%	0.56%
55	Conv. Trucks to CNG	–19.6	9.36%	4.34%	1.08%	0.49%	0.02%
56	Req. 1993 Truck Std.	55.	26.85%	10.86%	5.61%	0.83%	0.06%
57	Rpl. Gas Trucks	76.	9.42%	3.75%	1.98%	0.28%	0.18%
58	Pave Rds.	0.0088	0.00%	0.00%	0.00%	0.00%	0.00%
	TOTALS	1734	129.39%	74.85%	36.68%	126.00%	70.65%

Table F.4 Percent Each Option Reduces the Total Emissions of Five Pollutants (Assuming Private Autos and Taxi's are Equipped with Catalytic Converters)

Option # (see Table B.2)	Description	Annual Cost (million $)	Emissions Reduction (% of Total)				
			CO	HC	NO_X	SO_2	Part
1	Prod. Int. Stand. Gas	195.	13.69%	6.58%	0.00%	0.00%	0.00%
2	Prod. Low S Diesel	16.6	0.00%	0.00%	0.16%	5.19%	0.11%
3	Prod. Low S Fuel Oil	50.8	0.00%	0.00%	0.68%	39.14%	0.20%
4	Ruta 100 Expand	34.	0.50%	0.28%	-0.05%	0.00%	0.00%
5	Auth. Bus Routes	7.9	0.36%	0.22%	0.14%	0.00%	0.00%
7	Expand Verification	29.	4.93%	6.24%	0.00%	0.00%	0.07%
8	LP Gas Conv. & CC's	39.3	7.01%	3.32%	1.47%	0.37%	0.31%
9	CC's on Colectivos	12.6	3.06%	1.34%	0.13%	0.00%	0.00%
10	Repl. Taxi & Combi	410.	1.54%	0.88%	0.86%	0.39%	0.09%
11	Sub NG for FO in Ind.	28.8	0.00%	0.00%	3.63%	53.82%	0.91%
12	Foundries	0.86	0.20%	0.00%	0.05%	0.22%	0.28%
13	Tune Boilers	7.	0.01%	0.03%	6.46%	0.96%	0.45%
14	NG Power Plants	1.	0.00%	0.00%	-2.00%	22.08%	0.00%
15	Reforestation	35.	0.00%	0.00%	0.00%	0.00%	66.62%
16	Remove Poll. Veh.	0.8	0.10%	0.28%	0.00%	0.00%	0.00%
18	Open Burning	0.23	0.60%	1.26%	0.40%	0.00%	0.71%
19	Paints & Finishes	52.7	0.00%	2.43%	0.00%	0.00%	0.00%
20	Reg. Trash Burners	0.07	0.00%	0.00%	0.00%	0.00%	0.00%
22	Vapor Recov. Sys.	-4.5	0.00%	3.61%	0.00%	0.00%	0.00%
23	Offic. Veh. Reduce	0.9	0.02%	0.01%	0.01%	0.02%	0.00%
31	Corrd. Traffic Lights	3.	0.06%	0.04%	0.05%	0.00%	0.00%
32	Traffic Info.	0.7	0.03%	0.01%	0.01%	0.00%	0.00%
33	Park-N-Ride	4.5	0.40%	0.22%	0.35%	0.12%	0.04%
34	Taxi Stands	-0.35	0.00%	0.00%	0.00%	0.00%	0.00%
35	Urban Tolls	3.	0.19%	0.13%	0.05%	0.08%	0.02%
36	Parking Org.	39.	0.04%	0.03%	0.03%	0.00%	0.00%
37	Line 8 Metro	60.	0.14%	0.11%	0.25%	0.00%	0.00%
38	Electric Trolley	0.2	0.03%	0.03%	0.15%	0.00%	0.00%
41	Hist. Dist. Park	60.	0.18%	0.12%	0.18%	0.07%	0.03%
43	Metal Cleaning	-1.6	0.00%	3.06%	0.00%	0.00%	0.00%
45	Dry Cleaning	2	0.00%	0.77%	0.00%	0.00%	0.00%
53	Purchase Old Cars	1.6	0.10%	0.07%	0.05%	0.00%	0.00%
54	CC's autos	466.	38.62%	19.43%	11.90%	1.96%	0.56%
55	Conv. Trucks to CNG	-19.6	9.36%	4.34%	1.08%	0.49%	0.02%
56	Req. 1993 Truck Std.	55.	26.85%	10.86%	5.61%	0.83%	0.06%
57	Rpl. Gas Trucks	76.	9.42%	3.75%	1.98%	0.28%	0.18%
58	Pave Rds.	0.0088	0.00%	0.00%	0.00%	0.00%	0.00%
	TOTALS	1734	117.44%	69.46%	33.59%	126.00%	70.65%

Table F.5 IMECA Value Reductions for the Options (Assuming No Vehicles Equipped with Catalytic Converters)

Option # (see Table B.2)	Description	Annual Cost (million $)	IMECA Value Reductions				
			CO	Ozone	NO_X	SO_2	Part
1	Prod. Int. Stand. Gas	195.	10.54	14.88	0.00	0.00	0.00
2	Prod. Low S Diesel	16.6	0.00	0.05	0.12	7.75	0.30
3	Prod. Low S Fuel Oil	50.8	0.00	0.20	0.50	15.53	0.53
4	Ruta 100 Expand	34.	0.39	0.61	-0.04	0.00	0.00
5	Auth. Bus Routes	7.9	1.39	1.98	0.26	0.00	0.00
7	Expand Verification	29.	3.80	14.12	0.00	0.00	0.19
8	LP Gas Conv. & CC's	39.3	5.40	7.94	1.09	0.00	0.84
9	CC's on Collctivos	12.6	2.36	3.07	0.09	0.00	0.00
10	Repl. Taxi & Combi	410.	5.95	8.31	1.59	0.17	0.25
11	Sub NG for FO in Ind.	28.8	0.00	1.06	2.68	21.12	2.46
12	Foundries	0.86	0.15	0.01	0.03	0.09	0.77
13	Tune Boilers	7.	0.01	1.96	4.78	0.38	1.22
14	NG Power Plants	1.	0.00	-0.59	-1.48	3.94	0.00
15	Reforestation	35.	0.00	0.00	0.00	0.00	179.86
16	Remove Poll. Veh.	0.8	0.08	0.63	0.00	0.00	0.00
18	Open Burning	0.23	0.47	2.98	0.29	0.00	1.92
19	Paints & Finishes	52.7	0.00	5.49	0.00	0.00	0.00
20	Reg. Trash Burners	0.07	0.00	0.00	0.00	0.00	0.00
22	Vapor Recov. Sys.	-4.5	0.00	8.17	0.00	0.00	0.00
23	Offic. Veh. Reduce	0.9	0.06	0.09	0.02	0.01	0.00
31	Corrd. Traffic Lights	3.	0.24	0.39	0.08	0.00	0.00
32	Traffic Info.	0.7	0.12	0.14	0.01	0.00	0.00
33	Park-N-Ride	4.5	1.54	2.37	0.64	0.05	0.11
34	Taxi Stands	-0.35	0.01	0.01	0.00	0.00	0.00
35	Urban Tolls	3.	0.72	1.28	0.08	0.04	0.05
36	Parking Org.	39.	0.13	0.31	0.05	0.00	0.00
37	Line 8 Metro	60.	0.54	1.25	0.46	0.00	0.00
38	Electric Trolley	0.2	0.11	0.40	0.28	0.00	0.00
41	Hist. Dist. Park	60.	0.69	1.25	0.33	0.03	0.07
43	Metal Cleaning	-1.6	0.00	6.92	0.00	0.00	0.00
45	Dry Cleaning	2.	0.00	1.74	0.00	0.00	0.00
53	Purchase Old Cars	1.6	0.08	0.17	0.03	0.00	0.00
54	CC's autos	466.	29.73	47.44	8.80	0.76	1.50
55	Conv Trucks to CNG	-19.6	7.20	10.14	0.80	0.19	0.05
56	Req. 93 Stds. Trucks	55.	20.68	26.21	4.15	0.32	0.15
57	Repl. Gas Trucks	76.	7.25	9.07	1.47	0.11	0.48
58	Pave Roads	0.0088	0.00	0.00	0.00	0.00	0.0045
Sum		1734	100	180	27	50	191
MAX IMECA VALUES			77	280	74	54	270

Table F.6 IMECA Value Reductions for the Options
(Assuming all Private Vehicles and Taxis are Equipped with Catalytic Converters)

Option # (see Table B.2)	Description	Annual Cost (million $)	IMECA Value Reductions				
			CO	Ozone	NO_X	SO_2	Part
1	Prod. Int. Stand. Gas	195.	10.54	14.88	0.00	0.00	0.00
2	Prod. Low S Diesel	16.6	0.00	0.05	0.12	7.75	0.30
3	Prod. Low S Fuel Oil	50.8	0.00	0.20	0.50	15.53	0.53
4	Ruta 100 Expand	34.	0.39	0.61	–0.04	0.00	0.00
5	Auth. Bus Routes	7.9	0.28	0.53	0.10	0.00	0.00
7	Expand Verification	29.	3.80	14.12	0.00	0.00	0.19
8	LP Gas Conv. & CC's	39.3	5.40	7.94	1.09	0.00	0.84
9	CC's on Collctivos	12.6	2.36	3.07	0.09	0.00	0.00
10	Repl. Taxi & Combi	410.	1.19	2.25	0.64	0.17	0.25
11	Sub NG for FO in Ind.	28.8	0.00	1.06	2.68	21.12	2.46
12	Foundries	0.86	0.15	0.01	0.03	0.09	0.77
13	Tune Boilers	7.	0.01	1.96	4.78	0.38	1.22
14	NG Power Plants	1.	0.00	–0.59	–1.48	3.94	0.00
15	Reforestation	35.	0.00	0.00	0.00	0.00	179.86
16	Remove Poll. Veh.	0.8	0.08	0.63	0.00	0.00	0.00
18	Open Burning	0.23	0.47	2.98	0.29	0.00	1.92
19	Paints & Finishes	52.7	0.00	5.49	0.00	0.00	0.00
20	Reg. Trash Burners	0.07	0.00	0.00	0.00	0.00	0.00
22	Vapor Recov. Sys.	–4.5	0.00	8.17	0.00	0.00	0.00
23	Offic. Veh. Reduce	0.9	0.01	0.02	0.01	0.01	0.00
31	Corrd. Traffic Lights	3.	0.05	0.10	0.03	0.00	0.00
32	Traffic Info.	0.7	0.02	0.03	0.00	0.00	0.00
33	Park-N-Ride	4.5	0.31	0.61	0.26	0.05	0.11
34	Taxi Stands	–0.35	0.00	0.00	0.00	0.00	0.00
35	Urban Tolls	3.	0.14	0.31	0.03	0.04	0.05
36	Parking Org.	39.	0.03	0.08	0.02	0.00	0.00
37	Line 8 Metro	60.	0.11	0.33	0.18	0.00	0.00
38	Electric Trolley	0.2	0.02	0.11	0.11	0.00	0.00
41	Hist. Dist. Park	60.	0.14	0.32	0.13	0.03	0.07
43	Metal Cleaning	–1.6	0.00	6.92	0.00	0.00	0.00
45	Dry Cleaning	2.	0.00	1.74	0.00	0.00	0.00
53	Purchase Old Cars	1.6	0.08	0.17	0.03	0.00	0.00
54	CC's autos	466.	29.73	47.44	8.80	0.76	1.50
55	Conv Trucks to CNG	–19.6	7.20	10.14	0.80	0.19	0.05
56	Req. 93 Stds. Trucks	55.	20.68	26.21	4.15	0.32	0.15
57	Repl. Gas Trucks	76.	7.25	9.07	1.47	0.11	0.48
58	Pave Roads	0.0088	0.00	0.00	0.00	0.00	0.00450
	Sum	1734	90	167	25	50	191
MAX IMECA VALUES			77	280	74	54	270

G. LP PROGRAM

1. General Description of LP Process

The LP optimizes a linear relationship subject to linear constraints on the variables. The variables can either be integers or continuous variables. The solution is provided by a standard mathematical process and for this project a commercial LP solver "Superlindo" (Schrange 1991) was used as the software to provide solutions to the LP problem. The general procedure for creating an LP problem is to determine a linear relationship between the variables that can be either maximized or minimized. Next the linear constraints that act upon the variables are determined. A determination also needs to be made as to whether a particular variable can have any value or can only have integer values.

The LP approach was selected to represent the procedure for selecting those options to be part of a strategy because the LP approach models the process that occurs in a real life situation when groups of options are selected from a list. The standard way to chose a group of options from a much larger list, be it air pollution reduction alternatives, investment opportunities, or vacation itineraries, is to optimize some attribute such as cost of program, return on investment, or number of historic places visited, subject to constraints such as a requirement for pollution reduction, cash available, or time. Because this procedure occurs so frequently in real life situations, the LP approach was a logical approach for modeling the processes that occur in choosing ways to combat air pollution.

2. Statement of LP Problem

Three strategies were chosen to demonstrate the methodology developed for the strategic analysis section of the Mexico City Project. The IMECA values for February 22, 1991 were used as the base IMECA numbers for this calculation since this is the day that was used by the modeling group as their reference day. This particular day was chosen as a reference because it was a bad pollution day and it occurred in the middle of a measuring campaign. Therefore considerable amounts of measurements were available to provide data for the models and to validate the model results.

The criteria for the selection of the first strategy was to obtain the group of options that represented the least costly way to reduce the IMECA ozone number by a value of 95 or 33%. This strategy involved minimizing cost, which is the sum of the individual option costs for those options that were selected, while requiring that the reduction in the IMECA ozone number be greater than 95. This strategy represents the policy of implementing all the options that are less expensive than the proposed option of requiring catalytic converters on new private vehicles and taxis. This particular policy was chosen because the requirement that vehicles be equipped with catalytic converters is a very expensive option to implement but also has the largest potential of any option to reduce ozone levels. For this strategy, it is hypothesized that this expensive step of requiring catalytic converters does not need to be taken. Since there is already a requirement in Mexico City for all new automobiles to be equipped with catalytic converters, it is unlikely that consideration will be given to eliminate the requirement. Therefore, the inclusion of this policy is to serve as a check that the methodology gives an answer that agrees with the general opinion about the attractiveness of the strategy.

The criteria for the selection of the second strategy was to obtain the group of options that presented the least costly way to reduce the IMECA ozone number by a value of 120 or 43%. Again, this strategy involves minimizing the cost of the options while requiring that the ozone level be reduced a specified amount. This strategy represents a moderately aggressive policy to reduce ozone levels in Mexico City (see Figure G.1). Catalytic converters would be required, as well as many of the most cost-effective options.

The criteria for the selection of the third strategy was to identify the most attractive set of options that would reduce IMECA ozone numbers by a value of 120 or 43% or the same amount as strategy two. This strategy assumes that those options which represented reduction in industrial emissions were twice as attractive as they would be in a normal optimal cost analysis. This strategy is a moderately aggressive policy to reduce ozone, but one where industrial sources are targeted for reduction.

3. Details of LP Calculation

The LP calculation incorporated some additional restrictions on the options. In order to conform to the base case emissions inventory, the hydrocarbon emissions reductions have been multiplied by a factor of four. The modeling

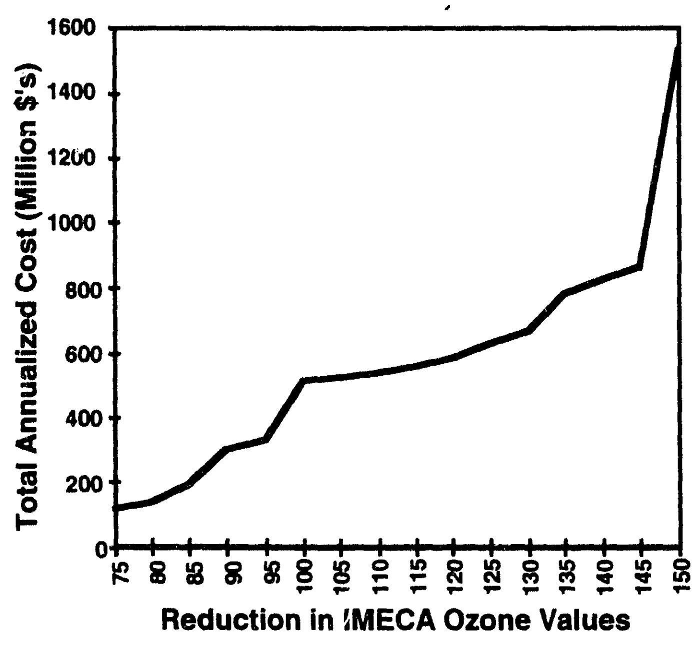

Figure G.1. The cost-effectiveness curve for ozone. This plot was generated by using the LP to select the most cost-effective group of options that would achieve the various reductions in the IMECA value for ozone.

group found that multiplying the hydrocarbon emissions by a factor of four provided a better match between the model predictions and the actual measurements. Also the CO emissions have been changed. When the total emissions reductions for CO were summed, they amounted to 150% of the emissions in the inventory. Since most of the CO emissions reductions were obtained from the World Bank Study (World Bank 1992), the total CO emission numbers used in the World Bank Study were substituted for the total CO emission values normally in the database. This reduced the total possible CO emissions to 130% of the total. Since the constraints on CO emissions have no effect in the regime of emissions reductions that were used for the strategies selection, this had no effect on the outcome of the LP modeling.

There are three cases where restrictions have been applied as to how options can be used in a strategy. These restrictions were programmed into the LP model or have been incorporated in the database.

- The estimated emissions reductions for inspection and maintenance and for the purchase of old cars was subtracted from the estimated emission reductions for catalytic converters. The emissions reductions for catalytic converters assumed that all vehicles will meet the standard. The Inspection and Maintenance (I & M) program would be implemented to catch those vehicles that do not meet the standard. Likewise the old vehicle purchase is designed to remove those cars that do not meet the standard. Therefore, the number of cars that would actually meet the standard without I & M and purchase of old cars is all the vehicles (as assumed by the catalytic converter option), minus those who would have been caught by the I & M process and those old cars which would have been purchased under the purchase option.
- The emissions reductions for converting industrial boilers and power plants to natural gas and the emissions reductions for production of low sulfur fuel oil are mutually exclusive. That is, a boiler can either be switched to low sulfur fuel oil or natural gas, but not both. Allowing both options to be exercised at the same time is double counting.
- The emissions reductions for having all gasoline trucks meet standards and options for switching gasoline trucks to LPG and CNG or replacing the trucks with new trucks are also mutually exclusive.

An additional restriction was used in the LP model but could not be incorporated into the data or programmed: if the catalytic converter option is selected, those strategies that reduce traffic will result in lower emissions reductions because cars with catalytic converters are being removed from the road. This is in comparison to the case where uncontrolled cars, those without catalytic converters, are being removed from the road. For the two strategies where catalytic converters were selected as part of the options package, this restriction was handled manually. This restriction reduced the emissions reductions for those options involving traffic reductions by 60% for NO_X, 88% for operating HC, 50% for evaporative HC (74% average), and 80% for CO. The actual percentage of emissions reductions for the two cases is given in Tables F.3. and F.4.

The option for paving roads was entered in the database as an annualized cost per km of paved road. Thus, the LP program will select the number of kilometers of roads that should be paved to reduce dust emissions to the desired level. A restriction was applied that only 100 km of roads could be paved in a year. Since this option was not selected for any of the strategies, this restriction had no effect.

4. Results of LP Calculation

There are two results obtained from the selection of three strategies with the LP model. The first of these are strategies that model the actions that would be taken if the respective policies were implemented. Taking into consideration not only cost and air quality improvement but also social, political, and technical factors through the decision analysis method, the specific options selected allow for an analysis of the consequences of choosing a particular policy. The second result is a grouping of the options into categories that provide an indication of the cost-effectiveness of particular options. Thus, there is a group of options that was selected for all three strategies, a group that was selected by some of the strategies, and a group that was not selected by any strategy. By examining the groups, one should be able to gain some insight into which options are the most cost-effective and should be initially implemented.

The primary assumption in using the LP process to model the process of selecting measures designed to carry out a policy is that the options selected by the LP model for the particular policy will have the same characteristics as the measures that would be taken to implement a policy. The options were selected by finding the least costly group of options to fulfill a specific goal, or in the case of strategy three the options were selected with a bias toward reducing industrial sources. In general this is the method used by decision makers when they decide on the measures to implement a policy. Thus, the comparison between the various strategies using the decision analysis method will be a comparison between groups of options that are representative of what would actually be done if the policy were implemented. This allows us to formulate a group of hypothetical policies, determine what measures or options would be used to implement the policies, and then compare the advantages and disadvantages of each policy with the other policies.

5. Suggestions for Improvement

The results of this project could be even more accurate if more data were generated for incorporation into the models. As in any modeling effort, the results can always be improved with additional data. Different options assume different emission databases, causing some difficulty in obtaining meaningful results from the calculations. Fortunately, most of the large discrepancies were in the CO emissions, and with the present information, CO would not be a problem for Mexico City if measures were taken to significantly reduce ozone levels. Cost information could also use some improvement, although in general the accuracy of the cost values for the options was adequate.

Another activity that would be useful is to involve even more organizations concerned with Mexico City air quality in identifying options, determining data, and suggesting possible hypothetical policies to be examined. The project team went to great lengths to involve other organizations in the decision analysis process, and therefore the results were understood and met with general approval. Possibly because the LP model part of the process was developed in the U.S., there was minimal input from Mexican organizations and the process was viewed as more of a "black box" by the Mexicans. In future projects even more effort should be made to involve other Mexican organizations in the process, including running the models and observing the results of the calculations when various conditions are imposed.

The use of linear assumptions for ozone production produced results that were sensitive to the assumptions on end points, particular isopleths, and assumptions on emissions. Additional work is needed on incorporating the ozone chemistry in the LP. This might include rules for selecting endpoints, piece-wise linear equations for calculating the effects of NO_X and hydrocarbon reductions, or more detailed calculations for endpoints and emissions reductions rather than the approximate formulas used in this study. Modeling the procedure of implementing policy with a linear program is somewhat limited, especially when ozone is being considered. Further effort is needed to determine whether a quadratic optimization or another optimization technique would have any advantages in the modeling process.

H. DECISION ANALYSIS

1. General Description of Decision Analysis Method

We developed a method based on Multi-Attribute Decision Theory (MADT), a common procedure used in comparing and selecting between different possibilities, that was designed to help the Mexican decision makers rank air pollution control measures and strategies (a set of options), taking into account economic, technical feasibility, environmental, social, political, and institutional factors. The method allows decision makers to evaluate measures and strategies to obtain the best results with the least cost. Best results are those that not only result in air quality improvement but also take into consideration social and political impacts.

The MADT was chosen because it is a very easily understood method of obtaining and documenting a comparison between various alternatives. The structure of the decision analysis can be established by nonexperts in decision theory with the assistance of some one familiar with the techniques involved. Data for the decision analysis can be obtained by people that may be experts in a particular field but are not necessarily knowledgeable in decision analysis. Because all the criteria are stated in layman's terms, the MADT provides an easily understood method of examining the factors that were part of the decision making process.

When comparing different strategies to reduce air pollution, the two common elements considered by the traditional cost/benefit analysis, are the amount the air quality is improved (or alternatively the amount the emissions of pollutants are reduced) and the cost of obtaining this improvement. However, there are many more factors that need to be considered when choosing a strategy to reduce air pollution. Factors such as the increase in imports required, the ability of the administrative structure to implement the new rules and regulations, the popularity of the measures being proposed, and cost distribution are also important parts of the decision. Decision analysis techniques allow these factors to be considered in a structured and easily understood manner.

The procedure for the MADT starts with the identification of the important criteria in the decision and assigning each criteria a relative weight. Next, a method of measurement is determined for each criterion. These evaluations are then normalized on a scale of 0 to 1 using a utility function. This utility function defines the relationship between the criteria evaluation and its value.

The result of applying the decision analysis method is the scores for the strategies and experience gained using the process. The formal process insures that important factors in the decision have been considered. As decision makers work through the process, they are involved in a hands-on experience that makes the decision analysis method extremely relevant. The weights for the criteria and the utility values assigned for each strategy provide a record of how the decision was made. This record is useful when the decision needs to be explained or defended.

2. Procedure for Obtaining Decision Tree

To develop the decision tree, a panel of experts in environmental pollution (Table B.1) was formed. The panel, with IMP and LANL guidance, formed the decision tree and chose two pollution mitigation options to test for weaknesses in the tree. Several meetings of the panel were required to correct the weaknesses, identified by this test, in the decision tree structure.

a. Panel of Experts

The MADT method requires a panel of experts to build the decision tree. In this case, the panel consisted of representatives of the Mexico City government who were experts in environmental issues. Mexico City government representatives were chosen to insure that the decision tree was built to reflect the priorities of Mexico as related to valuation of clean air and its impacts.

Mexico City is located within the boundaries of the Distrito Federal (DF) and EdoMex, so representatives of both governments were invited to be a part of the panel of experts. People from Comisión Metropolitana para la Prevención y Control de la Contaminación en el Valle de México (Metropolitan Commission to Prevent and Control Pollution in the Valley of Mexico) were also invited to participate on the panel. This commission was formed with representatives from DDF, EdoMex and SEDESOL. SEDESOL is the department in charge of pollution problems in Mexico. Among its other duties, it was formed to coordinate efforts to fight pollution in Mexico City. SEDESOL and SSA are involved in setting pollution standards in Mexico, so representatives from both departments were considered integral parts of the panel. As pollution and energy consumption are very closely related, representatives from the energy sector, PEMEX (the Mexican Petroleum Company) and CFE (Electricity Federal Commission) were invited to be on the panel. Both companies are owned by the Mexican government. People from IMP and LANL assumed advisory positions on the panel.

In each meeting, about 15 experts from each office acted as representatives. The same representatives did not attend all meetings, which resulted in a slower work pace but also contributed to a broader range of ideas that ultimately enriched the methodology. As more people participated in the meetings, knowledge of the project spread rapidly. The list of participants in the various meetings of the panel of experts and their affiliations is given in Table B.1.

b. Test Problems

To test the methodology, two pollution mitigation options were chosen to be compared:

- The installation of catalytic converters on new vehicles sold in Mexico from October 1990 onward
- The substitution of natural gas instead of fuel oil in the two major electric power plants in the MCMA

These two options were selected because one controls emissions from mobile sources and the other from stationary sources. At the time they were suggested, the two options, unlike others that were considered, had been studied thoroughly and had available data. Appendix B shows the study finished in June 1991 with more than 140 pages of data. The study contains a description of the different catalytic converters used in the Mexico City fleet, projections of car sales up to 1996 for the Valley of Mexico, and based on these projections, emissions estimations of the first option implementation. For the second option the study shows natural gas supply and demand, emissions of the two power plants in Mexico City: "Valle de México" and "Jorge Luque," and cost and emissions estimations for the implementation of the option. The information for the two options was gathered from publications and also from visits and surveys of the two power plants, the Mexican association of the automobile industry, and the Mexican catalytic converter canning industry. Based on this information, the experts graded the options and also found weaknesses in the methodology that were corrected in several meetings. The results of the evaluation of these options, using the final version of the methodology, are shown in Section H.3 of this volume.

c. Revisions to Decision Tree

The panel of experts began meeting in May 1990 to design the decision tree. Since that time, there have been about a dozen meetings. The most recent meeting occurred in June 1993. In the first meetings, the panel used the Delphi technique to divide the problem into general and specific criteria, assign weighting factors to each criteria, according to their estimated importance in Mexico, and define utility functions for the Specific Criteria or Attributes. The main branches of the decision analysis tree, those elements considered to be the General Criteria, were technical, economic, environmental, social, political, and institutional. Each of these general criteria were divided into specific criteria. As the methodology developed, it became necessary to define the specific criteria. As a result, there are subdivisions of the specific criteria. The complete Decision Analysis Tree is shown in Figure B.2.

The two options previously mentioned, installing converters and substituting natural gas, were analyzed using the decision tree. The analyses showed several weaknesses in the method. In the panel meeting of June 1991, modifications of the decision tree started: changing definitions of utility functions, and adding to the methodology the concept of the criterion "go/no go." This criterion prevents options or strategies with big disadvantages from obtaining high scores in the evaluation, hence preventing these measures from being selected for implementation. This criteria discards options or strategies that obtain less than 16.5 in the attribute "Technological Evaluation" and/or less than 12.7 in the attribute "Investment and Financing", and/or less than 13.6 in the attribute "Air Quality" (some of these attributes have a different name in the final version of this methodology). It must also be mentioned that the criterion "go/no go" was ultimately abandoned because the decision analysis was to be applied only to strategies or groups of options. This required that every option in the list be practical. Impractical options that would have been identified by the go/no go criteria would not be included in the list. Thus go/no go criteria were applied to options before they were included in the options list and the go/no go criteria could then be removed from the decision analysis procedure. In the June 1991 meeting, as the first part of the analysis, LP was adopted as a way to generate air pollution strategies from the option list.

The other important change in the method occurred in the meeting of January 1993. In this meeting, the criteria "go/no go" was abandoned and the action of this criterion was embedded in the new definition of the FOM. This new definition is in the final version of this method and is shown in Section H.3.

3. Decision Tree

The final version of the decision tree for evaluating options and strategies to mitigate air pollution, and spatially tailored for Mexico City, is shown in Figure B.3.

a. Utility Functions

The utility functions for the decision tree Attributes and the weighting factors for the General Criteria and Attributes are shown in Tables H.1 through H.4.

b. Weighting Factors and FOM

The method was designed so the sum of the general criteria weighting factors is equal to 100, i.e., if A, B, C, and D are the weighting factors for the general criteria then

$$A + B + C + D = 100.$$

Similarly, the weighting factors for the Attributes under a general criterion must sum 100, i.e., if ai is one of the attribute weighting factors under one of the general criterion then

$$a_1 + a_2 + \ldots + a_n = 100.$$

This is true for attribute weighting factors of the four general criteria and is the same for any other subdivision of an attribute, i.e., if an attribute is subdivided into subattributes, then the subattribute weighting factors must sum to 100 as well.

A utility function was assigned to each of the attributes. The utility function for a certain attribute was defined by the experts to evaluate the specific characteristic or characteristics of a measure or strategy that was considered within this attribute. As a result, a measure or a strategy could be graded according to this evaluation in a scale from 0 to 1. For example, in constructing a utility function for cost, any costs up to a certain amount would have a utility of 1 (i.e., up to a certain amount the cost would have no effect on the desirability of choosing the strategy). As costs increase, the utility would decrease until a certain maximum cost, after which the utility would be 0 (i.e., any strategy that costs more than this amount is too expensive to be considered).

Based on these definitions, the total grade or FOM of a measure or strategy was defined as follows:

$$\mathbf{FOM = GIM \times GIT \times GSS \times GII \times GFI \times GAQ \times GPR \times GT \times WAG}$$

where

GIM = Grade obtained in the attribute "Input Materials and Energy Availability and Consumption."

GIT = Grade obtained in the attribute "Implementation Capabilities and Technological Innovation."

GSS = Grade obtained in the attribute 'Service and Spare Parts."

GII = Grade obtained in the attribute "Initial Investment."

GFI = Grade obtained in the attribute "Financing and Investment Recovery."

GAQ = Grade obtained in the attribute "Air Quality Indexes Reduction."

GPR = Grade obtained in the attribute "Pollutant Emission Reductions."

GT = Grade obtained in the attribute "Time."

WAG = Average Weighted Grade, defined as

$$WAG = \sum_{j=1}^{4} GCWj \frac{1}{100} \sum_{i=1}^{nj} AGji\ AWji$$

where

GCW_j = Weighting factor of the j-th general criterion.

AG_{ji} = Grade obtained by the measure or strategy corresponding to the i-th attribute under the j-th general criterion.

AW_{ji} = Weighting factor of the i-th attribute under the j-th general criterion.

n_j = Number of attributes under the j-th general criterion.

If an attribute is subdivided into subattributes then

$$AG_{ji} = \frac{1}{100} \sum_{k=1}^{n_{ji}} SAG_{jik}\ SAW_{jik}$$

where

SAG_{ji} = Grade obtained by the measure or strategy corresponding to the k-th subattribute under the i-th attribute that is under the j-th general criterion.

SAW_{ji} = Weighting factor of the k-th subattribute under the i-th attribute that is under the j-th general criterion.

n_{ji} = Number of subattributes under the i-th attribute that is under the j-th general criterion.

Comparing the FOM for different options or strategies, we can rank them in order of importance from the highest to the lowest. On the other hand, the WAG is useful to look at the contribution of each general criteria to the final score or FOM.

4. Inputs into the Decision Tree for Options and Strategies

a. Options

The panel of experts dynamics to evaluate options were to ask each expert to grade each of the options being evaluated in the first attribute, then the grades from all the experts for the first option were collected and the average was calculated. The average was defined as the panel of experts grade for the first option in that attribute. The same was done for the other options. Once all the options were graded in the first attribute, the experts continued in the same manner with all the other attributes (except the attributes graded with results from simulations and emissions estimations, marked in Figure B.2). Finally the FOM and the WAG were calculated.

The experts graded the options based on their own knowledge and on information previously collected about the options from reports, publications and estimations. Before grading, the experts shared comments about the characteristics of the options they were evaluating.

TABLE H.1 Utility Functions for the Technical Criterion

Technical Criterion				**27.00**
1. Technological Evaluation				**37.50**
Availability				28.00
Available and Applicable			1.00	
Available but needs some adaptation			0.75	
Available but needs large adaptation			0.50	
Exists but not available			0.25	
It does not exist			0.00	
Technological Level				23.50
High			1.00	
Medium			0.50	
Low			0.00	
Implementation Capabilities and Technological Innovation				23.20
Implementation		**Innovation**		
Easy to implement	1	Can be innovated	1	
Difficult to implement	0.3	Can not be innovated	0	
Impossible to implement	0			

$$I \& I = \frac{\textbf{Implementation + Innovation}}{2}$$

Technology efficiency				25.30
Percentage reduction of pollutants			0.00 to 1.00	
2. Input Materials and Energy Availability and Consumption				**34.40**
Availability		**Consumption**		
High Availability	1	Low Consumption	1	
Medium Availability	0.5	Medium Consumption	0.5	
Low Availability	0.25	High Consumption	0	

$$A \& C = \frac{\textbf{Availability + Consumption}}{2}$$

3. Service Repair		**28.10**
Available	1.00	
Available with few limitations	0.75	
Available with limitations	0.50	
Available with lots of limitations	0.25	
Not available	0.00	

TABLE H.2 Utility Functions for the Economic Criterion

Economic Criterion		**24.20**
1. Investment, Financing, and Investment Recovery		**26.00**
Initial Investment		48.90
Very Low	1.00	
Low	0.75	
Medium	0.50	
High but manageable	0.25	
High, not manageable	0.00	
Financing (financed by) & Investment Recovery		51.10

Financing		**Investment Recovery**	
Users	1.00	Short term (<5 years)	1
National Enterprises	0.75	Medium term (5-10 years)	0.75
Financial Institutions	0.50	Long term (>10 years)	0.25
Government	0.25	No recovery	0
Does not exist	0.00		

$$\mathbf{F\ \&\ IR} = \frac{\textbf{Financing + Investment Recovery}}{\mathbf{2}}$$

2. Operation, Maintenance Cost		**21.30**
Low cost	1.0	
Medium cost	0.5	
Very high cost	0.0	
3. Good or Service Price for the User		**18.20**
Market defined	1.00	
Subsidized	0.50	
Free	0.25	
4. Implementation Period Cost (before results)		**17.40**
Low cost	1.00	
Medium cost	0.50	
High cost	0.25	
5. Balance of Payments		**17.10**
No international help required	1.00	
Small international help required	0.75	
Medium international help required	0.50	
Large international help required	0.25	
Total international help required	0.00	

TABLE H.3 Utility Functions for Environmental Criterion

Environmental Criterion	**25.30**
1. Air Quality Indexes Reduction	**42.50**

$$I = \left[\frac{C_a - C_n}{N} \right] \times \left[\frac{C_a}{2N} \right]$$

$$F = \begin{cases} 1.0 \text{ if } N > 1.0 \\ I \quad \text{if } N < 1.0 \end{cases}$$

where:

C_a = Current concentration
C_n = New concentration after implementation
N = Air quality standard (concentration)
I = Impact
F = Utility function

2. Pollutant Emission Reductions	**26.40**

(THC, NO_X, SO_2, Pb, TSP, CO)

$$R = \frac{\sum_{i=1}^{6} [T_{ai} - T_{ni}] \times T_i}{\text{Max } (j = 1, 2, \ldots, 6) [T_{aj} \times T_j]}$$

$$F = \begin{cases} 1.00 \text{ if } R > 1 \\ R \quad \text{if } R < 1 \end{cases}$$

where:

T_{ai} = Current emission (tons of pollutant i)
T_{ni} = After implementation emissions (tons of pollutant i)
T_i = Toxicity factor of pollutant i
R = Emission reductions factor
F = Utility function

TABLE H.3 Utility Functions for Environmental Criterion (Cont.)

3. Total Suspended Particles' Impact on Visibility **10.00**

$$F = \frac{P_a - P_n}{P_a}$$

where:

P_a = Current tons of total suspended particles emissions
P_n = Tons of particle emissions after implementation
F = Utility function

4. Time **21.10**

Impact		**Range**	
Immediately	1	Permanent	1
Short (1-3 years)	0.5	Medium range	0.5
Long (after 3 years)	0.25	Temporary	0

$$I \,\&\, R = \frac{\text{Impact} + \text{Range}}{2}$$

b. Strategies

For evaluation of strategies the experts evaluated one strategy at the time. The experts formed a roundtable to discuss, in each attribute, the grading of each of the options forming the strategy. If opinion discrepancies appeared about the grading, then the grade was defined by voting. For all the attributes the average of the option grades obtained in an attribute was defined as the strategy grade in that attribute. In four of the attributes, the options were evaluated with results from simulations and emissions estimations.

TABLE H.4 Utility Functions for Social, Political, and Institutional Criterion

Social, Political and Institutional Criterion		**23.50**
1. Income and Employment Impact		**20.50**

Income		**Employment**	
Increase in low income sectors.	1	Increase in low income sectors.	1
Increase in high income sectors.	0.75	Increase in high income sector.	0.75
No income impact.	0.5	No employment impact.	0.5
Decrease in high income sectors.	0.25	Decrease in high income sector.	0.25
Decrease in low income sectors.	0	Decrease in low income sectors.	0

$$I \& E = \frac{\text{Income} + \text{Employment}}{2}$$

2. Public Opinion		**19.80**
500–person telephone survey		
PO = Average of the answers	0.00 to 1.00	
3. Citizen Participation		**18.40**
No need	1.00	
Government participation required	0.75	
Industrial or commercial associations' participation required	0.50	
Civilian associations' participation required	0.25	
All citizens participation required	0.00	
4. Political Interest		**20.50**
Presidential initiative	1.00	
Pollution Prevention and Control, Metropolitan Commission for Mexico Valley initiative	0.75	
Federal government office initiative	0.50	
Institutional initiative	0.25	
Measure without political interest	0.00	
5. Administration Capabilities		**20.00**
Administration entities with technical and professional capabilities normative faculties, and established norms exist	1.00	
Administration entities with technical and professional capabilities, normative faculties exist, but there are no norms established	0.75	
Administration entities with technical and professional capabilities exist but no normative faculties or established norms exist	0.50	
No administration entities exist	0.00	

I. APPLICATION OF METHODOLOGY

1. Description of Problem

Three strategies were chosen to illustrate the strategic evaluation method as follows:
They were

- Reducing the ozone by 95 IMECA points,
- Reducing the ozone by 120 IMECA points, and
- Reducing the ozone by 120 IMECA points with an emphasis on industrial sources.

Reductions in the IMECA values were obtained from the cost-effectiveness curve for ozone reduction (Figure G.1). For the first two cases, the LP model determined the cost-optimized group of options that would reduce ozone by the desired amounts. All other requirements for pollutant reductions were held constant. For the third case the LP model determined the cost-optimized group of options that would reduce the ozone to the desired amount where the costs for industrial sources had been divided by two.

The relationship between the decrease in ozone concentration caused by the reduction in hydrocarbon and NO_X emissions was

$$\mathbf{Oz = NO_X \times 0.126 + HC \times 0.095 + 0.029}$$

where

Oz is the ozone concentration,
NO_X is the NO_X concentration, and
HC is the HC concentration

This equation was obtained by choosing three points on an isopleth (Figure I.1) and calculating the plane that went through the three points.

Three points were chosen as follows:

- The base case concentration of hydrocarbons and NO_X
- The concentration of hydrocarbons and NO_X that would occur if all options were exercised.
- The approximate concentrations of hydrocarbons and NO_X that were expected to occur in a strategy.

The isopleth was generated using the EKMA trajectory model. The model assumed that the peak ozone concentration would occur in Pedregal, but that the air mass that contained the peak ozone started in Xalostoc and then was transported over the city using winds modeled by the HOTMAC computer program. As the air mass was transported over a particular part of the city, the emissions representative of that city sector and time of day were added to the air mass. The air chemistry that occurred in this air mass was calculated to obtain the ozone concentration.

The LP model for the first two cases obtained the cost-optimized group of options that would reduce the ozone level to the specified level. This would model the actions of a staff developing measures to carry out a policy of reducing the ozone to a particular level in the most cost-effective manner.

The first strategy models a very relaxed policy for reducing air pollution. The underlying assumption for this policy is that the accumulated social/political/cost disadvantages of

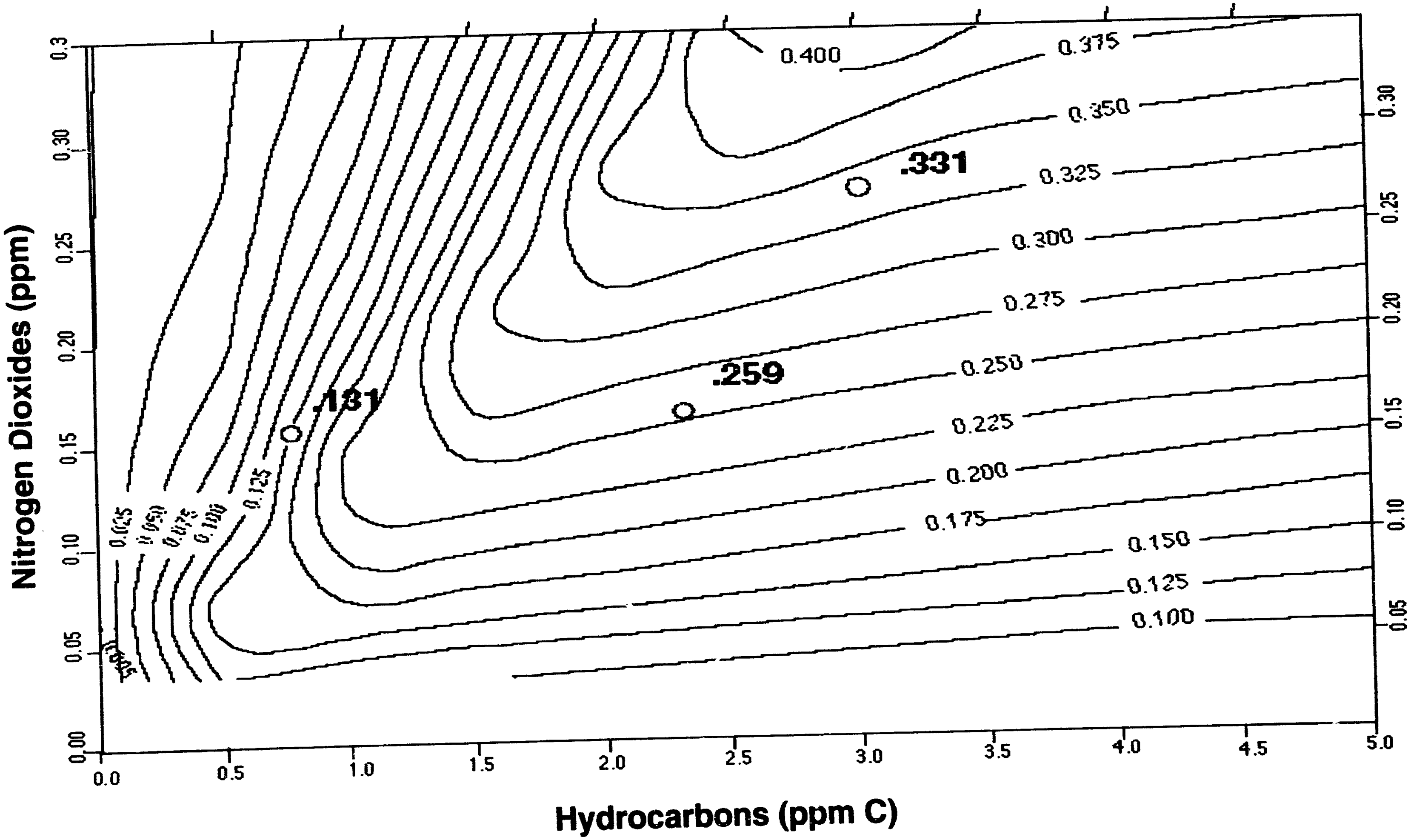

Figure I.1. Isopleth showing the relationship between the hydrocarbon and NO_X concentrations and the resulting peak ozone concentrations. The isopleth was created for conditions existing on February 22, 1991. The three points shown were the points used to generate a plane for the linear approximation of the relationship between HC and NO_X concentrations and the peak ozone levels.

a policy become more important than improving the air quality. The strategy to reduce ozone by 95 IMECA points was chosen because it represents doing everything to reduce air pollution that is cheaper than requiring catalytic converters on all new cars and taxis. Thus, it can represent a policy of reducing air pollution without requiring catalytic converters on automobiles.

The second strategy, to reduce air pollution by 120 IMECA points, is a base case. It represents a moderately aggressive policy to reduce air pollution that will require that all new cars and taxis be equipped with catalytic converters. The ozone, irrespective of its source, is assumed to be reduced in the most cost-effective manner. This base case can be compared with the relaxed approach in strategy one and with strategy three where reduction of emissions from industrial sources are preferentially selected.

The LP model for the third strategy involved inserting a bias toward reducing industrial sources. This was a model of the actions of a staff that assumed that preferentially reducing industrial sources was politically/socially the best policy. The bias toward choosing options that reduce the emissions from industrial sources was added to the LP model by reducing the cost for the industrial options by 1/2. Thus, those nonindustrial options that were very cost-effective were still selected for the strategy, and those industrial options that were very expensive were still not selected in the strategy. Again, this assumes that the staff developing measures to carry out a policy would preferentially choose measures to reduce industrial sources but would not eliminate very inexpensive or effective measures to reduce mobile sources. Conversely, they would not necessarily choose measures that were very expensive to reduce industrial emission.

In the strategic evaluation procedure developed in this project, we test this assumption by using the decision analysis method to consider all factors that are important in evaluating policy. We compare the results of applying the decision analysis method to the industrial case versus the cost-optimized case where the emissions reductions were estimated to be the same. The results will be given in the decision analysis portion of this section.

2. Strategies Selected by the LP Model

The strategies or groups of options chosen by the LP model for the three cases are given in Table I.1. The expected annual costs and improvements in air quality for the three strategies are presented in Table I.2. This table uses as a starting point the peak IMECA values for February 22, 1991, the reference day chosen by the modeling group. The air quality improvement resulting from emissions reductions are subtracted from these staring points to obtain an estimate of the ultimate IMECA values if the strategy had been implemented.

An initial insight from the options selected is a grouping of the options into three groups. The first group is the options that were selected by all three strategies and thus represent the most cost-effective of the options. Since the implementation of an emissions reduction program is a time consuming process, these options would be the initial options that should be implemented. No matter what general policy on emissions reductions is adopted, these options will probably be included in measures that will be adopted to carry out the policy. The second group of options are those that are selected depending on what policy is followed. These would be the next

TABLE I.1 Percent of Options Selected for the Three Strategies

Option #	Description (See Table B-2)	Cost-Optimized IMECA Reduction of 95	Cost-Optimized IMECA Reduction of 120	Industrial Emphasis IMECA Reduction of 120
1	Prod. Int. Stand. Gas	100		
2	Prod. Low S Diesel			
3	Prod. Low S Fuel Oil			
4	Ruta 100 Expand			
5	Auth. Bus Routes	100		
7	Expand Verification	100	100	100
8	LP Gas Conv. & CC's	100	100	
9	CC's on Collectivos	62.5	9.4	89.2
10	Repl. Taxi & Combi			
11	Sub NG for FO in Ind.			
12	Foundries			
13	Tune Boilers	100	100	100
14	NG Power Plants			
15	Reforestation	72.6	71.8	72.3
16	Remove Poll. Veh.	100	100	100
18	Open Burning	100	100	100
19	Paints & Finishes			100
20	Reg. Trash Burners			
22	Vapor Recov. Sys.	100	100	100
23	Offic. Veh. Reduce			
31	Corrd. Traffic Lights			
32	Traffic Info.			
33	Park-N-Ride	100		
34	Taxi Stands	100	100	100
35	Urban Tolls	100		
36	Parking Org.			
37	Line 8 Metro			
38	Electric Trolley	100	100	100
41	Hist. Dist. Park			
43	Metal Cleaning	100	100	100
45	Dry Cleaning	100	100	100
53	Purchase Old Cars			
54	CC's autos		100	100
55	Conv Trucks to CNG	100	100	100
56	Req. 93 Stds. Trucks	67	67	67
57	Repl. Gas Trucks			
58	Pave Roads			

TABLE I.2 Estimated Peak IMECA Values for February 22, 1991 with Strategies Implemented and Annualized Cost for the Three Strategies

	Annual Cost (million $)	Estimated Peak IMECA Feb. 22, 1991				
		Ozone	CO	NO_X	SO_2	Part
Maximum IMECA for Feb. 22, 1991		280	77	74	54	270
		Peak IMECA Values with Strategies Implemented				
Strategy #1 Reduction of Ozone IMECA Value by 33%	333	185	30	63	53	135
Strategy #2 Reduction of Ozone IMECA Value by 43%	582	160	16	55	52	135
Strategy #3 Industrial Emphasis	606	160	20	56	52	135

priority for implementation. The last group of options were not selected by any strategy and these would be the lowest priority options for implementation.

3. Results of Decision Analysis

a. Options

Evaluation results for the options: "Installation of catalytic converters on new vehicles sold in Mexico from October 1990 onward" and "Substitution of natural gas instead of fuel oil in the two major electric power plants in the MCMA" are shown in Table I.3. Table I.4 shows the FOM that was calculated based on Table I.3. The attribute "Air Quality Indexes Reduction" should be evaluated with 3-D air quality simulations results, though at the time this exercise was done, the simulation programs were not ready, so the attribute was graded by the experts. Another remark is that even though a few of the attributes and some of the utility functions were changed after the experts evaluated these options, the grades for the attributes were not modified. The grades were not modified because this would have required another convening of the panel of experts, and it was felt that the original grades would adequately represent, for this demonstration case, the panel's opinion on the new attributes.

Graphs of the WAG and the FOM are shown in Figures I.2 and I.3.

In Figure I.3 the FOM of the two options is shown. The FOM ranks the options, taking into account the technical, economic, environmental, social, political, and institutional factors. In this case the option with the higher FOM, i.e., the one that in the overall evaluation presents the best advantages, is "Installation of catalytic converters on new vehicles sold in Mexico from October 1990 onward." The option GAS performed

TABLE I.3 Decision Tree Utility Values for the Two Test Cases—Requiring Catalytic Converters (CC) and Converting Power Plants to Natural Gas (GAS)

Criteria	Attributes	Sub-Attributes	Utility Values CC	GAS
Technical	Technological Evaluation	Technology Availability	0.5	0.75
		Technology Level	1	0.5
		Tech. Innovation and Implementation Capability	0.75	1
		Technological Efficiency	0.81	0.9
	Materials and Energy Availability		0.5	0.5
	Service and Spare Parts		0.75	0.75
Economics	Investment and Financing	Initial Investment	0.75	1
		Financing and Investment Recovery	1	0.25
	Operating and Maintenance Cost		1	1
	Goods or Service Price to the User		1	0.5
	Cost Incurred Before Results are Apparent		1	1
	Balance of Payments		0.5	0.25
Environmental	Reduction of Air Quality Indexes		0.75	0.5
	Reduction of Pollutant Emissions		0.75	0.75
	Suspended Particle Impact on Visibility		1	0.5
	Implementation Time and Durability		0.63	1
Social, Political, and Institutional	Impact on Income and Employment		0.5	0.5
	Public Opinion		1	1
	Citizen Participation Required		0.05	0.75
	Political Interest		1	1
	Administrative Capabilities		1	1

TABLE I.4 Figure of Merit and Weighted Average Grades for the Two Test Case—Requiring Catalytic Converters (CC) and Converting Power Plants to Natural Gas (GAS)

General Criteria	Weighting Factors	Weighted Average Utility Functions CC	Gas
Technical	26	18.0	18.3
Economic	24.2	21.4	16.5
Environmental	25.3	19.0	17.0
Social, Political, and Institutional	23.5	18.9	20.0
Weighted Average Grade		77.2	71.8
FOM		100	65.6

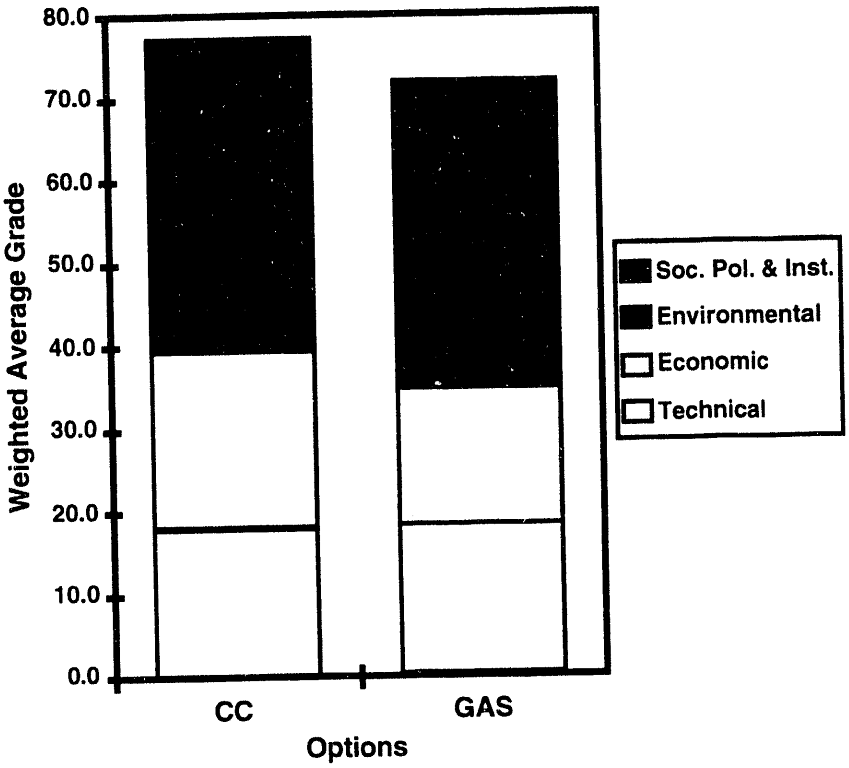

Figure I.2. The WAG for the options "installation of catalytic converters on new vehicles sold in Mexico from October 1990 onwards (CC)" and "substitution of natural gas instead of fuel oil in the two major electric power plants in the MCMA" (GAS). The WAG shows the contribution of each of the general criteria for the FOM.

slightly better in the technical and social-political-institutional general criteria than the other option, mainly because switching from fuel oil to gas in the power plants involves only minor technical modifications, and because the cost of the option was paid by the government, the general public supports this action. Nevertheless, this option scores worse economically than the CC because it is paid by the government compared to the healthier economics of CC, which is paid by the user. Environmentally CC has a larger positive impact than GAS. Because of the scores of CC in the economical and environmental general criteria this option was the one with the highest rank.

b. Strategies

This section presents the evaluation of three strategies (sets of options). The evaluation was made utilizing the MADT method. The strategies were formed using LP as it is shown in Section G of this volume. The strategies were formed from a list of 37 options shown in Table F.2 . Cost-effectiveness studies of the 37 options were used to optimized formation of groups of options (strategies) to combat air pollution. Also a sensitivity analysis graph of ozone reduction vs. cost (shown in section F) was used to select the three strategies evaluated with the MADT method. The lists of options forming strategies

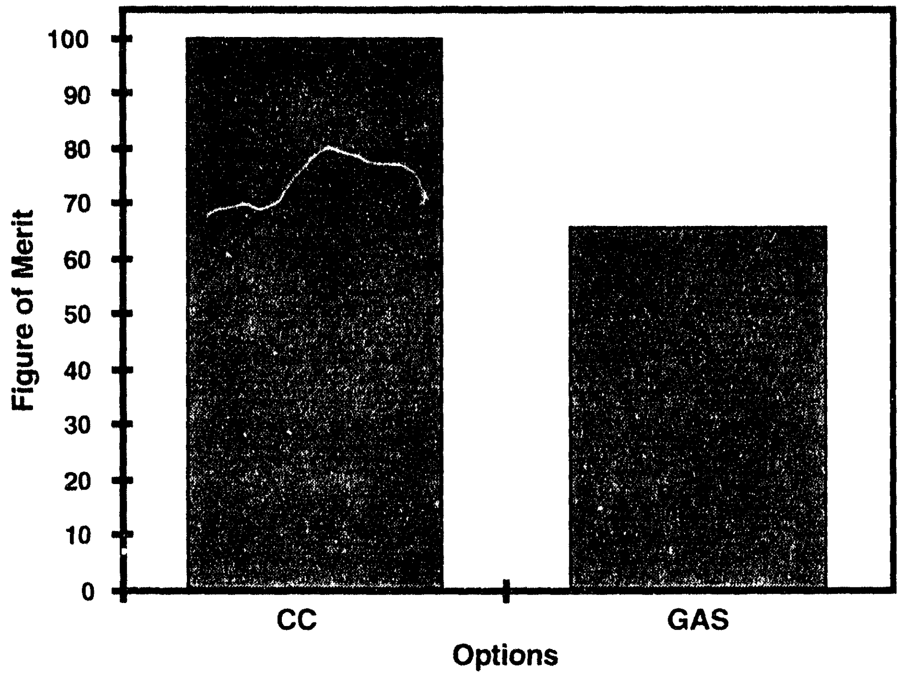

Figure I.3. The FOM of the options "installation of catalytic converters on new vehicles sold in Mexico from October 1990 onwards (CC)" and "substitution of natural gas instead of fuel oil in the two major electric power plants in the MCMA" (GAS). The FOM ranks the options; in this example, the option CC obtained the highest rank.

1, 2 and 3 are shown in Table I.1. To form strategies 1 and 2 all options were treated the same, and the philosophy to select options was to obtain the most cost-effective set of options. For strategy 3, options controlling industrial sources were preferentially chosen.

Strategy number 1 was evaluated first by the panel of experts, then strategy 2 and 3. A roundtable was formed with the experts where the option's grades in each attribute were discussed. For each strategy the grading was as follows: The score for the first option in the first attribute was discussed until a grade for the option was agreed on by a consensus or by voting, the same was done with all the options forming the strategy. The average of these grades was defined as the grade of the strategy in that attribute. The same mechanics were used to obtain the strategy grades in all the attributes except technology efficiency, air quality indexes reduction, pollutant emission reductions, and total suspended particles impact on visibility. Grades for these attributes were calculated using results from 3-D air quality simulations and emissions reductions estimations.

The scores obtained by the three strategies are shown in Table I.5. Grades from Table I.5 were used to calculate the WAG and the FOM of the three strategies. Table I.6 shows these numbers.

TABLE I.5 Utility Values for the Decision Tree for the Three Sample Strategies

Criteria	Attributes	Sub-Attributes	Utility Values Strat 1	Strat 2	Strat 3
Technical	Technological Evaluation	Technology Availability	0.81	0.83	0.80
		Technology Level	0.78	0.80	0.77
		Technology Innovation and Implementation Capability	0.78	0.73	0.77
		Technological Efficiency	0.36	0.43	0.40
	Materials and Energy Availability		0.51	0.59	0.56
	Service and Spare Parts		0.67	0.68	0.67
Economics	Investment and Financing	Initial Investment	0.54	0.52	0.50
		Financing and Investment Recovery	0.51	0.52	0.52
	Operating and Maintenance Cost		0.60	0.61	0.60
	Goods or Service Price to the User		0.79	0.78	0.78
	Cost Incurred Before Results are Apparent		0.61	0.65	0.6
	Balance of Payments		0.47	0.47	0.45
Environmental	Reduction of Air Quality Indexes		0.06	0.12	0.12
	Reduction of Pollutant Emissions		0.74	0.88	0.82
	Suspended Particle Impact on Visibility		0.50	0.50	0.50
	Implementation Time and Durability		0.73	0.68	0.70
Social, Political, and Institutional	Impact on Income and Employment		0.63	0.60	0.61
	Public Opinion		0.71	0.71	0.70
	Citizen Participation Required		0.61	0.58	0.58
	Political Interest and Attractiveness		0.72	0.72	0.70
	Administrative Capabilities		0.85	0.88	0.87

TABLE I.6 Figure of Merit and Weighted Average Grades for the Three Sample Strategies

General Criteria	Weighting Factors	Weighted Average Utility Functions Strat 1	Strat 2	Strat 3
Technical	27	16.7	17.8	17.2
Economic	24.2	14.4	14.5	14.3
Environmental	25.3	10.7	12.1	11.7
Social, Political, and Institutional	23.5	16.6	16.5	16.3
Weighted Average Grade		58.39	60.83	59.5
FOM		44.43	100	87.5

The WAG shows the influence of each general criteria in the FOM. In this case, as it can be seen in Figure I.4, strategy 2 obtained the highest scores in the technical and environmental general criteria.

As a result, this strategy is the one with the highest FOM (Figure I.5). In other words, after the overall evaluation, this strategy was seen as more convenient to implement. It was followed by strategy 3 and strategy 1.

4. Discussion of Results

There are not large differences in the results, both in the particular options chosen for the strategies and in the results of the weighted average grades between the three cases. However, when the FOM (see Section I.3.b) is calculated for the three strategies, larger differences appear. The fact that the options selected for all three strategies are similar is an indication that there is a wide range of cost-effectiveness for the different options, and even changing costs by a factor of two has little effect on the relative cost-effectiveness of the options. A broader range of differences in the options selected for the three strategies would have been observed if more options were available to be included in the analysis. Also, in many cases, there were alternative methods to accomplish the results for an option. For this study only one of these alternative methods was chosen. Inclusion of the various alternatives for options might increase the diversity of the results because there would be a larger number of options that could be selected, and this could reduce the number of options that

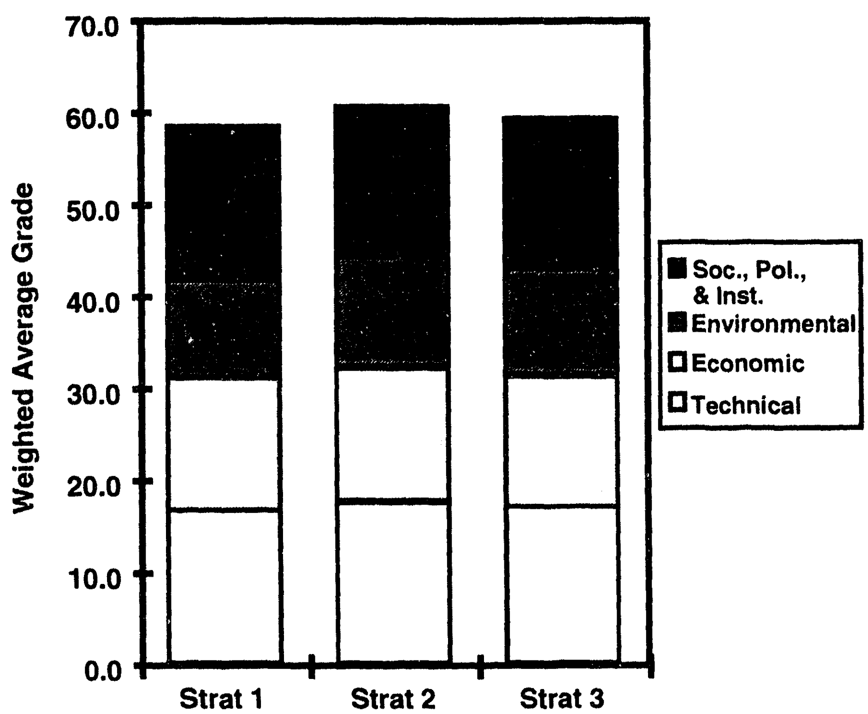

Figure I.4. The WAG for the three strategies. The WAG illustrated the impact for each strategy of the four general criteria in the decision tree.

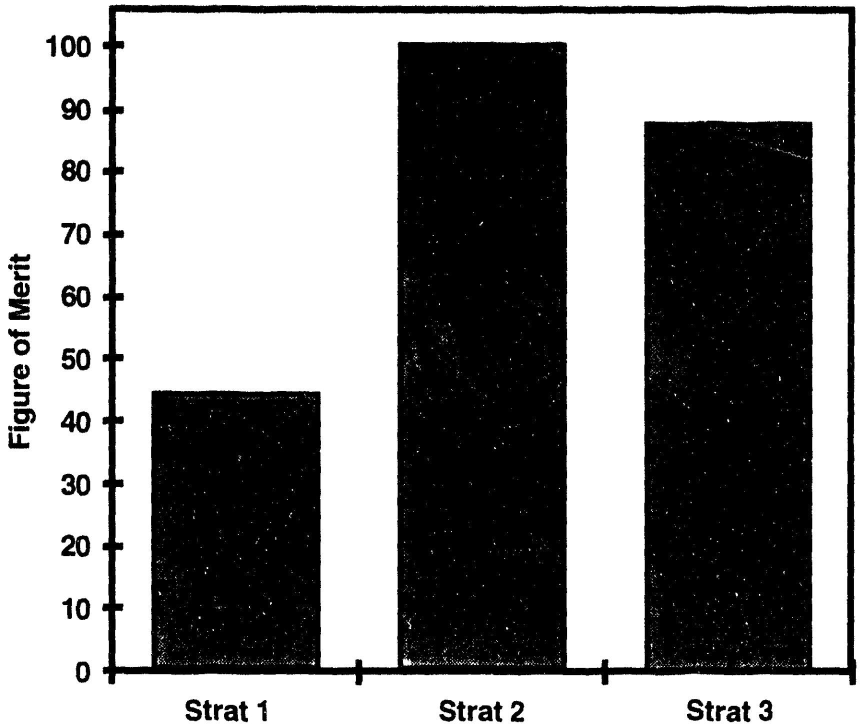

Figure I.5. The figure of FOM for the three sample strategies. Using the specific information presented in the report, Strategy 2 was ranked as the most desirable strategy to pursue.

were common to the various strategies. The positive aspect of the result obtained for this report is that because of the wide range of cost-effectiveness, the priority for implementation of the options is more certain.

Strategy 2, reducing the ozone level by 43% in the most cost-effective manner, was selected as the best of the three strategies that were analyzed. The differences in the FOM are quite large compared with the ranking using the WAG. This shows the importance of the additional weighting given to the most important factors in the decision tree.

As one would expect, strategy 2 achieved a better score in the environmental criteria than did strategy 1, which did not reduce ozone as much. Strategy 2 also ranked higher in the environmental area compared to strategy 3 primarily because strategy 2 resulted in a larger reduction in emissions than did strategy 3. The other area in which strategy 2 was ranked higher was the technical criteria. This was due primarily to the greater efficiency of the options selected for strategy 2 compared to strategies 1 & 3 and because of the availability of materials required to implement the options in strategy 2.

The scores for the economic and social, political and institutional criteria were very similar for all strategies. Thus the difference in the annual cost between strategy 1 and strategy 2 was compensated for by the projected higher initial costs for the options in strategy 1. The scores for the various portions of the social, political, and institutional criteria were all very similar with strategy 1 projected to have less impact on employment and strategy 2 requiring less administrative capability.

J. SUMMARY

1. Utility of Methodology

This project has developed a versatile methodology to analyze potential policies designed to reduce the air pollution in Mexico City. By modeling the process that is used to implement policy in organizations, the methodology gives results that can be used by decision makers to gain insight into the implications of implementing a particular policy and to allow for a comparison of hypothetical policies. Because each step of the methodology uses a set of easily understandable rules in its process, the logic and reasons for the results of the analysis can be easily discerned.

One of the advantages of using the methodology is that it facilitates communication between different organizations in the discussion of policy. Performing the decision analysis on a strategy will insure that all the important criteria, agreed on by participating groups, have been examined. The preset group of rules for selecting strategies facilitates the discussion of why particular options were selected to be included in the strategy. Because the process is easily understood, the connection between changes in the input and the resulting output can be established.

Because the methodology, once established, does not require a large number of man-hours to evaluate a policy, a significant number of policies can be analyzed at a low cost. Policies can also be analyzed in a short period of time using the criteria that are a part of the methodology. Thus the methodology can be used as a screening tool to examine a large number of policies and select those that appear to be the most favorable for further detailed analysis. Also, because the methodology requires that all the important criteria be examined for each strategy, the methodology highlights areas where more or better data are required to adequately analyze policies.

2. Additional Possibilities with Methodology

The LP program can be modified in many ways to reflect different policies under consideration. The example problem for this project used the LP program only to find the least costly set of options for a given reduction in ozone. Other modifications of the LP program could be used to find the maximum ozone reduction for a fixed cost or could look at the maximum emissions reductions for a certain cost.

The industrial policy strategy biases the LP program to select industrial sources. Other biases such as preferentially reducing NO_X emissions, reducing the ozone level preferentially in certain parts of the city, or preferentially selecting those options where cost was paid primarily by consumers could be programmed into the LP technique. Altering the data to reflect the emissions reductions that could be achieved in 5 years for each strategy would allow an analysis of the options that would make the most sense to implement if there was a 5 year planning horizon.

Policies such as reducing the average man-year exposure versus reducing the peak exposure could be modeled. Also, the model, with some modifications, could examine ways to minimize the total exposure to pollutants over a period of years. For example, the program could find the options and their optimum time of implementation that would minimize the total exposure over a 10-year time period, given that only a certain amount of money is available each year for pollution control.

In the above examples the LP optimizes objective values such as cost, emissions reductions and air quality improvement. The LP can also be used to optimize subjective factors such as public acceptance or political attractiveness. Thus, one could model a policy where the options were selected to maximize the public acceptance of a strategy subject to cost and emission reduction constraints. A similar problem could be formulated for political attractiveness.

The ways in which the LP technique can be used to model the procedure and biases of the process of implementing policy is only limited by the imagination and knowledge of the people formulating the LP problems. Continued use of the LP by a wider range of organizations and people will result in additional ideas for using and applications for it.

3. Suggestions for Improvement in Process

Most of the suggestions for improving the process that appear below have been mentioned previously in the discussions of specific parts of the methodology. Ideas have been put forward to address some of the problems listed below and we hope some of these improvements can be instituted in additional follow-up projects or by users of the methodology.

The most important aspect that needs to be improved is the data that are required for analysis, especially the emissions databases. A standardized database needs to be used and better information included in the database. Also, better data for the emissions reductions and cost of the various options are required. Problems were encountered in the strategic evaluation with total emissions reductions that were larger than the emissions in the emissions database that was adopted for MARI. This and the fact that the MARI team members felt that hydrocarbon emissions were underestimated by a factor of four, meant that the strategic evaluation probably gave an overly optimistic view of how much the air quality could be improved with the identified options. Although some reports had very detailed analyses of cost for various options, some of the options only had a cursory analysis. Since costs tend to change upon closer examination, this meant that costs for the options were not all on the same basis. Thus, a more detailed cost analysis of some of the options could change their attractiveness significantly.

Some additional work needs to be done on determining ozone reductions occurring because of reduction in hydrocarbon and NO_X emissions. This will involve more accurate calculations of emission reduction effects and some experimentation with methods to incorporate the calculation of ozone reduction in the LP model. The present optimization with the LP method depends on a linear relationship between NO_X and hydrocarbon reductions and the resulting ozone level. The actual process is far from linear. Thus, one can not assume that the LP method has actually found an optimum point. Because the relationship between NO_X and hydrocarbon reductions and ozone depends on the end points or the total reduction for the strategy for those two emissions, the resulting linear relationship is only accurate for small variations in the total NO_X and hydrocarbon reductions. This limits the number of policies that can be analyzed on a consistent basis and increases the work load in examining different policies.

More cooperative effort between organizations responsible for pollution reduction in Mexico City needs to be encouraged in the area of defining options and policy for the LP. The decision analysis portion of the project did a very good job on this aspect and in future work should emphasize the cooperative aspect with other organizations in the initial parts of the methodology. With most options there are a large number of variations in the manner in which the options could be exercised, and each variation would result in significant differences in costs and emissions reductions. For MARI, assumptions were made by the Los Alamos and IMP team members as to what were to be included in the options and the methods used to implement the options. If personnel that are responsible for developing and implementing options to improve air quality in Mexico City have a larger role in the analysis of the possible options and determining the associated costs and emissions reductions, results will more accurately reflect what is actualıy being considered for Mexico City.

The efforts to improve the structure developed for the decision analysis need to continue. The initial WAG did not produce a wide variation in results for the three strategies. The FOM formulation was introduced, which produced a wider variation between the results for the strategies. The investigation of ways to introduce more separation in the results should continue. The identification of more air pollution reduction options will also help to increase the separation of the results. Larger differences will occur because there will be more options to choose from and it will be less likely that the different strategies will contain many of the same options.

Even though improvements in the data and procedures can and should be made, the strategic evaluation team has established a versatile methodology for evaluating policy related to reducing air pollution in Mexico City. As this methodology is used, it is certain that additional applications and improvements of the methodology will be discovered. Also, as more people become involved in using the methodology, more ways for improving the methodology will be identified.

REFERENCES

(AQMP 1991)
"Air Quality Management Program for the MCMA: Short-Term Program," Vol. 1 & 2, Departamento Distrito Federal, Mexico City, Mexico 1991.

(EPA 1985)
"Compilation of Air Pollutant Emission Factors Volume I: Stationary Point and the Area Sources Fourth Edition," Environmental Protection Agency Report, PB86-124906, Research Triangle Park, N.C., Sept. 1985.

(EPA 1989)
"User's Guide to MOBILE4," U.S. Environmental Protection Agency Report, EPA-AA-TEB-89-01, Ann Arbor, Mich., Feb. 1989.

(JICA 1991)
"The Study on the Air Pollution Control Plan of Stationary Sources in the Metropolitan Area of the City of Mexico," Japan International Cooperation Agency, Mexico City, Mexico, Sept. 1991.

(OECD 1992)
"Emission Control for Nitrogen Oxides and Volatile Organic Compounds: Technology and Cost Compendium,"Organization for Economic Cooperation and Development Report OCDE/GD (91), 223, Paris, France, 1992.

(PICCA 1990)
"Programa Integral Contra la Contaminación Atmospherica: Un Compromiso Común," Departamento Distrito Federal, Mexico City, Mexico Oct. 1990.

(Comisión 1992)
"Programa para el Control de Emisiones Contaminantes al Aire Provenientes de la Industria en la Zona Metropolitana de la Ciudad de México," Comisión Metropolitana Para la Prevención y Control de la Contaminación Ambiental en al Valle de México, Mexico City, March 1992.

(SCAQMD 1989)
"Final Appendix IV-A: Stationary Source Control Measures, Point Sources," South Coast Air Quality Management District, Diamond Bar, California ,1989.

(SCAQMD 1991)
"Final Appendix IV-A: Stationary Source Control Measures, Point Sources, 1991 Revisions," South Coast Air Quality Management District, Diamond Bar, California, 1991.

(Schrange 1991)
Schrange, L., *LINDO: An Optimization Modeling System*, Fourth Edition, The Scientific Press, South San Francisco, California, 1991.

(World Bank 1992)
Mumme C-H., J. Cargajo, G. Eskeland, S. Margulis, K. Wijetilleke, P. Cornwell, J. Cracknell, P. Glaessner, C. Weaver, and T. Yamada, "Mexico: Transport Air Quality Management in the Mexico City Metropolitan Area: Sector Study," Latin America and the Caribbean Regional Office, World Bank Report, Rept. No. 10045-ME, Feb. 1992.

Appendix A
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APPENDIX A
SUMMARY DESCRIPTIONS OF INDIVIDUAL OPTIONS

(note: all options are listed in Table B.1)

Option 1: Produce Gasoline Conforming to International Standards

OPTION DESCRIPTION

This option is assumed to have two parts. One is to reformulate Nova gasoline by adding 5% methyltertiarybutyl ether (MTBE) and reducing the Reid vapor pressure (RVP). The other part of the option is to reformulate Magna Sin gasoline by adding 5% MTBE and reducing RVP.

EMISSIONS REDUCTION

For the first case the annual emissions are (p. 175 World Bank 1992)

	Present	New	Reduction
SO_2	9,132 tons/yr.	9,132 tons/yr.	0
NO_X	52,300 tons/yr.	52,300 tons/yr.	0
HC	193,664 tons/yr.	167,715 tons/yr.	26,000 tons/yr.
CO	2,784,916 tons/yr.	2,375,533 tons/yr.	410,000 tons/yr.
PM-10	3,509 tons/yr.	3,509 tons/yr.	0

For the second part of the options the annual emissions are (pp. 179 and 180 World Bank 1992)

	Present	New	Reduction
SO_2	4,329 tons/yr.	4,329 tons/yr.	0
NO_X	25,597 tons/yr.	25,597 tons/yr.	0
HC	33,464 tons/yr.	26,193 tons/yr.	7,300 tons/yr.
CO	563,558 tons/yr.	512,837 tons/yr.	51,000 tons/yr.
PM-10	1,605 tons/yr.	1,605 tons/yr.	0

The total annual emissions reductions would be

HC	33,300 tons/yr.
CO	461,000 tons/yr.

COSTS

No capital (initial) cost was given for this option.

The annual operational cost of producing the NOVA gasoline is (p. 178 World Bank 1992)
$137 million.
The annual operational cost of producing the Magna Sin gasoline is (p. 180 World Bank 1992)
$58 million.
The total annual operational cost for this option would be
$195 million per year.
Over five years the total cost (capital plus annual operational costs) would be
$975 million.
The total annualized cost of producing International Standard gasoline would be
$195 million per year.

Option 2: Produce Low-Sulfur Diesel

OPTION DESCRIPTION

This option would be to produce diesel fuel with a sulfur content of 0.1% (compared to standard diesel sulfur content of 1% for Mexico).

EMISSIONS REDUCTION

The emissions generated for the two cases of sulfur content are (p. 183 World Bank 1992, using uncontrolled emissions)

	Present	New	Reduction
SO_2	11,752 tons/yr.	1,175 tons/yr.	10,600 tons/yr.
NO_X	29,017 tons/yr.	28,727 tons/yr.	290 tons/yr.
PM-10	3,849 tons/yr.	3,355 tons/yr.	500 tons/yr.

The total annual emissions reductions would be

SO_2	10,600 tons/yr.
NO_X	290 tons/yr.
PM-10	500 tons/yr.

COSTS

No capital (initial) costs were given for this option
The total annual operating cost given for this option is (p. 183 World Bank 1992)
$16.6 million per year.
Over five years the total cost (capital plus annual operational costs) would be
$83 million.
The total <u>annualized cost</u> of producing low-sulfur diesel would be
$16.6 million per year.

Option 3: Produce Low-Sulfur Fuel Oil

OPTION DESCRIPTION

This option would produce low-sulfur fuel oil for use in industrial boilers and the power plants.

EMISSIONS REDUCTION

The emission factors for the present fuel oil are (p. S-35 JICA 1991)

NO_X	0.74 kg/10^6 kcal
SO_2	7.00 kg/10^6 kcal
PM-10	0.28 kg/10^6 kcal

The amount of heavy oil used in Mexico City in 1989 (p. S-12 JICA 1991) was $1{,}607 \times 10^3$ m^3.
The calorific value of the heavy oil is 9.77×0^6 kcal/m^3 (p. S-35 JICA 1991).
Therefore, the annual emissions from the burning of heavy oil is

NO_X	11,600 tons/yr.
SO_2	110,000 tons/yr.
PM-10	4,400 tons/yr.

The emissions reductions for heavy oil with most of the sulfur removed are (p. S-36 JICA 1991)

NO_X	10%
SO_2	73%
PM-10	20%

The total annual emissions reductions would be

NO_X	1,200 tons/yr.
SO_2	80,000 tons/yr.
PM-10	880 tons/yr.

COSTS

The cost for fuel oil with most of the sulfur removed was given as 0.033 new pesos*/1000 kcal (p. S-36 JICA 1991) compared to 0.023 new pesos/1000 kcal for normal fuel oil.

No capital (initial) costs were given for this option.

The total annual operational cost for this option would be
1.53×10^8 new pesos or $50.8 million.

Over five years the total cost (capital plus annual operating cost) would be
$254 million.

The total annualized cost for producing low-sulfur fuel oil would be
$50.8 million per year.

Option 4: Renovate Ruta 100

OPTION DESCRIPTION

This option is a combination of options presented in the Programa para el Control de Emisiońes Contaminantes de la Atmosfería (PICCA 1990) and the short-term Air Quality Management Program (AQMP 1991). The first part of the option is option #14 in the PICCA 1990. A description of the option appears on p. 55 in the PICCA 1990. The option is to renovate 1,750 of the Ruta 100 vehicles by installing new engines. The second part of the option is presented in the short-term AQMP 1991. This is to centralize the maintenance facilities for Ruta 100. The estimate is that this would increase the number of Ruta 100 vehicles on the road by 10%. A description of the plan is presented on pp. 9-36 to 9-40 in the short term AQMP 1991.

EMISSIONS REDUCTION

Renovation of the buses on Ruta 100 would cause the following reduction of total emission levels (p. 46 PICCA 1990).

NO_X	0.4%
HC	0.2%
CO	0.2%

*Exhange rate is 3 new pesos to the dollar.

Using the % of emissions from mobile sources given on p. 33 of PICCA 1990, the reduction of mobile emissions would be

NO_X	0.5%
HC	0.2%
CO	0.2%

Providing a centralized workshop and thus increasing the number of vehicles operating in Ruta 100 is estimated to affect emissions by (p. 9-39 AQMP 1991)

CO	decrease 10,808 tons/yr.
HC	decrease 921 tons/yr.
NO_X	increase 382 tons/yr.

Using the emissions information on p. 153 of World Bank 1992, the effect on mobile source emissions will be

CO	decrease 0.3%
HC	decrease 0.3%
NO_X	increase 0.4%

The effect on total annual emissions reductions for this option would be

CO	decrease 0.5%	17,000 tons/yr. (p. 153 World Bank 1992)
HC	decrease 0.5%	1,400 tons/yr. (p. 153 World Bank 1992)
NO_X	increase 0.1%	increase 88 tons/yr. (p. 153 World Bank 1992)

COSTS

The cost of the renovation of the buses was estimated to be (p. 73 PICCA 1990)
$110.3 million.
The cost of upgrading and centralizing the workshop would be (p. 9-38 AQMP 1991)
$36 million.
The total capital (initial) cost of the option would be
$146.3 million.
There is no annual operating cost given for this option.
Over five years the total cost (capital plus annual operating cost) would be
$146.3 million.

The annualized cost of this option would be $29 million per year for renovating the buses assuming a five-year lifetime for the renovation, and $6 million per year for centralizing the workshop assuming a 10 year lifetime for the shops.

The total annualized cost for renovating Ruta 100 would be
$34 million per year.

Option 5: Authorize Expanded Bus Routes

OPTION DESCRIPTION

This option is option #17 in the PICCA 1990. A description of the option appears on p. 58 of the PICCA 1990. It would grant concessions to private operators of buses to increase the number of buses operating.

EMISSION REDUCTION

The emission reductions are given on p. 46 of the PICCA 1990 and are

NO_X	0.05%
HC	0.8%
CO	1.7%

of the total emissions.

If these values are normalized to mobile emissions using the percentages of emissions from transportation given on p. 33 of the PICCA 1990, the emission reductions in the mobile source would be

NO_X	0.7% or	620 tons/yr. (p. 153 World Bank 1992)
HC	1.5% or	4,200 tons/yr. (p. 153 World Bank 1992)
CO	1.8% or	60,600 tons/yr. (p. 153 World Bank 1992)

The total annual emissions reduction for this option would be

NO_X	620 tons/yr.
HC	4,200 tons/yr.
CO	60,600 tons/yr.

COSTS

The cost for this option is given on p. 73 of the PICCA 1990.

The total capital (or initial) cost for this option is

$30 million.

No annual operating costs were given for this option.

Over 5 years the total cost (capital plus annual operating cost) would be

$30 million.

Assume that the costs given are capital costs for buses and assume a five-year lifetime for the busses.

The total annualized cost of authorizing expanded bus routes would be

$7.9 million per year.

Option 7: Expand Verification Program for Gasoline and Diesel Vehicles

OPTION DESCRIPTION

The proposed changes in the Inspection and Maintenance (I/M) program is described starting on p. 8-2 of the AQMP 1991. A number of options are given for improving the I/M program. For this analysis, options 2 and 4 have been chosen.

Option 2 is to add Bureau of Automotive Repair (BAR) 90 analysis to the I/M system (p. 8-30 AQMP 1991).

Option 4 is to add centralized testing for high use vehicles (Taxis) and Diesel Vehicles (p. 8-45 AQMP 1991).

EMISSIONS REDUCTION

For option 2 the emission reductions are (p. 8-37)

HC	24,000 tons/yr.
CO	130,000 tons/yr.

For option 4 the additional emission reductions are (p. 8-48)

HC	7,600 tons/yr.
CO	36,000 tons/yr.
PM-10	312 tons/yr.

Option 7

Using the emission values for mobile sources given on p. 153 of World Bank 1992 the percentage of change in emissions for the mobile sources will be

HC	increase 11%
CO	increase 5%
PM-10	increase 2%

The total annual emissions reductions for this option would be

HC	31,600 tons/yr.
CO	166,000 tons/yr.
PM-10	312 tons/yr.

COSTS

The cost estimates for five-year operation for the options are

Option 2	$9 million initial (p. 8-36 AQMP 1991).
	$21.9 million annual (.9 Admin. 21 repair).
	$118.5 million total (5 years).
Option 4	$3.6 million initial p. 8-47 AQMP 1991.
	$3.7 million annual (.7 Admin. 3 repair).
	$22.1 million (5 years).

The capital (initial) costs for the option is
$13.6 million.
The total annual operating cost of this option is
$25.6 million per year ($1.6 million Admin./$24 million repair).
Over five years the total cost (capital plus annual operating cost) would be
$140.6 million.

Assuming a five-year lifetime for the BAR analyzers and a 10 year lifetime for the centralized testing facilities, the annualized cost would be

Option 2	$24 million per year.
Option 4	$5 million per year.

The total annualized cost of expanding the verification program would be
$29 million per year.

Option 8: Convert Delivery Trucks to LP Gas and Install Catalytic Converters

OPTION DESCRIPTION

The description of the program to convert delivery vehicles to LPG starts on p. 8-83 AQMP 1991 at the short-term AQMP 1991. The option being used here is the high-technology option: to convert the delivery trucks to LPG and install a 3-way catalytic converter. This option was chosen because it is the only option that controls NO_X. The assumption is that 45,000 delivery trucks are converted to LPG.

EMISSIONS REDUCTION

According to World Bank 1992 (p. 168) the emissions reductions of the retrofit would be (individual vehicle)

NO_X	70%
HC	84%
CO	80%
SO_2	100%
PM-10	50%

Assuming that the delivery trucks are part of the gasoline truck fleet, and using the number of vehicles (196,218) given on p. 152 of World Bank 1992, 45,000 vehicles represent 23% of the gasoline truck fleet. Therefore, the emissions reductions for the total gasoline truck fleet would be

NO_X	16%
HC	19%
CO	18%
SO_2	23%
PM-10	12%

Using emission factors on p. 153 of World Bank 1992, the reductions in total mobile emissions would be

NO_X	3%	2,600 tons/yr.
HC	6%	16,800 tons/yr.
CO	7%	236,000 tons/yr.
SO_2	5%	754 tons/yr.
PM-10	1%	1,400 tons/yr.

The total annual emissions reductions for this option would be

NO_X	2,600 tons/yr.
HC	16,800 tons/yr.
CO	236,000 tons/yr.
SO_2	754 tons/yr.
PM-10	1,400 tons/yr.

COSTS

The cost to retrofit the vehicles is estimated to be $50 million (p. 8-113 AQMP 1991).

The total capital (initial) cost of the option would be

$50 million.

Using the cost analysis in the AQMP 1991, the administrative costs would be

$0.45 million (p. 8-106 AQMP 1991), and an annual fuel savings of $4.7 million (p. 8-113 AQMP 1991) would be realized.

The total annual operating savings of this option would be

$4.25 million per year.

Over five years the total cost (capital plus annual operating cost) would be

$27 million.

The annualized costs for this option would be

Administrative costs.

$0.45 million per year.

Retrofit (assuming a five-year lifetime).

$13.2 million per year.

Fuel savings.

$4.7 million per year.

The total annualized cost of converting delivery trucks to LPG and installing catalytic converters would be

$8.5 million per year.

Option 9: Install Catalytic Converters on Collectivos

OPTION DESCRIPTION

This option is described starting on p. 8-120 of the AQMP 1991. Collectivos are limited to 49,000 vehicles registered in the DDF. Approximately 15% more than this are actually operating in Mexico City (p. 8-123 AQMP 1991). Collectivos consist of Combis (80% VW microbuses, 20% autos) and microbuses generally made by GM, Chrysler and Ford. The estimated 1992 numbers for the vehicles are 33,000 VW microbuses and 17,500 other microbuses operating in Mexico City (p. 8-123 AQMP 1991). Of the VW microbuses, about 7000 or 21% are suitable for retrofit of catalysts, while about 12,000 (3,600 Chrysler, 9,400 GM) or 68% of the other microbuses are suitable for retrofit.

EMISSIONS REDUCTION

Emission reduction rates for vehicles retrofitted with catalytic converters are (p. 8-134 AQMP 1991)

	HC	CO	NO_X	Fuel Economy
VW	55%	55%	0	increase 5%
GM	50%	50%	0	increase 5%
Chrysler	60%	60%	50%	increase 5%

Thus, the reductions in the emissions due to combis and microbuses will be

	HC	CO	NO_X
Combis	12%	12%	0
Microbuses	36%	36%	10%

The annual emission values found on p. 153 of World Bank 1992 for combis and mini buses were used to obtain the emission reduction.

The total annual emissions reductions for this option will be

HC	6,800 tons/yr.
CO	103,000 tons/yr.
NO_X	224 tons/yr.

COSTS

The cost per conversion kit are (p. 8-150 AQMP 1991)

VW	$1030
GM	$1000
Chrysler	$1210

Also assume $100 for loss of vehicle for a day (p. 8-151 AQMP 1991).

The initial costs per vehicle are

VW	7,000 × \$1030 + 7,000 × \$100 = \$7.9 million
GM	9,400 × \$1000 + 9,400 × \$100 = \$10.3 million
Chrysler	3,600 × \$1210 + 3,600 × \$100 = \$4.7 million
Total	\$22.9 million

Retrofit kits will have to be certified and an inspection program set up. These costs are (p. 8-148 AQMP 1991)

Certification	\$12,000
Training	\$5,260

The total capital (initial) costs for this option would be
\$22.9 million.
Enforcement would cost \$10,850 per year.

The conversions will cause an increase of 5% in fuel consumption for all vehicles. The fuel costs given on p. 8-153 AQMP 1991 are for the price difference between Nova and Magna Sin gasoline. Since this difference has been eliminated, there will only be a 5% increase in fuel costs. The annual increased fuel cost from increasing gasoline [illegible]om 0.710 new pesos/liter to 1 new pesos/liter is given as \$1,645 per vehicle per year. Thus, th[illegible]erage annual operating cost of a vehicle is equal to

$$\$1{,}645 \times \frac{0.710}{-0.710} = \$4{,}100 \text{ per year per vehicle.}$$

With gasoline at 1.2 new pesos/liter (p. viii World Bank 1992) the annual gasoline cost per vehicle would be

$$\frac{1.200}{0.710} \times \$4{,}100 = \$6{,}900 \text{ per year.}$$

A 5% increase in this cost would be
\$350 per year per vehicle.
Since 19,000 vehicles are being retrofitted, cost per year for the vehicle owners would be
\$6.6 million per year.
The total annual operational cost would be
\$6.6 million.
Over five years the total cost (capital plus annual operating cost) would be
\$55.9 million.

The annualized costs would be (assuming a five-year lifetime of the conversion)

VW	$7{,}000 \times 350 + 1000 \times 7{,}000 \times 0.264$ = \$4.3 million/yr.
GM	$9{,}400 \times 350 + 1000 \times 9{,}400 \times 0.264$ = \$5.8 million/yr.
Chrysler	$3{,}600 \times 350 + 1210 \times 3{,}600 \times 0.264$ = \$2.4 million/yr.
Admin. costs	\$0.07 million per year

The total annualized cost of installing catalytic converters on collectivos would be \$12.6 million per year.

Option 10: Replacement of Taxis and Combis

OPTION DESCRIPTION

This option would require that all taxis be newer than the 1984 model year and all combis be newer than the 1980 model year. From the 1991 registration of vehicles in the DDF, 97% of the taxis were older than 1985 and 65% of the combis were older than 1980.

EMISSIONS REDUCTION

Using emission values on p. 163 of World Bank 1992, the emissions per taxi would be

	Present	New	Difference
NO_X	1.53 g/km	0.62 g/km	0.91 g/km
HC	3.59 g/km	0.53 g/km	3.06 g/km
CO	57.19 g/km	2.1 g/km	55.09 g/km
SO_2	0.25 g/km	0.07 g/km	0.18 g/km
PM-10	0.091 g/km	0.07 g/km	0.021 g/km

Assuming 56,950 operating taxis (p. 152 World Bank 1992) traveling 73,000 km per year the net emissions reduction would be

NO_X	3,600 tons/yr.
HC	12,100 tons/yr.
CO	218,000 tons/yr.
SO_2	710 tons/yr.
PM-10	83 tons/yr.

The emissions reductions from combis was estimated from the present emissions form combis (p. 148 World Bank 1992) and new emission standards for minibuses (p. 165 World Bank 1992).

	Present	New	Difference
NO_X	1.58 g/km	1.5 g/km	0.08 g/km
HC	4.40 g/km	2.5 g/km	1.9 g/km
CO	70.8 g/km	55 g/km	14.2 g/km
SO_2	0.3 g/km	0.26 g/km	0.03 g/km
PM-10	0.181 g/km	0.06 g/km	0.121 g/km

Assuming 57,600 combis (p. 152 World Bank 1992) in Mexico City with 65% of them to be replaced, traveling 73,000 km annually, the net emissions reductions would be

NO_X	216 tons/yr.
HC	5,100 tons/yr.
CO	8,400 tons/yr.
SO_2	81 tons/yr.
PM-10	330 tons/yr.

The total annual emission reduction for the option would be

NO_X	3,800 tons/yr.
HC	17,200 tons/yr.
CO	260,000 tons/yr.
SO_2	790 tons/yr.
PM-10	410 tons/yr.

COSTS

The cost per taxi to replace taxis would be (p. 165 World Bank 1992)
$8,335.
The costs per minibus to replace minibuses would be (p. 165 World Bank 1992)
$10,000.
The total capital (initial) cost of the option would be
$850 million.
For taxis the annual fuel cost differential is
$1,760 per year per taxi.

The maintenance savings is
$800 per year per taxi.
Giving a net annual operating cost per taxi of
$960 per year, or a total operating cost for all the taxis of
$54.7 million per year.
For collectivos the annual fuel cost differential is
$4,137 per year;
Maintenance cost savings is
$500 per year,
for a net annual operating cost per vehicle of
$3,600 per year.
Assume 65% of 57,600 combis were replaced giving a net annual operating cost of
$134 million.
The total annual operating cost for the option would be
$190 million per year.
Over five years the total cost (capital plus annual operating cost) would be
$1,800 million.
Assuming a five-year lifetime for taxis, the annualized cost would be
$2,200 per vehicle.
Adding the increased operating expenses would bring the total annualized cost per vehicle to
$3,160 per vehicle year.
Replacing 56,950 taxis would bring the total annualized cost for replacing taxis to
$180 million per year.
For Minibuses (assuming a 10-year lifetime) the annualized capital cost per vehicle would be
$1,630 per vehicle per year.
Adding the increased operating expenses, the annualized cost per vehicle is
$5,230 per vehicle year.
Assuming 65% of the 57,000 combis are replaced, the annualized cost would be
$194 million per year.
The total annualized cost of replacing taxis and combi's would be
374 million per year.

Option 11: Substitute Natural Gas for Fuel Oil in Industry

OPTION DESCRIPTION

This option involves mandating the substitution of natural gas for fuel oil in industry boilers.

EMISSIONS REDUCTION

The emission factors for heavy oil are (p. S-35 JICA 1991)

NO_X	0.74 kg/10^6 kcal
SO_2	7.00 kg/10^6 kcal
PM-10	0.28 kg/10^6 kcal

Assuming 1,607 × 10^3 m^3 of heavy oil was used in Mexico City (p. S-12 JICA 1991) and that the calorific value of heavy oil was 9.77 × 10^6, the annual emissions due to the burning of heavy oil are

NO_X	11,600 tons/yr.
SO_2	110,000 tons/yr.
PM-10	4,400 tons/yr.

The emissions factors for natural gas are (p. S-35 JICA 1991)

NO_X	0.33 kg/10^6 kcal
SO_2	0.001 kg/10^6 kcal
PM-10	0.02 kg/10^6 kcal

Therefore, the emission from natural gas for a complete substitution for fuel oil is

NO_X	5,200 tons/yr.
SO_2	16 tons/yr.
PM-10	300 tons/yr.

The total annual emissions reductions for this option would be

NO_X	6,400 tons/yr.
SO_2	110,000 tons/yr.
PM-10	4,100 tons/yr.

COSTS

This options was assumed to have no capital (initial) costs associated with it.

The price per kcal of the present fuel oil is 23.3 pesos/10^3 kcal and for natural gas is 0.0288 new pesos/10^3 kcal. Thus, the price differential is 0.0055 new pesos/10^3 kcal (p. S-35 JICA 1991).

The total annual operating cost for this options is

8.6 × 10^7 new pesos or 28.8 million $ per year.

Over five years the total cost (capital plus annual operating cost) would be
$144 million.
The total annualized cost for substituting natural gas for fuel oil in industry would be
$28.8 million per year.

Option 12: Clean the Foundries in the Valley of Mexico

OPTION DESCRIPTION

On pp. 78 and 79 of Comisión 1992, there is a list of high priority industries for control. In this list about 30 of them are foundries or are concerned with metal production. Assume that these 30 industries account for 80% of the inventoried emissions from foundries on p. 7-36 of AQMP 1991.

EMISSIONS REDUCTION

The foundry emissions given on p. 7-36 are

SO_2	455 tons/yr.
NO_X	83 tons/yr.
CO	6,670 tons/yr.
Part	1,279 tons/yr.

Controls have already been established on 43% of the foundries so the additional reduction in PSTs that are available are 729 tons per year of PSTs.

The primary emission to be controlled in foundries is particulates, and the method chosen to control the particulates is a construction of bag houses. Bag houses are 92 to 99% percent efficient (p. 40 Comisión 1992) in removing particles from the air. Because not all the air from the foundry will go through the bag house, assume that construction of bag houses will reduce the particulate emission by $0.8 \times 0.9 \times 729 = 525$ tons per year.

The total annual emission reduction for this option would be

Part	525 tons/yr.

COSTS

The cost of a bag house ranges from $5,000 to $3.7 million (p. 40 Comisión 1992). Assume that most of the foundry operations are small, so that an average bag house cost would be $20,000. Installation of 17 bag houses would cost $0.34 million.

The total capital (initial) cost for this option is

$0.34 million.

The operating cost for a bag house is given as $45,000 per year (p. 40 Comisión 1992). Seventeen bag houses are assumed to be required.

The total annual operating costs for this option is

$0.76 million per year.

Over five years the total cost (capital plus annual operating cost) would be

$4.2 million.

The annualized capital cost fore installation would be

$0.09 million per year.

The total <u>annualized cost</u> for cleaning the remaining foundries would be

$0.86 million per year.

Option 13: Improve Composition and Install Control Equipment on Industrial and Commercial Boilers

OPTION DESCRIPTION

The program proposed by DDF to control industrial emissions is given on p. 60 of Comisión 1992, for this option use

1. Establishing an emission verification program.
2. Modernizing and improving maintenance on industrial and commercial oil boilers.
3. Putting scrubbers on top oil users.
4. Putting low-NO_X burners on 50 largest natural gas users.
5. Requiring all other natural gas users to incorporate low-NO_X strategies for boiler operation.

EMISSIONS REDUCTION

From p. 7-32, AQMP 1991 the annual fuel sales in the MCMA for non-transportation uses are

Fuel Oil	1,473,800 m^3/yr.
Diesel	458,000 m^3/yr.
Natural Gas	2,623,200,000 m^3/yr.

Using the distribution of fuel consumption given on p. 7-33 AQMP 1991, the amount of fuel consumed by each sector is

	Industrial	Commercial
Fuel Oil	500,000 m^3/yr.	206,000 m^3/yr.
Diesel	320,000 m^3/yr.	140,000 m^3/yr.
Natural Gas	2,260,000,000 m^3/yr.	260,000,000 m^3/yr.

Using the emission factors on p. 7-34 of the AQMP 1991, the emissions from each source would be

(Tons/yr.)	PM-10	SO_2	NO_X	CO	HC
Industrial					
Fuel Oil	2700	43,500	3,300	300	77
Diesel	77	14,000	770	200	21
Natural Gas	108	22	20,000	1,446	99
Commercial					
Fuel Oil	1091	17,922	1,360	32	124
Diesel	34	6,000	336	9	84
Natural Gas	12	2	2,288	11	166
Total	2,885	68,846	28,054	1,998	571

According to EPA 1985, pp. 1.3-2, unmaintained boilers can emit 10 to 100 times the amount of CO and HC as maintained boilers. Properly tuned boilers can reduce NO_X emissions by 5-20%. Assume that a combined program of inspection and increased maintenance will reduce CO, HC, and Particulate emissions by 50% and NO_X emissions by 10%. This would result in the following emission reductions:

PM-10	1,950 tons/yr.
NO_X	580 tons/yr.
CO	270 tons/yr.
HC	150 tons/yr

The top 10 of the oil users listed on pp. 12 and 13 of Comisión 1992 account for 5% of the industrial oil use (pp. 7-32, 33 AQMP 1991). If these facilities installed scrubbers, particulates would be reduced by 68%, and NO_X by 95% (p. 40 Comisión 1992). SO_2 would be reduced by 90% (EPA 1985 p. 1.3-5). Therefore, the emissions reduction from this part would be

Part	92 tons/yr.
NO_X	157 tons/yr.
SO_2	1,960 tons/yr.

Installing low-NO_X burners on natural-gas-fired boilers will reduce the NO_X emissions by 60% (p. 40 Comisión 1992). The 50 top natural gas users (p. 15 Comisión 1992) account for 66% of the Industrial and Commercial natural gas use (pp. 7-32, 33 AQMP 1991) Using these values the emissions reductions would be

NO_X	8,800 tons/yr.

Tuning the remaining boilers for low-NO_X operation by limiting excess air could reduce NO_X emissions by 25%. Thus, the emission reduction from the remaining 34% of the boilers will be

NO_X	1,900 tons/yr.

The total annual emissions reduction for this option are

Part	2,042 tons/yr.
SO_2	1,960 tons/yr.
NO_X	11,400 tons/yr.
CO	270 tons/yr.
HC	150 tons/yr.

COSTS

Parts 1 and 2

Assume that 70% of the industrial and commercial establishments use fuel oil or diesel. There are approximately 30,000 industrial establishments in Mexico City (p. 3 Comisión 1992), so that 21,000 of these are assumed to use fuel oil or diesel. Establishing an inspection program to inspect each boiler once every five years would require 10 inspection teams assuming each inspection team would consist of two persons. Therefore, the costs of establishing and operating inspection teams would be

1. 10 cars @ $15,000.
2. Equipment @ $10,000 per vehicle.
3. Miscellaneous capital @ 10% of capital costs.
4. 20 inspectors @ $10,000 per year.
5. 10 auto operating costs @ $40 per day, 250 days per year.
6. Miscellaneous operating costs @ 25% of other costs.

Assume that as a result of the inspection an average repair of $1,000 is required per boiler.

The capital (initial) cost for parts 1 and 2 of the option is

$0.28 million.

The annual administrative costs for part 1 of the option is

$0.38 million per year.

The annual repair cost is

$4.2 million per year.

The annual operating cost for parts 1 and 2 of the option is

$4.6 million per year.

Part 3

The cost of installing scrubbers is estimated to be $0.2 million each, with an annual operating cost of $0.03 million (p. 40 Comisión 1992). Scrubbers are to be installed in the 10 largest facilities.

The capital (initial) cost for part 3 of the option is

$2 million.

The annual operating cost for part 3 of the option is

$0.3 million per year.

Part 4

Low-NO_X burners are estimated to cost $0.05 million each (p. 40 Comisión 1992), and an estimate of the annual operating cost is $10,000. Low-$NO_X$ burners would be installed on the top 50 natural gas users.

The capital (initial) cost for part 4 of the option would be

$1.25 million.

The annual operating cost for part 4 of the option would be

$0.5 million per year.

Part 5

In order to insure that natural gas boilers were tuned for low-NO_X operation, inspection at the boilers would be required. About 1/3 of the effort would be needed to inspect natural gas boilers because of the smaller number of boilers. Thus, the cost would be 1/3 of that to inspect fuel oil boilers.

The capital (initial) cost for part 5 of the option would be

$0.07 million.

The inspection cost for part 5 would be

$0.13 million per year.

Repair costs for natural gas boilers are estimated to be $100 per boiler. Thus, the annual repair cost would be

$0.2 million.

The total annual operating cost for part 5 of the option would be
$0.33 million per year.
The total capital (initial) cost for the option would be
$3.53 million.
The total annual operating cost for the option would be
$5.4 million per year.
Over five years the total cost (capital plus annual operating cost) would be
$33.5 million.
The annualized capital cost for part 1 and 2, assuming a five-year lifetime would be
$0.07 million per year
for a total annualized cost of
$4.6 million per year.
For part 3, the annualized scrubber capital costs (assuming a 10-year lifetime) would be
$0.8 million per year.
The total annualized cost for scrubber installation (part 4) would be
$1.1 million per year.
Low-NO_X burners (part 5) capital costs would have an annualized capital cost (assuming a 10-year lifetime) of
$0.4 million.
The annualized cost for installation of low-NO_X burners would be
$0.9 million per year.
The total annualized cost for improving composition and installing control equipment on industrial and commercial boilers would be
$7 million per year.

Option 16: Remove Very Obviously Polluting Vehicles and Prevent them from Entering the City

OPTION DESCRIPTION

There are two parts to this option. The first part is the Heavy-Duty Roadside Vehicle Inspection Program which is described on p. 8-183 of the AQMP 1991. The second part of this option is to allow traffic police to ticket obviously polluting vehicles in order to remove them from the roads. The roadside inspection program consists of inspection stations located on five main travel corridors into Mexico City. They would have test equipment to test vehicles. The vehicles would be selected for testing by observing them as they climbed a grade, and those that emitted smoke would be pulled over for testing. The other part of the option would be to have traffic police issue tickets to obviously polluting vehicles. The purpose of the tickets would be to remove the vehicle from the streets until its emissions were improved. For the second part assume that 5% of the most polluting 5% of cars were removed from the streets and replaced with cars with emissions equal to the median car emissions in Volume IV, Section C2.

EMISSIONS REDUCTION

The establishment of roadside inspection stations is estimated to reduce particulate emissions by 1,078 tons per year. Using emission factors on p. 153 of World Bank 1992, this represents 8% of the mobile source of PM-10. From the Volume IV, C.2, the top 5% of the cars emit 11.7% of the CO and 28.9% of the HC. Removing 5% of these vehicles will remove 0.6% of the CO and 1.4% of the HC emissions from private vehicles.

Since these cars will be replaced with cars that have emissions equal to the median car in Volume IV, C.2 data, not all of these emission reductions will be realized. Only 60% of the emissions reductions for CO and 89.6% of the emission reduction for HC will be realized when the cars are replaced. Therefore, the percentage reduction in the emissions of private vehicles will be

CO	0.1%
HC	0.5%

The mobile emissions on p. 153 of World Bank 1992 were used to generate the tons per year emission reductions.

The total annual emissions reductions for this option are

CO	3,400 tons/yr.
HC	1,400 tons/yr.

COSTS

The capital cost for the Heavy-Duty Vehicle Roadside Inspection is estimated to be $0.6 million (p. 8-197 AQMP 1991).

The total capital (initial) cost for the options is

$0.6 million.

The annual cost for the roadside inspection is $0.4 million (p. 8-197 AQMP 1991).

For the second part of the option, assume that the administrative costs per vehicle removed would be $300.

5% most polluting × 1% removed per year × 2.2 million vehicles = 1,100 vehicles per year, for a total cost of $0.52 million.

The total annual operating cost of the option would be

$0.92 million per year.

Over five years the total cost (capital plus annual operating cost) would be

$4.2 million.

The annualized capital cost for inspection stations assuming a 10-year lifetime would be $0.1 million per year.

The total annualized cost for removing very obviously polluting vehicles and preventing them from entering the city would be

$0.8 million per year.

Option 18: Prohibit All Open Burning

OPTION DESCRIPTION

There are three sources of open fires given in the AQMP 1991 (p. 7-44): trash fires, forest fires, and burning of agricultural waste. In order to enforce the prohibition of open fires, some surveillance will be needed. We propose to use light planes with infrared sensors that will patrol the city and locate open fires. One plane could probably cover the city, but in order to have the capability for surveillance at any time, 2 planes will be required. Also, six pilots and observers will be required for 24-hour capability. Information on fires would be relayed to ground personnel for verification. I assume that this surveillance will eliminate 80% of the trash fires, 80% of the agricultural fires, and 50% of the forest fires. Increased fire-fighting equipment may also be required, but it is not taken into account in the calculation of cost.

EMISSIONS REDUCTION

The estimated emissions from open burning are (p. 7-44 AQMP 1991)

	Trash	Agricultural	Forest
NO_X	785 tons/yr.		146 tons/yr.
HC	5,655 tons/yr.	1801 tons/yr.	881 tons/yr.
CO	10,997 tons/yr.	11,230 tons/yr.	5135 tons/yr.
Part	2,095 tons/yr.	1,483 tons/yr.	623 tons/yr.

The total annual emissions reductions for this option are

NO_X	700 tons/yr.
HC	6,400 tons/yr.
CO	20,349 tons/yr.
Part	3,200 tons/yr.

COSTS

The requirements necessary to carry out this option are

1. 2 light planes @ $70,000.
2. Miscellaneous equipment @ 10% of capital.
3. Six pilots @ $30,000 per year.
4. Six observers @ $15,000 per year.
5. Three full time equivalent ground personnel @ $15,000 per year.
6. Miscellaneous operating expenses @ 10%.

The total capital (initial) costs for this option would be
$0.154 million.
The total annual operating costs for this option would be
$0.194 million per year.
Over five years the total cost (capital plus annual operating cost) would be
$1.12 million.
The annualized capital costs assuming a five-year lifetime for the planes would be
$0.04 million per year.
The total annualized cost of prohibiting open burning would be
$0.23 million per year.

Option 19: Limit Use of Paints and Finishes

OPTION DESCRIPTION

Actions to reduce emissions from paints and finishes are

1. Convert residential oil-based paints to water-based.
2. Convert auto refinishing paints and cleaners to water-based or high-solids-content paint.
3. Require emission controls on assembly line auto painting.
4. Convert other paints to water-based or high-solids formulation.

EMISSIONS REDUCTION

The amount of paints and finishes used in Mexico City is given on p. 7-39 AQMP 1991. The values are

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Centimeter

Inches

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Residential oil-based	10,800 m^3/yr.
Residential water-based	24,620 m^3/yr.
Auto refinishing	1,980 m^3/yr.
Auto painting	1,540 m^3/yr.
Metallic furniture	2,590 m^3/yr.
Wood furniture	8,100 m^3/yr.
Cans & other containers	2,880 m^3/yr.
Other industrials	1,170 m^3/yr.
Solvents & thinners	10,600 m^3/yr.

The emission factors for these items are given on p. 7-43 AQMP 1991. Multiplying the factors times the amount used, the following emissions from paints and finishes are obtained:

Residential oil-based	4,860 tons/yr.
Residential water-based	1,230 tons/yr.
Auto refinishing	1,250 tons/yr.
Auto painting	1,970 tons/yr.
Furniture	1,950 tons/yr.
Wood furniture	3,159 tons/yr.
Cans & other containers	1,296 tons/yr.
Other industries	456 tons/yr.
Solvents & thinners	8,162 tons/yr.

Part 1

Convert residential oil-based paints to water-based. Assume that 80% of the present day oil-based paint used for residential buildings can be replaced with water-based paints. From p. 7-43 of AQMP 1991, water-based paints reduce hydrocarbon emissions by 90% compared to oil-based paints. Therefore, converting 80% of the present oil-based paint to water-based would reduce emissions of HC by 3,460 tons per year.

Part 2

Convert auto refinishing paints and cleaners to water-based or high-solids content. Assume lacquers constitute 19%, enamels 45%, and primers 36% of paints used for auto refinishing. (PC-3 SCAQMD rule 1151). The as-bought paints are thinned by adding solvents. The amount of solvent that is typically added is

Lacquer	1.25 l/l
Enamel	0.40 l/l
Primer	1 l/l

The amount of paint (as sold) and solvent used in auto refinishing in Mexico City is

Lacquer	376 m^3/yr.
Enamel	891 m^3/yr.
Primer	712 m^3/yr.
Solvent	1,424 m^3/yr.

In addition to solvent use in paints, solvent is used for surface preparation and equipment clean-up. The SCAQMD estimates that the solvent use is 30% of the as-sold paint use or 600 m^3/year for Mexico City (p. C-2 SCAQMD rule 1151).

The weighted emission factors for the as-applied paint can be calculated using emission factors for paint and solvent given on p. 7-43 of AQMP 1991 and the dilution factors for the various paints. The as-applied emission factors are

Lacquer	0.707 kg/l
Enamel	0.67 kg/l
Primer	0.70 kg/l

Clean-up solvent and the as-applied amounts are

Lacquer	850 m^3/yr.
Enamel	1,250 m^3/yr.
Primer	1,400 m^3/yr.

Thus, the HC emissions for each component are

Lacquer	600 tons/yr.
Enamel	840 tons/yr.
Primer	900 tons/yr.
Clean-up solvent	462 tons/yr.

The use of water-based and high-solids-content paint is assumed to reduce emissions of as-applied paint by (p. C-2 and 13 SCAQMD rule 1151)

Lacquer	40%
Enamel	33%
Primer	60%

Also, the SCAQMD analysis stated that 100% of the solvent used for equipment cleaning could be recovered, eliminating emissions from that source. Assume that this is 75% effective in Mexico City. Thus, the emissions from auto refinishing would be reduced by

Lacquer	240 tons/yr.
Enamel	277 tons/yr.
Primer	540 tons/yr.
Clean up Solvent	350 tons/yr.
For a total of	1,400 tons/yr.

Part 3

Require emission controls on assembly-line auto painting. According to SCAQMD 1991, p. A-7, emission reductions of 10 to 30% are possible for auto manufacturers' painting operations. Assuming a 20% reduction, the emission reductions from auto assembly painting would be

190 tons of HC per year.

Part 4a

Use water-base and high-solids paints for metallic furniture.

Assuming the same distribution of lacquers, enamels, primer, and cleaning solvent for coatings of metallic furniture as that for autos, the amount of each would be

Lacquer	490 m^3/yr.
Enamel	1200 m^3/yr.
Primer	930 m^3/yr.
Clean-up solvent	780 m^3/yr.

The emissions for the paint would be (p. 7-43 AQMP 1991)

Lacquer	340 tons/yr.
Enamel	900 tons/yr.
Primer	700 tons/yr.
Clean-up solvent	600 tons/yr.

Assuming that the above values are for as-applied paints and assume the reduction from the use of water-based or high-solids paint is the same as that for automobile refinishing, and that reclamation of clean-up solvent is 50% effective, the emission reductions would be

Lacquer	140 tons/yr.
Enamel	300 tons/yr.
Primer	420 tons/yr.
Clean-up solvent	300 tons/yr.
For a total HC reduction of	1,160 tons/yr.

Part 4b

Convert finishes for wood furniture to water-based or high-solids finishes.

Assume that coverings use is equally divided between varnishes, stains, sealers, enamels, and primer, or 1,600 m^3/yr. use of each. Assume that the substitution of water-based or high-solids formulation will reduce emissions by the following amounts:

Varnish, stain, sealer 60% (sealer reduction p. 4.2.2.5.-4 EPA 1985)

Enamel	33%
Primer	60%

Therefore, using the emission factor on p. 7-43 AQMP 1991 and the above reductions, the emission reductions will be

Varnish, stain, sealer	1,120 tons HC/yr.
Enamel	206 tons/yr.
Primer	375 tons/yr.
For a total of	1,800 tons/yr. of HC

Part 4c

Replace paint presently used for coating cans with water-based paint. The reduction in HC emissions from substitution of water-based paints is estimated to be 60-90% (p. 4.2.2.2-4 EPA 1985) Assuming a reduction of 75%, the emission reduction for HC's for can coating would be

972 tons per year.

Part 4d

Convert industrial paints to water-based or high-solids formulations. Conversion to water-based paints can reduce emissions by 60 to 90% (p. 4.2.2.1-4 EPA 1985). Assuming a 75% reduction, the emission reduction would be

342 tons of HC per year.

Part 4e

Solvents and Thinners.

Of the 7,800 m^3/yr. of solvent and thinner use in Mexico City unaccounted for, assume 50% would not be required if the shift to water-based or high-solids-content formulations were accomplished. Therefore, the reduction in emissions for solvents and thinners would be (p. 7-43 AQMP 1991)

3,000 tons of HC per year.

The total annual emissions reductions for this option would be

12,300 tons of HC per year.

COSTS

Part 1

A check on local prices indicates that water-based architectural paint was $8 per gallon cheaper than oil-based architectural paint. The analysis assumed that 2,300,000 gallons of oil-based paint was replaced by water-based paint, resulting in a net savings of:

$18.2 million per year.

Part 2

SCAQMD (p. D-7 SCAQMD rule 1151) estimates the total cost of substituting water-based for oil-based paints in auto refinishing at $7,000 per ton of HC emissions reduced. This includes costs for additional lamp dryers and a system to capture clean-up solvent. For a reduction of 1,400 tons per year the cost would be

$9.8 million per year.

Part 3

Emission reductions from automobile manufacturing were estimated to cost $19,000 per ton at HC (p. A-5 SCAQMD 19991). Thus, the cost of this part of the option would be

$3.6 million per year.

Part 4a

Metal furniture painting. Assume the costs for emission reductions are the same as those for auto refinishing, or $7,000 per ton of HC reduced. The cost for this part of the option would be

$8.1 million per year.

Part 4b

Wood furniture finishing. The SCAQMD estimates that the cost differential between water-based and oil-based primers is $13 per gallon (p. D-1 SCAQMD rule 1151). Assuming the same cost differential for varnishes, stains, and sealers, the annual cost for converting these items to water-based would be

$22 million per year.

The cost differential between oil-based and water-based enamel was estimated to be $35 per gallon (p. D3 and 4 SCAQMD rule 1151). Thus, the cost of converting the enamel to water-based would be

$17 million per year.

The total cost for this part of the option would be

$39 million per year.

Part 4c

Can coating. Assume the costs for reducing emissions in can coating is similar to those for auto refinishing, or $7,000 per ton of HC emissions reduced. The cost for this part of the option would be

$6.8 million per year.

Part 4d

Industrial painting. Assume the cost of switching industrial painting to water-based paints is $35 per gallon, the cost of this part of the option would be

$10.8 million per year.

Part 4e

Solvents and Thinners. Assuming that 50% of the unaccounted for solvents and thinners are not required because of the switch to water-based paints and that a typical solvent cost is $7.00 per gallon, the cost of this part of the option would be

$7.2 million per year.

There was no capital (initial) cost assumed for this option

Part 1–the annual savings would be

$18.2 million per year.

Part 2–The annual cost would be

$9.8 million per year.

Part 3–The annual cost would be

$3.6 million per year.

Part 4a–The annual cost would be

$8.1 million per year.

Part 4b–The annual cost would be

$39 million per year.

Part 4c–The annual cost would be
$6.8 million per year.
Part 4d–The annual cost would be
$10.8 million per year.
Part 4e –The annual savings would be
$7.2 million per year.
The total annual operating cost for this option would be
$52.7 million per year.
Over five years the total cost (capital plus annual operating cost) would be
$264 million.
The total annualized cost for limiting use of paints and finishes would be
$52.5 million per year.

Option 20: Limit Operation of Closed Trash Burners to Optimum Time of Day

OPTION DESCRIPTION

This option examines the possibility of restricting the hours of burning trash in incinerators to the optimum time of day for environmental consideration. The operation of incinerators would be restricted to the time period 2:00 p.m. to 7:00 p.m. The assumption for this option is that the amount of trash incinerated will not change, just the time the incinerators are operational.

CHANGE OF HOURLY EMISSIONS

About 5,200,000 tons of trash is generated in Mexico City per year (p. 7-38 AQMP 1991). Of that amount 5% is burned in the open (p. 7-38 AQMP 1991) and 3,864,000 tons are deposited in sanitary landfills (p. 7-42 AQMP 1991). This leaves 1,110,000 tons per year to be disposed of in closed trash burners. Assuming 1,000,000 tons of trash is burned in industrial single-chamber trash burners, they would emit (p. 2.1.2 EPA Stationary Source Emission Factors)

Particulates	7,500 tons/yr.
SO_2	1,250 tons/yr.
HC	7,500 tons/yr.
NO_X	1,000 tons/yr.
CO	10,000 tons/yr.

Assume that at present these emissions are produced equally 24 hours a day. The option restricts incinerator operation to optimum hours: from 2:00 p.m. to 7:00 p.m.

Using the total stationary area emissions on p. 7-44 of the AQMP 1991 and assuming an even distribution over 24 hours, the stationary area source would be reduced by the following percentage from 8:00 p.m. to 2:00 p.m. the following day:

Particulates $\frac{7{,}550}{236{,}131} = 3.2\%.$

SO_2	5%
HC	4.6%
NO_X	14.6%
CO	35%

The stationary area emissions would be increased for the hours 2:00 p.m. to 7:00 p.m. by

Particulates $\frac{24}{6} \times 3.2\% = 12.8\%.$

SO_2	20%
HC	18%
NO_X	58%
CO	140%

The hourly reductions in pollutants for 8:00 p.m. to 2:00 p.m. would be

Part	0.9 tons/hr.
SO_2	0.14 tons/hr.
HC	0.85 tons/hr.
NO_X	0.3 tons/hr.
CO	1.14 tons/hr.

The hourly increases in pollutants for 2:00 p.m. to 7:00 p.m. would be

Part	2.7 tons/hr.
SO_2	0.42 tons/hr.
HC	2.7 tons/hr.
NO_X	0.33 tons/hr.
CO	3.4 tons/hr.

COSTS

The cost estimate for this option assumes that 3 inspectors would be hired to monitor the trash burners and one car would be purchased for transportation.

The total capital (initial) costs for this option would be

$0.016 million.

The operational costs would consist of three inspectors @ $15,000 per yr.

The total annual operational costs for this option would be

$0.07 million per year.

Over five years the total cost (capital plus annual operating cost) would be

$0.37 million.

The annualized capital cost (assuming a five-year lifetime) would be

$0.004 million per year.

The total annualized cost for restricting the hours of trash burning would be

$0.07 million per year.

Option 22: Install Vapor Recovery Systems in the Gasoline Distribution System

OPTION DESCRIPTION

This option proposes to install vapor recovery systems in the three stages of gasoline distribution: loading delivery trucks at a central terminal, loading storage tanks at individual stations, and refueling vehicles. A description of the proposed technology for each of the stages or phases is given starting on p. 10-3 AQMP 1991.

EMISSIONS REDUCTION

The estimated emission reductions from phase 0 or the transfer of fuel to delivery trucks at a central terminal is estimated to be (p. 10-9 AQMP 1991)

5,610 tons of HC per year.

The estimated emission reductions from phase 1 or the delivery of gasoline to individual stations is estimated to be (p. 10-16 AQMP 1991)

6,689 tons of HC per year.

The estimated emission reductions from phase II or the refueling of individual vehicles to be (p. 10-22 AQMP 1991)

5,985 tons of HC per year.

The total emissions reductions per year for this option are

18,300 tons of HC per year.

COSTS

The estimated costs for phase 0 are (p. 10-11 AQMP 1991)

$6.8 million capital

$0.6 million per year maintenance and insurance.

The estimated costs for phase I are (p. 10-18 AQMP 1991)

$1.05 million capital

$0.95 million per year maintenance and insurance.

The estimated costs for phase II are (p. 10-23 AQMP 1991)

$10 million capital

$0.9 million per year maintenance and insurance.

The total capital (initial) cost for this options is

$17.85 million.

Maintenance and insurance of these systems is assumed to cost

$2.45 million per year.

In addition to these direct costs there is the cost of an administration and inspection system to insure the controls are functioning properly. The estimated cost for Los Angeles for this is $19,000 per year (p. B-7 Appendix IV-B 1991 SCAQMD). Assuming a similar cost for Mexico City, this will increase the annual costs to:

$2.64 million per year.

Also, there is a net savings of gasoline. Assuming the 95% of the recovered vapors is saved gasoline, and the net gasoline price is 1,200 pesos/liter this would be an annual savings of

$8.8 million per year.

The total annual operating savings for this option is

$6.16 million per year.

Over five years the total cost (capital plus annual operating cost) would be

–$13 million.

The annualized capital costs to phase 0 assuming a 10-year lifetime would be

$1.1 million per year

for a total annualized cost for phase 0 of

$1.7 million per year.

The annualized capital costs for phase I assuming a 10-year lifetime are

$0.17 million per year

for a total annualized cost for phase I of

$1.1 million per year.

For phase II the annualized capital costs assuming a 10-year lifetime are

$1.65 million per year

for an annualized cost for phase II of

$1.5 million per year.

The annual fuel savings is

–$8.8 million per year.

The total <u>annualized cost</u> for installing vapor recovery systems in the gasoline distribution system would be

–$4.5 million per year.

Option 23: Reduce Circulation of Official Vehicles by 30%

OPTION DESCRIPTION

This option would reduce the use of official vehicles in Mexico by 30%. The reductions would be accomplished by the use of electronic communications, sharing of vehicles, and more \efficient use of vehicles.

EMISSIONS REDUCTION

There are about 15,000 official vehicles in the DDF fleet (p. 8-121 AQMP 1991). If we use the emission factors for private vehicles (p. 148 World Bank 1992) minus the diurnal and hot soak evaporative emissions and the mileage accumulation factors for private cars (p. 152 World Bank 1992), 30% of the official vehicles will account for the following emissions:

The total annual emissions reductions for this option are

SO_2	31.5 tons/yr.
NO_X	58 tons/yr.
HC	178 tons/yr.
CO	2,542 tons/yr.
PM-10	6.8 tons/yr.

COSTS

No capital (initial) costs were assumed for this option.

Assuming that the average official vehicle travels 8,400 km per year (average for private vehicles p. 152 World Bank 1992) and 15,000 official vehicles, the total reduction in km traveled per year would be 38,000,000 km per year. Assuming a gasoline consumption rate of 10 km/l (p. vii World Bank 1992), reduced circulation would reduce official vehicle gasoline consumption by 3.8 million liters per year. At a gasoline price of 1.200 new pesos/l (p. viii World Bank 1992) this would mean a cost savings of $1.5 million per year.

Offsetting these savings would be time delay from ride-sharing and walking and increased use of phones and faxes (However, increased phone costs for faxes have been neglected). Assuming an annual DDF budget of 8.9×10^9 new pesos per year (p. 5-35 AQMP 1991) and assuming that not having a vehicle available will cause an average of 2 minutes delay per week per worker, then the cost of the reduced circulation would be

$$\frac{2 \times 8.9 \times 10^9}{40 \times 60} = 7.4 \times 10^6 \text{ new pesos} = 2.4 \text{ million } \$/\text{year}.$$

The total annual operating cost for this option would be
$0.9 million per year.
Over five years the total cost (capital plus annual operating cost) would be
$4.5 million.
The total <u>annualized cost</u> for reducing the circulation of official vehicles by 30% would be
$0.9 million per year.

Option 31: Coordinate Traffic Lights to Speed Flow of Traffic

OPTION DESCRIPTION

This option proposes to install automatic traffic-data collectors at 100 stations and to extend the computer-aided street light system to 1,200 traffic signals (p. 9-40 AQMP 1991).

EMISSIONS REDUCTION

The total annual emission reductions estimated for this options are (p. 9-43 AQMP 1991)

CO	10,600 tons/yr.
HC	800 tons/yr.
NO_X	200 tons/yr.

COSTS

The total capital (initial) cost of this option is (p. 9-41 AQMP 1991)
$8.6 million.
No operating costs were assumed for this option.
Over five years the total cost (capital plus annual operating cost) would be
$18.6 million.
Assume a 10-year lifetime.
The total <u>annualized cost</u> of coordinating traffic lights would be
$3 million per year.

Option 32: Implement Information System on Traffic Conditions

OPTION DESCRIPTION

This option proposes to use three small planes to fly over the city to gather traffic information (p. 9-49 AQMP 1991). This information would be given to a central processing area where it will be disseminated to the appropriate media.

EMISSIONS REDUCTION

The total annual emissions reductions for this option are (9-51 AQMP 1991)

CO	5,340 tons/yr.
HC	307 tons/yr.
NO_X	29 tons/yr.

COSTS

The assumptions used in estimating the cost of this option are

1. Purchase of 4 light planes @$70,000.
2. Hiring of 5 pilots @$30,000 per year.
3. Hiring of 5 controllers and communicators @$15,000 per year.
4. Flying 3 planes 5 days a week 6 hours a day @ $55 per hour.
5. Construction of a 400 m^2 building to house operations @ $500/$m^2$.
6. Miscellaneous costs 10% of initial and operating costs (non-flying costs).
7. Plane maintenance 25% of flying cost.

The initial costs are

1. Cost of planes	$0.28 million
5. Cost of building	$0.2 million
6. Miscellaneous	(10%) $0.05 million

The total capital (initial) cost of this option is
$0.53 million.

The annual costs are

2. Pilot cost $0.15 million/yr.
3. Ground personnel cost $0.08 million/yr.
4. Flying costs $0.25 million/yr.
6. Misc. costs (10%) $0.02 million/yr.
7. Plane maintenance costs $0.06 million/yr.

The total annual operating cost for this option is
$0.56 million per year.
Over five years the total cost (capital plus annual operating cost) would be
$3.3 million.
Assuming a five-year lifetime the annualized capital costs would be
$0.14 million per year.
The total annualized cost for implementing information systems on traffic conditions would be
$0.7 million per year.

Option 33: Improvement of Park-N-Ride Lots at Metro Stations

OPTION DESCRIPTION

This option is described starting on p. 9-64 of AQMP 1991. It consists of constructing lots for 50,000 vehicles, installation of information signs, and advertising the availability of such lots.

EMISSIONS REDUCTION

It is estimated that such a program would reduce the number of vehicle kilometers by 1 million per year. Using the per-kilometer emission factors on p. 148 of World Bank 1992 and assuming that only private car travel would be reduced, one million vehicle kms would reduce emissions by
The total annual emissions reductions for this option are

SO_2	250 tons/yr.
NO_X	1,530 tons/yr.
HC	4,730 tons/yr. (Does not include diurnal and hot soak evaporative emissions.)
CO	67,280 tons/yr.
PM-10	181 tons/yr.

COSTS

The total capital (initial) cost for this option is (p. 9-67 AQMP 1991)
$38.6 million.

Using 10 km/l for an average fuel efficiency for a private auto (p. vii World Bank 1992) and 1.2 new pesos/l gasoline cost, the annual saving in gasoline usage would be

$$\frac{1 \times 10^6 \text{ km}}{10 \text{ km/l}} \times \frac{1.2 \text{ pesos/l}}{3.0 \text{ pesos/\$}} = \$0.04 \text{ million per year.}$$

The total annual savings in operating costs for this option is
$0.04 million per year.

Over five years the total cost (capital plus annual operating cost) would be
$38.4 million.

Assuming a lifetime of 20 years, the annualized capital cost would be
$4.5 million per year.

The total annualized cost for improving Park-N-Ride lots would be
$4.5 million per year.

Option 34: Construction of Taxi Cab Stands in the City Center

OPTION DESCRIPTION

This involves the establishment of taxi stations in the Centro Historico. Taxis would pick up passengers at the stations rather than driving around until they encountered a passenger. Twenty stations would be established. This option is described on p. 9-70 in AQMP 1991. Each station is estimated to save 420 vehicle kilometers per day (p. 9-72 AQMP 1991).

EMISSIONS REDUCTION

These emission reductions would occur in the Centro Historico.
The total annual emissions reductions are

CO	283 tons
HC	25 tons
NO_X	4 tons

COSTS

The total capital (initial) cost of this option is
$0.033 million.

The annual cost for upkeep and administration of the option is estimated to be $9,600 per year. The estimated cost savings for the taxis from decreased gasoline consumption is estimated to be $356,000.

The total annual operating savings for this option would be
$0.346 million per year.

Over five years the total cost (capital plus annual operating cost) would be
–$1.7 million.

The annualized capital cost assuming a 10-year lifetime would be
$0.005 million per year.

The total annualized cost for the rationalization of yellow cab taxi traffic would be
–$0.35 million per year.

Option 35: Establish Urban Toll System

OPTION DESCRIPTION

This is a plan to establish a sticker system to allow access to the Circuito Interior during the day. The description of the plan starts on p. 9-74 of the AQMP 1991. It is estimated that this will reduce the traffic in the Circuito Interior by 5% (p. 9-75 AQMP 1991). The toll for a sticker to allow access to the Circuito Interior would be 49,000 pesos per month.

EMISSIONS REDUCTION

The emission reduction would occur in the Circuito Interior.

The total annual emissions reductions are (p. 9-79 AQMP 1991)

CO	31,400 tons/yr.
HC	2,800 tons/yr.
NO_X	200 tons/yr.
PM-10	86 tons/yr. (p. 9-77 AQMP 1991 + p. 155 private cars World Bank 1992)
SO_2	159 tons/yr. (p. 9-77 AQMP 1991 + p. 155 private vehicles World Bank 1992)

COSTS

The estimated cost for stickers and public information is $17 million.

The total capital (initial) cost for this option is
$17 million.

The estimates include that the tolls would pay for the administration of the program plus some extra. The tolls collected would be $1 million per year assuming 3,600,000 trips per year total (p. 9-77 AQMP 1991) with each vehicle making an average of 4 trips per day and paying a toll of 2.85 new pesos per day. Administrative costs are estimated to be 1/4 of this amount (p. 9-78 AQMP 1991) so the annual administrative cost would be 250,000 $ per year and the profit would be $750,000 per year. We assume that the profit would go into reducing taxes, so that the actual costs for the program would be the administrative cost.

The total annual operating cost of this option is
$0.25 million per year.

Over five years the total cost (capital plus annual operating cost) would be
$18.2 million.

Assuming a 10 year lifetime, the annualized initial costs would be
$2.8 million per year.

The total annualized costs for establishing an urban toll system would be
$3 million per year.

Option 36: Organization and Fees for Parking

OPTION DESCRIPTION

This option is given on p. 9-58 of the AQMP 1991. The option is to set a maximum number of parking spaces per square meter of building floor-space for new buildings, reduce the number of parking spaces, increase parking fees, and study ways to organize and control on-street parking.

EMISSIONS REDUCTION

The total annual emissions reductions for this option are (p. 9-63 AQMP 1991)

CO	5,900 tons/yr.
HC	653 tons/yr.
NO_X	123 tons/yr.

COSTS

There are no capital (initial) costs assumed for this option.

A 14% tax produces for the government (costs the consumer) 59,000 × 10^3 new pesos per year (p. 9-63 AQMP 1991). This is half the income from increased parking fees; therefore, the total cost to the consumer is 108,000 × 10^3 new pesos or $39 million per year, half of which goes to the government and half to the parking lot operators.

The total annual operating cost of this option is
$39 million per year.

Over five years the total cost (capital plus annual operating cost) would be
$195 million.

The total annualized cost for organizing and establishing new fees for parking would be
$39 million per year.

Option 37: Construct Line 8 of the Metro

OPTION DESCRIPTION

This option proposes to construct a metro line to serve the Iztapalapa Delegacion. The line will run from "Salto del Agua" to "Constitution de 1917" (p. 9-85 AQMP 1991). Sixteen stations will be added along the line.

EMISSIONS REDUCTION

The emission reductions would be concentrated in the southwest portion of Mexico City.

The total annual emissions reductions for this option are (p. 9-89 AQMP 1991)

CO	23,820 tons/yr.
HC	2,402 tons/yr.
NO_X	1,087 tons/yr.

COST

The total capital (initial) cost for this option is (p. 9-88 AQMP 1991)
$562 million.

No annual operating cost was assumed to be associated with this option.

Over five years the total cost (capital plus annual operating cost) would be
$562 million.

Assume a 30 year lifetime for the metro system.

The total annualized cost for constructing line 8 of the Metro would be
$60 million per year.

Option 38: Improve and Expand Electric Trolley Transport

OPTION DESCRIPTION

This is a combination of two options presented in the AQMP 1991. The first is to acquire 200 trolley buses (p. 9-28 AQMP 1991) and the second is to modernize and rationalize the electric Transport Service Company (p. 9-90 AQMP 1991).

EMISSIONS REDUCTION

The purchase of 200 Trolleys is expected to reduce emissions (in 1995) by (p. 9-31 AQMP 1991)

CO	3,658 tons
HC	493 tons
NO_X	504 tons

concentrated in the central portions of the city. The improvement of the electric transport company involves reorganizing the company and improving the maintenance section. This will result in an increased number (77) of units which would become available (p. 9-95 AQMP 1991). This would reduce the emissions in the central portion of the city by

CO	1,189 tons
HC	160 tons
NO_X	164 tons

The total annual emissions reductions would be

CO	4847 tons/yr.
HC	653 tons/yr.
NO_X	668 tons/yr.

COSTS

The cost for the purchase of the 200 Trolleys is estimated to be (p. 9-31 AQMP 1991)
$40 million.

The cost of reorganizing the (STE) is estimated to be (p. 9-95 AQMP 1991)
$5 million.
The total capital (initial) cost of the option is
$45 million.
The annual profit on the operation of the 200 trolleys is estimated to be (p. 9-31 AQMP 1991)

$$\frac{0.356 \times 39.920 \times 10^3 \text{ pesos}}{3.0 \text{ pesos/\$}} = \$4.7 \text{ million.}$$

The annual profit to STE is estimated to be (p. 9-95 AQMP 1991)

$$\frac{3{,}200 \times 10^3 \text{ pesos}}{3.0 \text{ pesos/\$}} = \$1.1 \text{ million.}$$

The total annual operating profit (savings) of this option would be
$5.8 million per year.
Over five years the total cost (capital plus annual operating cost) would be
$16 million.
Assuming a 20 year lifetime for the trolleys, the annualized capital cost would be
$4.7 million per year.
The net income expected is
$4.7 million per year.
The annualized cost of reorganizing the STE assuming a five-year lifetime would be
$1.3 million per year.
The annual profit would be
$1.1 million per year.
The total annualized cost for improving and expanding the electric trolley transport would be
$0.2 million per year.

Option 41: Better Organization of Traffic and Parking in the Central Historical District

OPTION DESCRIPTION

A description of the measures proposed starts on p. 9-52 AQMP 1991. The steps proposed are

1. Improvement of street conditions.
2. Implementation of a street transit plan.
3. Traffic management and control.
4. Development of the Metro system and/or introduction of medium-capacity public transit modes.

5. Development and reorganization of ɾ ıblic transit routes and promotion of non-pollutant electrical transit system.
6. Development of regulations and rates for parking meters.
7. Authorization of parking meters on selected streets.

EMISSIONS REDUCTION

These measures are estimated to reduce present mobile emissions in the central historical area by 40% (p. 9-57 AQMP 1991). The present emissions in the Centro Historico are estimated to be 2.2% of the total mobile emissions in Mexico City. Using the emissions on p. 153 of World Bank 1992, the emission reductions are estimated to be

SO_2	$0.022 \times 0.4 \times 15{,}080 = 133$ tons/yr.
NO_X	$0.022 \times 0.4 \times 88467 = 780$ tons/yr.
HC	$0.022 \times 0.4 \times 279852 = 2{,}500$ tons/ yr.
CO	$0.022 \times 0.4 \times 3366428 = 30{,}000$ tons/yr.
PM-10	$0.022 \times 0.4 \times 13252 = 117$ tons/yr.

The total annual emissions reductions for this option are

SO_2	133 tons/yr.
NO_X	780 tons/yr.
HC	2,500 tons/yr.
CO	30,000 tons/yr.
PM-10	117 tons/yr.

COSTS

Cost values were obtained from similar type activities being proposed and scaled to the 900-block area covered by the Centro Historico.

1. Improve street conditions. The budget for 1991 for the commissioner of travel and urban transport was 933×10^9 new pesos (p. 5-35 AQMP 1991). Assume a 10% increase in the budget to improve streets.
   Cost = 93×10^9 new pesos, or $31 million.
2. Implement street-transit plan. A pilot street-transit plan is being planned for Tlanepantla for a 72-block area for a cost of $1.7 million (p. 9-17 to 19 AQMP 1991). Assume the cost for a 900-block area is 5 times that amount.
   Cost = $8.5 million.

3. Traffic management and Control. Computerizing traffic lights for 100 lights is expected to cost $18.6 million (p. 9-41 AQMP 1991). The central Historica has 150 traffic lights so cost would be 50% more.
   Cost = $27.9 million.
4. Development of Metro System. Costs for line 8 of the metro are estimated to be $562 million for 16.6 km (p. 9-88 AQMP 1991). Assume 6 km of metro extensions were put in the Centro Historico.
   Cost = $203 million.
5. Promotion of non-pollutant electrical transport system. The cost for new trolley lines is $0.2 million per trolley (p. 9-31 AQMP 1991) plus 0.02 million per trolley for infrastructure (p. 88 World Bank 1992). If we assume the Centro Historico could be covered by 50 trolleys, the cost would be
   Cost = $11 million.
6. Development of Regulations for Parking Meters.
   No cost estimate.
7. Authorization of Parking meters on selected streets.
   No cost estimate.

The total capital (initial) cost of this option would be
$350.4 million.
The total annual operating cost for this option would be
$31 million per year.
Over five years the total cost (capital plus annual operating cost) would be
$505 million.
The annual cost of part 1 would be
$31 million per year.
The annualized cost of part 2 assuming a 10 year lifetime would be
$1.4 million per year.
The annualized cost of part 3 assuming a 10 year lifetime would be
$4.5 million per year.
The annualized cost or part 4 assuming a 30 year lifetime would be
$22 million per year.
The annualized cost of part 5 assuming a 20 year lifetime would be
$1.3 million per year.
The total annualized cost for better organization of traffic and parking in the Central Historical District would be
$60 million per year.

Option 43: Reduce Emissions from Metal Cleaning and Degreasing

OPTION DESCRIPTION

This option assumes that controls will be established on both small and large cleaning and degreasing operations. For small operations we assume a recycle program is established to recycle used solvents, operators are trained in better operating practices to reduce solvent loss, and higher sideboards are constructed on cleaning baths. The option requires larger users to install carbon absorbers or refrigerator chiller units and to reduce solvent usage by improving operating practices.

EMISSIONS REDUCTION

From p. 4.6-3 of EPA 1995, the emission factor is 1.8 kg per person per year for small degreasers. If we assume this is true for Mexico City, the small degreasers will emit 27,000 tons of HC per year. Also from AQMP 1991 p. 7-39, 3,363 tons of perchlorethylene per year is used as a degreasing agent. Perchlorethylene is typically used in larger-scale operations. Page 45 of the reference OECD 1992 shows that emissions from small degreasers could be reduced 50% by recycling waste solvent, closing covers, and draining cleaned parts. Also on p. 45 of OECD 1992, larger-scale degreasers could reduce their emissions by 60% by improving operating practices, installing a carbon absorber, or adding a refrigerator chiller.

The total annual emissions reduction for this option would be
15,500 tons of HC per year.

COSTS

To realize these savings a solvent recycling program would have to be established, and inspection of degreasers done. Also, a training program to teach good operating practices would have to be established. Assume that the solvent would be collected at centralized locations and that 100 locations would be sufficient. Each location would consist of storage barrels, an operator, and scales for weighing the solvent. Trucks to pick up the solvent for recycling would also be required. Five trucks with drivers should be sufficient. The recycling would be done by a private firm, who could then sell the solvent. Therefore, the requirements for a recycle program would be

1. 120 operators of recycling locations @ $3,000 per year.
2. 10 truck drivers @ $3,500 per year.
3. Operational costs for trucks @ $10,000 per year.
4. Miscellaneous operational costs 25% of above.
5. 100 Recycling Centers @ $5,000 center.
6. 5 trucks @ $30,000/truck.
7. Miscellaneous costs 10% of above.

The capital cost for this part of the option would be

$0.72 million.

The operating costs for this part of the option would be

$0.46 million.

From OECD 1992, p. 45, the capital cost of reducing emissions for small degreasers is $150 per unit, and a annual cost savings of $340 per unit is realized because of solvent savings. Each small unit is assumed to use 3 tons per year of solvents; thus, there are an estimated 9,000 small degreasers in Mexico City.

The capital cost to reduce emissions from these degreasers would be

$1.35 million.

The annual savings for this part of the option would be

$3 million per year.

From p. 45 OECD 1992 a large degreaser uses 9.5 ton per year of solvent. The capital cost to reduced emissions is $9,600 per unit. There would be an estimated 350 units at this size in Mexico City. The annual savings per unit from solvent saving is estimated to be $1,000 per year.

The capital cost for reducing emissions from large units would be

$3.4 million.

The annual savings from this part of the option would be

$0.4 million per year.

The total capital (initial) cost for this option would be

$5.5 million.

The total annual operating savings for this option would be

$2.94 million per year.

Over five years the total cost (capital plus annual operating cost) would be

–$3.3 million.

The annualized capital cost for small units assuming a five-year lifetime would be

$0.36 million per year.

The total annualized savings for small units would be

$2.6 million per year.

The annualized capital cost for large units assuming a five-year lifetime would be

$0.9 million per year.

The total annualized cost for large units would be

$0.5 million per year.

The annualized capital cost of a recycling center assuming a 10-year lifetime would be

$0.12 million per year.

The total annualized cost would be

$0.5 million per year.

The total annualized cost for reducing emissions from degreasing and metal cleaning would be

–$1.6 million per year.

Option 45: Reduce Emissions from Dry Cleaning

OPTION DESCRIPTION

This option assumes that dry cleaning establishments will b required to install carbon absorbers on dryer and washer vents.

EMISSIONS REDUCTION

According to p. 7-39 AQMP 1991, the solvent use in dry cleaning in Mexico City is 7,850 tons per year, and all of that is emitted. Assuming that there are no controls on emissions at present, the addition of carbon absorbers to the dryer and washer vents will reduce overall emissions by 50% (p. A54 SCAQMD 1989).

The total annual emissions reductions for this option will be
3,900 tons of HC per year.

COSTS

The net cost (installation minus solvent recovery) of installing carbon absorbers is given in p. A54 Final Appendix IV-A, SCAQMD 1989, as $2,000 per ton of emissions reduced.

The total capital (initial) cost for this option would be
$7.8 million.
No operating costs were assumed for this option.
Over five years the total cost (capital plus annual operating cost) would be
$7.8 million.
Assume a five-year lifetime of a solvent recovery system.
The total <u>annualized cost</u> for reducing emissions from dry cleaning establishments would be
$2 million per year.

Option 53: Purchase of Old, Polluting Cars

OPTION DESCRIPTION

Assume that this program will purchase 22,000 cars or about 1% of the present fleet of private vehicles in Mexico City. The 1% of the total fleet is assumed to come from cars that are in the top 5% of the worst polluters. Thus, this option is assumed to remove 20% of the top 5% polluters. The cars that are removed are assumed to be replaced with cars that have emissions equal to the median vehicle described in Volume IV, Section C. 2.

EMISSIONS REDUCTION

The average emissions from the most polluting 5% of the cars (from the Volume IV, C.2 data) are

CO 3125 g/gal. of gasoline consumed
HC 603 g/gal.

The emissions from the median vehicle in the Volume IV, C.2 data are

CO 1264 g/gal.
HC 63 g/gal.

Also from the same data, the top 5% polluters emit 11.7% of the CO and 28.9% of the HC. Since we will be removing 20% of these cars, the emissions removed will be 20% times these values, or 2.34% for CO and 5.78% for HC. The replacement cars will only add back 40% (1264/3125) of the CO and 10.4% (63/603) of the HC emissions. Therefore, 60% of the CO and 89.6% of the HC emission reductions from removing the cars will be realized.

Multiplying 60% times 2.34% gives the total CO emission reduction percentage for private vehicles or 1.4%. Similarly 89.6% times 5.78% is the emission reduction for HC or 5.2%. Experience from the UNOCAL program is that the effects of NO_X reduction is one-fifth that of CO so NO_X would be reduced by 0.3%.

Private vehicles account for 37% of the total mobile emissions of CO and 43% of the total mobile emissions of HC (p. 153 World Bank 1992). Multiplying these times the above percentage reductions, we see that the total mobile emissions are reduced by 0.5% for CO, 2.2% for HC, and 0.1% for NO_X. The total emissions for autos is given on p. 153 of World Bank 1992.

The total annual emissions reductions for this option would be

HC 6,157 tons/yr.
CO 16,832 tons/yr.
NO_X 76 tons/yr.

COSTS

Assuming the cars are purchased for $500 and assuming administrative costs of 20%, the total cost per car is $600. Assume the total cost for 22,000 cars would be treated as a capital expense item.

The total capital (initial) cost of this option is
$13.2 million.

No annual operating cost is assumed for this option.

Over five years the total cost (capital plus annual operating cost) would be
$13.2 million.

Assume the purchase is financed over five years.

The total <u>annualized cost</u> of purchasing old polluting vehicles would be
$3.5 million per year.

Option 54: Require Catalytic Converters on all Automobiles Past 1993 Model Year

OPTION DESCRIPTION

This option would require all private automobiles and taxis past the 1993 model year to be equipped with three-way catalytic converters, or meet emission levels comparable to those vehicles equipped with three-way catalytic converters.

EMISSIONS REDUCTION

Emissions for private autos and taxis with catalytic converters meeting the 1993 Mexican standards are given on pp. 161-162 of World Bank 1992. Assuming that all automobiles meet the 1993 Mexican standards and the annual travel for private vehicles and taxis given on pp. 161 and 162 of World Bank 1992 are correct, the annual emission per vehicle would be

	Private	Taxi
NO_X	5.2 kg	45 kg
Exhaust HC	2.1 kg	18 kg
Evaporative HC	2.4 kg	20 kg
CO	17.6 kg	153 kg
SO_2	0.6 kg	5 kg
PM-10	0.6 kg	5 kg

Assuming 2,210,000 operating private vehicles and 48,000 operating Taxis (p. 150 World Bank 1992), the total annual emissions if all automobiles were equipped with catalytic converters would be

	Private	Taxi
NO_X	11,500 tons/yr.	2,200 tons/yr.
Exhaust HC	4,600 tons/yr.	880 tons/yr.
Evaporative HC	5,200 tons/yr.	980 tons/yr.
CO	39,000 tons/yr.	7,400 tons/yr.
SO_2	1,400 tons/yr.	245 tons/yr.
PM-10	1,300 tons/yr.	245 tons/yr.

Subtracting these values from the present day emissions (p. 153 World Bank 1992), the emission reductions due to catalytic converters are obtained as follows:

	Private	Taxi	Total
NO_X	16,900 tons/yr.	4,200 tons/yr.	21,000 tons/yr.
Exhaust HC	70,725 tons/yr.	16,000 tons/yr.	87,000 tons/yr.
Evaporative HC	40,440 tons/yr.	2,660 tons/yr.	43,000 tons/yr.
CO	1,200,000 tons/yr.	272,000 tons/yr.	1,500,000 tons/yr.
SO_2	3,246 tons/yr.	794 tons/yr.	4,000 tons/yr.
PM-10	2,000 tons/yr.	507 tons/yr.	2,500 tons/yr.

This assumes that all automobiles meet Mexican 93 emission standards. However, all cars will not meet the standards, and two of the options, I/M and the purchase of polluting vehicles, are designed to improve the number of cars that meet the standards. Assume that the amount of emission reduction found for those two options is equal to the additional emissions from vehicles not meeting the standard if those two options were in force. Thus, the total reduction calculated above for vehicles meeting the 1993 Mexico standard is really the sum of three components: installation of catalytic converters, improved I/M, and purchase of old polluting cars.

Therefore, the actual emission reduction from catalytic converters is the emissions reductions calculated above minus the projected emissions reductions for improved I/M and purchase of old polluting cars

	Emission Red.	Improved Inspect.	Purchase of Cars	Net Red.
NO_X	21,000 tons/yr.	---	---	21,000 tons/yr.
HC	130,000 tons/yr.	39,600 tons/yr.	6157 tons/yr.	98,400 tons/yr.
CO	1,500,000 tons/yr.	166,000 tons/yr.	---	1,300,000 tons/yr.
SO_2	4,000 tons/yr.	---	---	4,000 tons/yr.
PM-10	2,500 tons/yr.	310 tons/yr.	---	2,500 tons/yr.

The total annual emissions reductions for this option are

NO_X	21,000 tons/yr.
HC	98,400 tons/yr.
CO	1,300,000 tons/yr.
SO_2	4,000 tons/yr.
PM-10	2,500 tons/yr.

COSTS

The costs per vehicle given on pp. 161 and 162 of World Bank 1992 for equipping them with catalytic converters are

Private	Taxi
$630	$630

Assume that 2,210,000 private vehicles and 48,000 taxis are equipped with three-way catalytic converters.

The total capital (initial) cost for the option is

$1,700 million.

The additional operating costs given on pp. 161 and 162 for World Bank 1992 for catalytic-converter equipped vehicles are

Private	Taxi
$104	decrease $36

Assume that 2,210,000 private vehicles and 48,000 taxis are equipped with three-way catalytic converters.

The total annual operating cost for the option is

$228 million per year.

Over five years the total cost (capital plus annual operating cost) would be

$2,570 million.

Assuming a lifetime of 10 years for the converters for private vehicles and five years for taxis, the annualized initial cost would be

Private	Taxis
$230 million/yr.	$8 million/yr.

The annualized operating costs would be

Private	Taxis
$230 million/yr.	decrease $1.18 million/yr.

The total <u>annualized cost</u> for requiring all vehicles starting with the 1993 model year be equipped with catalytic converters would be

$466 million per year.

Option 55: Convert Gasoline Trucks to CNG

OPTION DESCRIPTION

This options is detailed on p. 167 of World Bank 1992. It assumes that 48,000 trucks would be converted to CNG. The gasoline truck fleet consists of 137,000 operating vehicles (p. 152 World Bank 1992). This conversion would affect 35% of the fleet.

EMISSIONS REDUCTION

The emissions reductions per km per vehicle are (p. 168 World Bank 1992)

NO_X	1.34 g/km
HC	15.37 g/km
CO	219 g/km
SO_2	0.75 g/km
PM-10	0.6 g/km

Assume an annual travel of 30,000 km per vehicle.
The total annual emission reduction for this option would be

NO_X	1,900 tons/yr.
HC	22,000 tons/yr.
CO	315,000 tons/yr.
SO_2	1,000 tons/yr.
PM-10	90 tons/yr.

COSTS

The capital cost per vehicle is (p. 168 World Bank 1992)
$3,500
48,000 vehicles would be converted.
The total capital (initial) cost of the option would be
$168 million.
The annual savings per vehicle is (p. 168 World Bank 1992)
$1,350 per year.
Assume 48,000 vehicles would be converted.
The total annual operating savings for the option would be
$64 million per year.

Over five years the total cost (capital plus annual operating cost) would be
–$152 million.
The annualized capital cost assuming a five-year lifetime would be
$44.4 million per year.
The total annualized cost for converting gasoline trucks to CNG would be
–$19.6 million per year.

Option 56: Require Gasoline Trucks to Conform to 1993 Standards

OPTION DESCRIPTION

This option would require that all trucks meet the 1993 emission standards and is described on p. 167 of World Bank 1992.

EMISSIONS REDUCTION

The estimated emission reductions per km for each vehicle are (p. 167 World Bank 1992)

NO_X	2.42 g/km
HC	13.5 g/km
CO	220 g/km
SO_2	0.42 g/km
PM-10	0.6 g/km

Assume a gas-fueled truck fleet of 137,000 vehicles and an annual average of 30,000 km traveled (p. 167 World Bank 1992).

The total annual emissions reductions for this option would be

NO_X	9,900 tons/yr.
HC	55,000 tons/yr.
CO	904,000 tons/yr.
SO_2	1,700 tons/yr.
PM-10	250 tons/yr.

COSTS

The capital costs per vehicle are (p. 167 World Bank 1992)
$1,500
Assume a total fleet of 137,000 vehicles.
The total capital (initial) cost for the option would be
$205 million.
The annual operating costs per vehicle are
$180 per year.
Assume a fleet of 137,000 vehicles (p. 167 World Bank 1992).
The total annual operating cost for this option would be
$22 million per year.
Over five years the total cost (capital plus annual operating cost) would be
$315 million.
The annualized cost of the capital requirements, assuming a 10 year lifetime would be
433 million per year.
The total annualized cost for requiring that all trucks meet 1993 emission standards would be
$55 million per year.

Option 57: Replace Gasoline Trucks that Cannot be Converted to CNG or LPG

OPTION DESCRIPTION

This options assumes that 48,000 trucks would be replaced (p. 167 World Bank 1992) because conversion to CNG of LPG would not be cost-effective.

EMISSIONS REDUCTION

The emission reduction per vehicle for each km traveled would be (p. 167 World Bank 1992)

NO_X	2.42 g/km
HC	13.46 g/km
CO	220 g/km
SO_2	0.4 g/km
PM-10	0.6 g/km

Assume 48,000 vehicles each traveling 30,000 km per year.

The total annual emission reduction for this option would be

NO_X	3,500 tons/yr.
HC	19,000 tc..s/yr.
CO	317,000 tons/yr.
SO_2	580 tons/yr.
PM-10	800 tons/yr.

COSTS

The capital costs per vehicle are (p. 168 World Bank 1992)
$14,000
Assume 48,000 vehicles would be replaced.
The total capital (initial) cost for this option would be
$672 million.
The annual cost saving per vehicle for replacing trucks is (p. 168 World Bank 1992)
$480
Assume 48,000 vehicles would be replaced.
The total annual operating savings for this option would be
$23 million per year.
Over five years the total cost (capital plus annual operating cost) would be
$557 million.
The annualized capital cost assuming a 10-year lifetime is
$109 million per year.
The total annualized cost for replacing gasoline trucks that cannot be converted to CNG or LPG is
$76 million per year.

Option 58: Pave Roads

OPTION DESCRIPTION

This option examines paving roads with asphalt to reduce the dust generation from dirt roads. The numbers given below are for kilometers of dirt road paved per year.

EMISSIONS REDUCTIONS

The reduction expected (p. 193 World Bank 1992) for paving roads is 7.52 tons per year of particles per km of road paved.

COSTS

The cost of paving a road is (p. 193 World Bank 1992)
$75,000 per km.
Assume a 20 year lifetime for the paving.
The total annualized cost per kilometer of paving roads would be
$8,800 per kilometer per year.

Appendix B
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APPENDIX B
COST-EFFECTIVENESS STUDY OF SCRAPPING OLD CARS IN MEXICO CITY

(note: This unedited appendix has been printed from master copy provided by Adrián Barrera-Roldan of the Instituto Mexicano del Petróleo)

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ABSTRACT

This paper reports on a cost-effectiveness study of buying and then scrapping old cars in Mexico City. The selection of cars to be bought was based on a Mexico City automobile market study and on *in situ* car exhaust emissions measurements conducted by the Instituto Mexicano del Petróleo and the University of Denver. From these measurements and information from the automobile plates registration department a fleet profile of hydrocarbons and carbon monoxide emissions was obtained. Based on these data the cars which resulted in the most cost-effective reduction of exhaust emissions were found and total program cost and emissions reductions calculations were done assuming 5000 of those cars were bought. The cost-effective coefficient for this air pollution mitigation measure was found to be 1478 US dls/ton by year.

INTRODUCTION

Mobile emission sources in Mexico City Metropolitan Area, MCMA, produce about 77% of atmospheric pollution, and private cars by themselves are responsible for 35% of total atmospheric pollution[1]. The above figures show that private cars are major contributors to air pollution in the MCMA. For this reason it is important to design measures to reduce their emissions, as the old cars scrapping program implemented in Los Angeles, CA[2].

This paper presents a cost-effectiveness study of scrapping old and polluting cars in Mexico City. Used car market prices gathered from different sources were utilized for the analysis along with carbon monoxide and hydrocarbon emissions from cars exhausts measured, while the cars were in motion, at five different sites in Mexico City. Information on the year and make of the monitored vehicles was obtained from the Permanent Plate Program Office. Information on scrap prices was obtained from foundries and junk yards.

Methodology

The cost-effectiveness coefficient (CE) was defined as

$$CE = \frac{\text{market price}}{\text{pollutant emission}_i}$$

where

i = carbon monoxide, hydrocarbons

Using this definition, private cars with the lowest CE coefficients are the best choices for scrapping. These cars are the ones that pollute more and have a low market price.

Market prices for the vehicles were calculated with information from the newspapers: "El Excelsior", "El Sol de México", and "Novedades", and the weekly publication "Segunda Mano" (publication dedicated to buying and selling used articles). Those prices were checked with the cash value lists for private vehicles from two insurance companies "Seguros La Provincial" and "Seguros America". All the information was obtained for the period April-June of 1992. The average of prices from the newspapers information and the publication "Segunda Mano" were used as the vehicles' market price in the calculation of the CE coefficients.

Information for vehicle emissions estimates was obtained from a monitoring experiment conducted in February 1991 using the "Fuel Emission Automotive Test", FEAT, technique[3]. This experiment was done as part of the Mexico City Research Initiative[4]. The principle behind this technique is the absorption by vehicle exhaust gases of an infrared (IR) beam directed perpendicular to the traffic flow. The IR source is placed on one side of a one lane traffic road and consists of an IR lamp and a mirror that sends a collimated beam about 25 cm above the road surface to a detector unit. This unit measures relative concentrations of hydrocarbons (HC), carbon monoxide (CO) and carbon dioxide (CO_2) with wavelength specific detectors. The data from the detector unit is send to a computer for analysis and storage. A video camera triggered by the computer, records a freeze frame of the rear of the passing vehicle to record the license plate as well as the date, time, and the measured emissions. With this technique, the license plate, volumetric concentration exhaust emissions of HC, CO, and CO_2 of moving vehicles traveling at speeds between 4 and 240 Km/h can be measured. FEAT results have been compared with those of an on-board instrument measuring CO and HC[5], giving satisfactory correlations.

Approximately 32000 vehicles were measured with the FEAT technique at five different sites in the city. Additional information was gathered on vehicle manufacturer, model year and engine size only for vehicles registered in the Federal District ("Distrito Federal"), because the Federal District is the only Federal entity that has a digitized data base. Year, make, type, and number of cylinders was obtained from 1992 records of the Permanent Plate Program Office of the Federal District Department ("Dirección del Programa de Placa Permanente del Departamento del Distrito Federal"). Records from taxis were discarded because in the MCMA taxi plates belong to the person not the vehicle. The plates can be and are routinely transferred from vehicle to vehicle thus the taxi plates recorded during the measurements in 1991 were likely to be on a different car in 1992 when the information from the permanent plate office was obtained. After considering only vehicles registered in the Federal District and discarding taxis, a sample of 15653 vehicles was obtained for this study. This sample (from now on FEAT sample) represents 0.7% of the estimated 1991 private cars fleet of the MCMA. Measurements were done on different days of the week and without knowing the drivers their vehicles were being tested. These facts made the data from the FEAT experiment a good representation of vehicle's emissions in the MCMA, so the FEAT sample was taken as a representing sample of the MCMA private cars fleet.

The size of private cars in the MCMA fleet for February 1991 was estimated considering the 1989 fleet (2 210 000 private cars[6]), plus the number of private cars sold in 1990[7] and 20% of the cars sold in 1991[8] in Mexico City Valley. From this we estimated that there were 2403000 private vehicles in the MCMA at the beginning of 1991.

The average CO and HC exhaust emissions (volumetric concentration) by model year from 1970 to 1991 were plotted in Figure 1 to identify the highest polluting vehicles. This Figure shows that both CO and HC exhaust emissions tend to be less the newer the vehicle, in fact, 1991 vehicles show about a 50% reduction in emissions compared with the previous model. This reduction is understandable because 1991 was the first year that new vehicles in Mexico were required to use catalytic converters. On the other hand, the emissions from vehicles older than model 1985 remained basically constant. Therefore this study was concentrated on vehicles older than model year 1985.

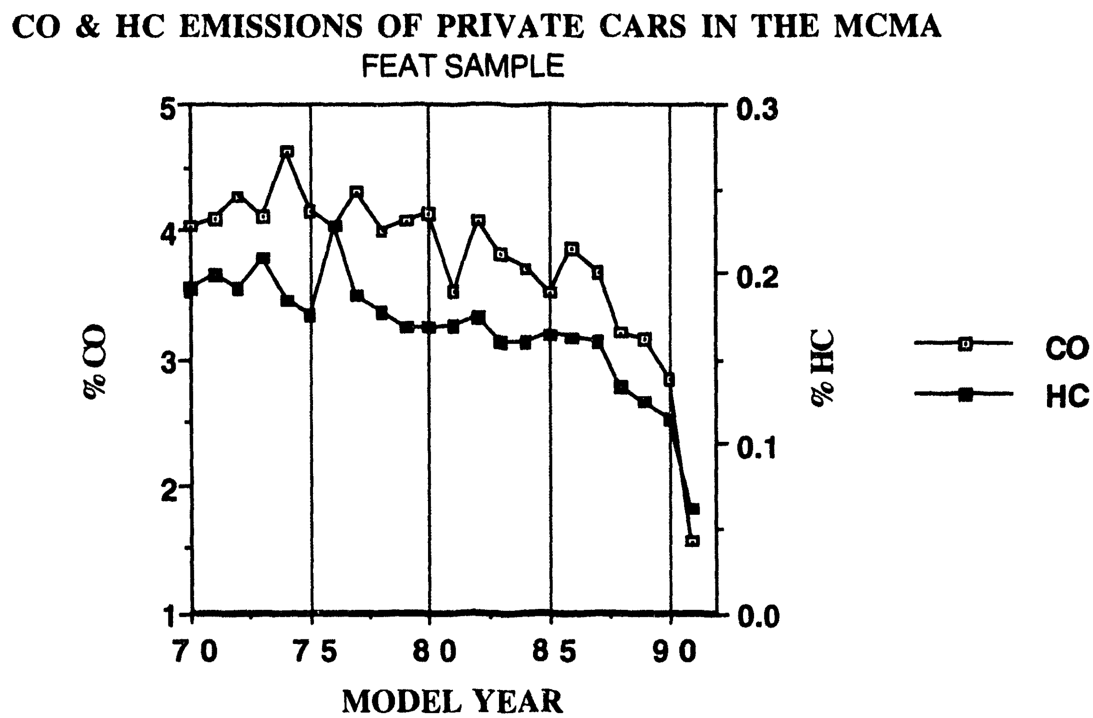

Figure 1. Plot of average CO and HC exhaust emissions by car, as a function of model year, from 1970 to 1991.

Figure 2 shows a plot of the average market price by model year and make of private vehicles in the MCMA. The market price for vehicles model 1970 and older show almost no variation as a function of model year. Vehicles older than the 1970 model year were chosen for scrapping because they were among the most polluting cars and also because they were the cheapest. The average market price of these cars was 1290 US dls per unit.

As mentioned above the FEAT experiment measured only volumetric concentrations of CO and HC emissions, not total emissions. Therefore, the FEAT data could not differentiate between two vehicles emitting the same volumetric concentration of pollutants even though they had different size engines emitting different volumes of gases. In order to estimate the relative total emissions emitted by a vehicle, the volumetric concentration emissions from vehicles with 4, 6 an 8 cylinders were multiplied by 1, 1.5 and 2, respectively. Using these weighted emissions the cost-effectiveness coefficients were calculated.

Figures 3 and 4 show the cost-effectiveness (CE) coefficient for CO and HC, respectively, for vehicles model year 1971 and older of the FEAT sample. Figure 3 shows that Datsuns followed by Americans had the lowest CE coefficients for CO emissions, and Figure 4 shows that Americans and Datsuns had also the lowest CE coefficients for HC, so Americans and Datsuns were chosen for scrapping.

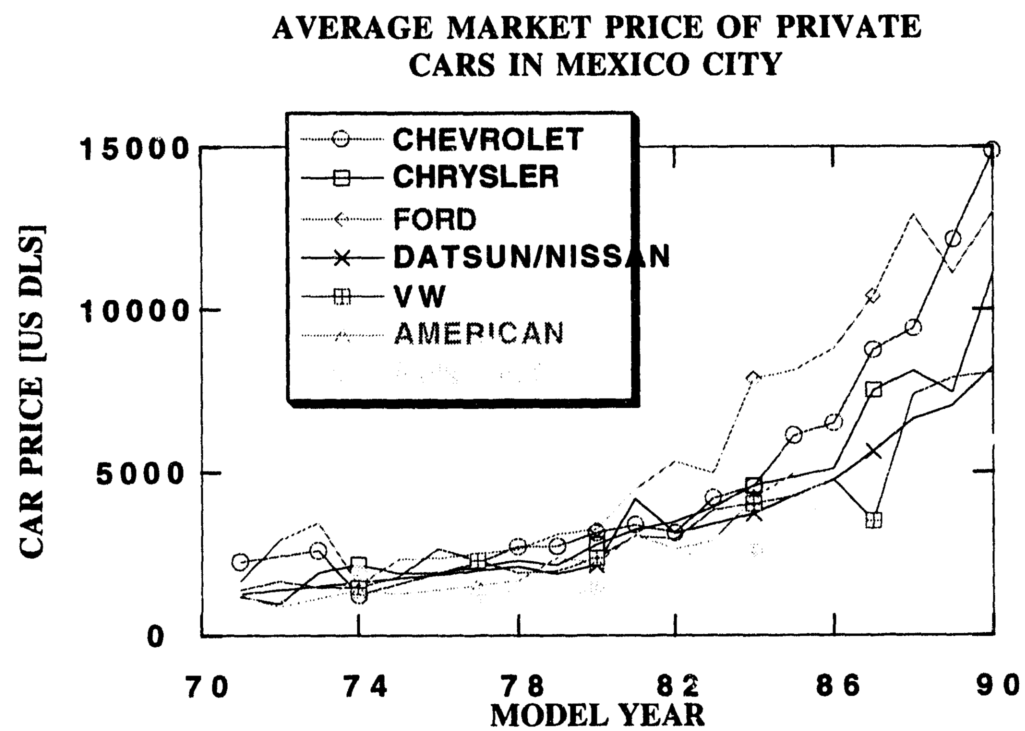

Figure 2. Average market price in 1992 of private cars in MCMA, by make.

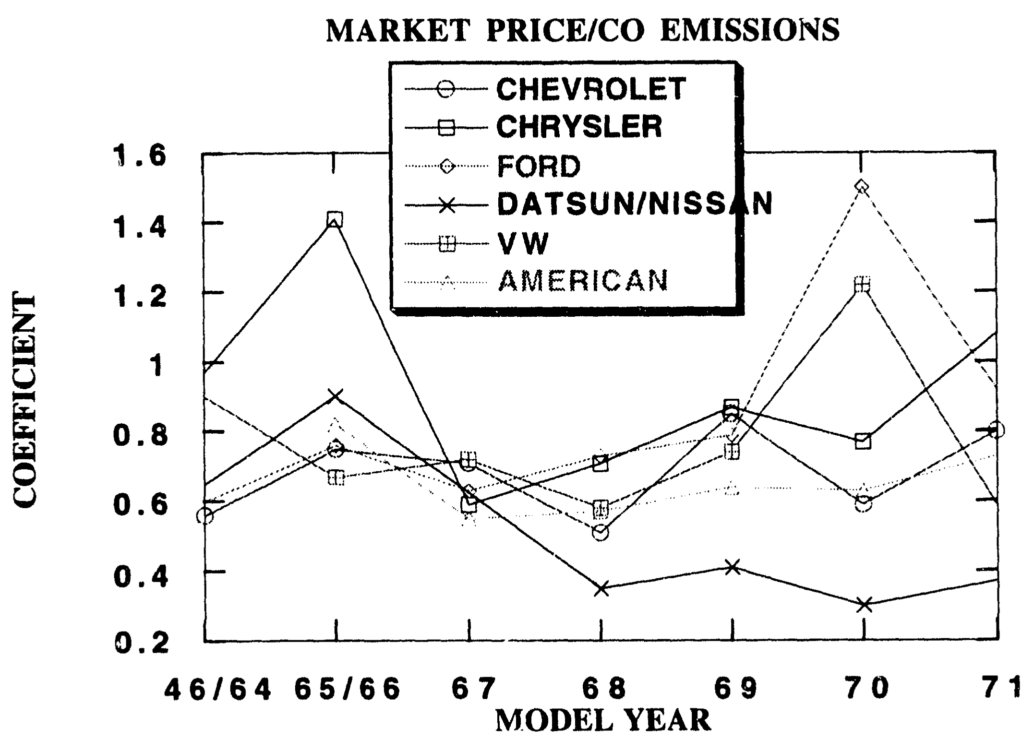

Figure 3. Average CE coefficient for CO emissions as a function of model year by vehicle's make, for model year 1971 and older. From FEAT sample.

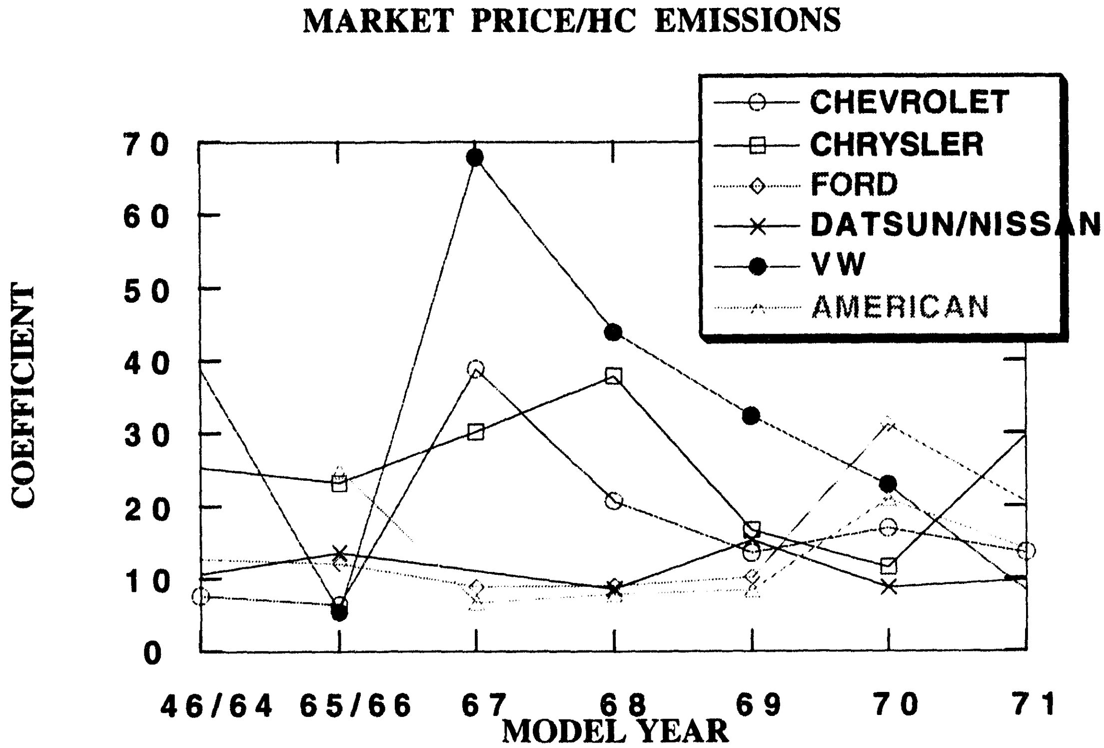

Figure 4. Average CE coefficient for HC emissions as a function of model year by vehicle's make, for model year 1971 and older. From FEAT sample.

Results

Cost calculations were made for scrapping 5000 vehicles. Calculations were made for buying 4000 Americans and 1000 Datsuns. Ten percent was added to this cost for program management, and 97 dls per vehicle were subtracted to the cost for recycling revenues[9]. According to this considerations the total cost of the program would be 6612903 US dls (Table 1).

Total emissions emitted per year by the MCMA private car fleet was calculated using pollutant emissions factors per kilometer, the average annual kilometers traveled by[6], and the estimated number of private cars in the MCMA in 1991.

Table 1. Costs in US dollars (1 US dl = 3.1 New Pesos) of buying 5000 cars for scrapping.

Make	Number of cars	Price/ car	Total Price	Management	Recycling Profits	Total
Datsun	1000	1290	1290323	129032	96774	1322581
American	4000	1290	5161290	516129	387097	5290323
TOTAL	**5000**		**6451613**	**645161**	**483871**	**6612903**

To obtain emissions reductions estimations, the MCMA private car fleet was assumed to have the same distribution by make and model year as the FEAT sample, and the emissions distribution given by the FEAT sample considering number of cylinders, was assumed to be the same as the MCMA private car fleet. With these assumptions CO and HC emissions reductions were calculated.

To calculate emissions reductions of sulfur dioxide (SO_2), nitrogen oxides (NO_X), particulate matter smaller than 10 microns (PM_{10}) and lead (Pb), it was assumed that the percentage reductions of emissions of SO_2, PM, and Pb was equal to the percentage reduction in CO emissions, and the percentage reduction in NO_X emissions was set equal to the percentage reduction of HC emissions. The estimations results are shown in Table 2. Total emissions reductions were calculated to be 4474 tons per year.

Total costs and total emissions reductions give a cost-effectiveness coefficient for this measure of 1478 US dls/ton by year.

Table 2. Emission reduction estimations of scrapping 5000 private cars in MCMA.

Make	Number of cars	Emissions Reductions [tons/year]					
		CO	HC	NO_X	SO_2	PM_{10}	Pb
Datsun	1000	1064	88	21	4	3	0.5
American	4000	2842	350	82	11	8	1.4
TOTAL	**5000**	**3906**	**438**	**103**	**15**	**11**	**2**

CONCLUSIONS

This study was done using available data on automobile emissions. Experimental data was only available for HC and CO exhaust emissions. This experimental data along with some assumptions and information from the Permanent Plate Program Office provided a private cars exhaust emissions profile by make and model year for these pollutants. For pollutants other than CO and HC the same profile of either one of these pollutants was assumed. This kind of assumption for NO_X emissions is very rough because these emissions do not correlate well with CO or HC emissions. Therefore to improve the automobile profile for NO_X emissions and hence obtain better emissions reductions estimations for this and other programs for private cars it is very important to obtain experimental data for NO_X's.

Even though important assumptions were made for obtaining pollutant emissions reductions for scrapping cars in Mexico City, results compare reasonable well with findings from the Los Angeles 1990 SCRAP program. The LA SCRAP program found that the average scrapped vehicle emitted more than 680 Kg (1500 pounds) a year[2], whereas in this study it was estimated that the average vehicle chosen for scrapping emitted 895 Kg a year.

The SCRAP program for Mexico City was compared with a cost-effectiveness study made by the World Bank[10] for the Mexico City case which contained 31 measures with cost-effectiveness coefficients varying from 38 to 14726 US dls/(weighted ton) per year. In the World Bank study the different annual pollutant emissions were weighted using toxicity factors to produce a composite weighted ton per year emission for pollutants. The Mexico City SCRAP program would have obtained a ranking of 29th in this study with a cost-effectiveness coefficient of 4055 US dls/(weighted ton) per year.

REFERENCES

1. *Programa Integral Contra la Contaminación Atmosférica de la Zona Metropolitana de la Ciudad de México*, Departamento del Distrito Federal, México D. F., 1990.
2. *South Coast Recycled Auto Project, SCRAP*, Unocal Corp., P.O. Box 7600, Los Angeles, CA 90051.
3. Tejeda, J. D.; Aquino, V.; *On road remote sensing of automotive CO and HC emissions in Mexico City*; Zannetti, P.; Brebbia, C. A.; García, J. E., et. al., Eds; Computational Mechanics Publications, London, 1993.
4. Guzman, F.; Streit, G. E.; *Mexico City air quality research initiative*; Zannetti, P.; Brebbia, C. A.; García, J. E., et. al., Eds;
   Computational Mechanics Publications, London, 1993.
5. Bishop, G.A.; Starkey, J.R.; Ihlenfeldt, A.; et al.; IR *Long Path Photometry: A Remote Sensing Tool for Automobile Emissions*; Anal. Chem. 61, pp 671A-677A, 1989.
6. Coordinación General del Transporte del DDF, personal communication, 1992.
7. Asociación Mexicana de la Industria Automotriz; *Reporte de la Industria Automotriz 1981-1990*; 1990.
8. División de Estudios Económicos; *Estudio Global de la Calidad del Aire en la Ciudad de México: Evaluación de Estrategias*; Instituto Mexicano del Petróleo, junio 1992.
9. Visit to 3 foundries and 7 junk yards located in the Mexico City Metropolitan Area, personal communication, 1992.
10. World Bank; *World Development Report*, 1992.

APPENDIX C
CONVERSION OF GASOLINE TRANSPORT VEHICLES AND DELIVERY TRUCKS TO LPG

(note: This unedited appendix has been printed from master copy provided by the IMP)

Gasoline vehicle fleet that can be converted to gas and its emissions (World Bank 1992)

			NMHC					
	SO_2	NO_X	Exhaust	Evap	CO	PM10	Lead	number of vehicles
taxis	1039	6361	16879	3641	279707	752	132	56950
combis	1261	6644	18501	4008	297700	761	134	57600
minibuses	349	2236	9108	2254	187556	137	37	8864
gasoline truck	3090	15823	64446	29627	1327073	968	394	137353
total	5739	31064	108934	39530	2092036	2618	697	260767

tons/year

Assuming 45000 gasoline vehicles are converted to gas from those listed above, the percent fleet (above) converted is 17.08%.

	SO_x	NO_x	NMHC Exhaust	NMHC Evap	CO	PM10	Lead
% reductions due to LPGV's conversions (Marshall 1992)	100	90	90	100	90	100	100
total reductions due to LPGV's conversions	990	4825	16919	6821.6	324916	452	120
Total Emissions (all sources) (AQNP 1991)	205700	180800	572100		2950600	450600	
% reductions with respect to Total Emissions from all sources	0.48	2.67	4.15		11.01	0.10	

% reductions due to CNGV's conversions (Marshall 1992)	100	80	90	100	90	100	100
total reductions due to CNGV's conversions[1]	990	4289	16919	6821.6	324916	452	120

Units data are in tons/year.
LPGV = Liquid Petroleum Gas Vehicles.
CNGV = Compressed Natural Gas Vehicles.

LPG COSTS:

Pemex Investments (PEMEX 1992)	194
Vehicles conversion[2]	75
20 gas stations[3]	1.2
5 years fuel savings (AQMP 1991)	-23.5
Total cost	246.7

Millions of US dollars

1 CNGV's emit more methane than gasoline V's, therefore they provide only 50% exhaust reduction of total HC.

2 According to "Programa para el uso de gas licuado de petróleo y gas natural comprimido en el transporte público y concesionado" report made by "Comisión Metropolitana para la Prevención y Control de la Contaminación Ambiental en el Valle de México" (February 1992) the conversion cost to LP gas per vehicle varies between 4.4 and 7.1 millions of pesos. For our calculations we assumed 5 million pesos.

3 Assume that a gas station with 2 dispensers is able to fuel 800 vehicles in 8 hrs., and each vehicle needs to refuel every three days, so to fuel a 45000 + 7% V's fleet requires 20 gas stations. The cost of each gas station in the USA excluding land is 60000 dls., therefore the total cost is 1200000 dls. Information on cost and fueling capabilities of an LPG station was obtained in a private conversation with Larry Osgood from Phillips Petroleum Co.

REFERENCES

(AQMP 1991)
"Air Quality Management Program for the MCMA: Short-Term Program," Vol. 1 & 2, Departamento Distrito Federal, Mexico City, Mexico, 1991.

(Marshall 1991)
Private conversation with Bill Marshall, National Institute for Petroleum and Energy Research, Bartlesville, Oklahoma, 1992.

(PEMEX 1992)
PEMEX report for the project "Proyecto de Sustitución de Gasolinas por Gas en Vehículos del Valle de México," made by Subdirección de Petroquímica y Gas, Coordinación Ejecutiva de Comercialización de Gas Natural y Gas LP, Mexico City, 1992.

Appendix D
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APPENDIX D
ANALYSIS OF TWO OPTIONS USED AS TEST CASES:

Requiring New Cars to be Equipped with Catalytic Converters

and

Requiring Power Plants to Convert to Natural Gas

(In Spanish)
(note: This unedited appendix has been printed from
master copy provided by the IMP)

This appendix contains a Spanish version of the description of the analysis done for the two options used as test cases for the decision analysis tree: requiring new cars to be equipped with catalytic converters, and requiring the power plants in Mexico City to convert to natural gas. The analysis contains estimates of the costs of implementing the options plus an estimate of the emission reductions that would be achieved if each option were implemented. Also, some information is presented as to how each option was judged using the attributes for the decision tree.

RESUMEN EJECUTIVO

Presentacion

EL IMP EN FORMA CONJUNTA CON EL LABORATORIO NACIONAL DE LOS ALAMOS (E.U.) REALIZA UN ESTUDIO GLOBAL DE LA CALIDAD DEL AIRE EN LA CIUDAD DE MEXICO, CON EL PROPOSITO DE DESARROLLAR LA HERRAMIENTA Y LA TECNOLOGIA DE PUNTA QUE PERMITA IDENTIFICAR OPCIONES QUE CONLLEVEN UN MEJORAMIENTO DE LA CALIDAD DEL AIRE.

PARA CUMPLIR CON ESE OBJETIVO, EL ESTUDIO SE ESTRUCTURO EN DOS AREAS DE TRABAJO FUNDAMENTALES, UNA TECNICA Y OTRA DE EVALUACION DE LAS ESTRATEGIAS SELECCIONADAS. ESTA SEGUNDA, CONSTITUYE EL MOTIVO DEL PRESENTE TRABAJO, EL CUAL SE DEDICA EN PRIMERA INSTANCIA Y COMO UN EJERCICIO PRELIMINAR A LAS SIGUIENTES

ESTRATEGIAS: A) INTRODUCCION DE CONVERTIDORES CATALITICOS EN EL PARQUE AUTOMOTRIZ Y, B) SUSTITUCION DE COMBUSTOLEO POR GAS NATURAL EN TERMOELECTRICAS.

Objectivos

- EVALUAR LOS EFECTOS SOCIOECONOMICOS DE LAS ESTRATEGIAS SELECCIONADAS.
- EVALUAR EL POTENCIAL DE LAS ESTRATEGIAS DE MITIGACION SELECCIONADAS PARA REDUCIR LOS EFECTOS NEGATIVOS DE LA CONTAMINACION DEL AIRE EN LA ZONA METROPOLITANA DE LA CIUDAD DE MEXICO (ZMCM).
- IDENTIFICAR Y JERARQUIZAR LOS CRITERIOS DE EVALUACION DE LAS ESTRATEGIAS, ASI COMO IDENTIFICAR Y EVALUAR LOS ATRIBUTOS Y FUNCIONES DE UTILIDAD DE DICHOS CRITERIOS.

Metodologia

LA EVALUACON DE LAS ESTRATEGIAS FUE REALIZADA CON UNA METODOLOGIA QUE COMBINA TECNICAS DE CONSULTA DE EXPERTOS CON INVESTIGACION DIRECTA DE CAMPO Y DOCUMENTAL, CUYOS RESULTADOS SON RESUMIDOS EN FUNCIONES DE UTILIDAD. LA APRECIACION GRAFICA COMPARATIVA DE ESAS FUNCIONES PERMITE PONDERAR EL EFECTO GLOBAL Y CADA UNO DE LOS CRITERIOS QUE INTERVIENEN EN LA EVALUACION.

DICHOS CRITERIOS ESTAN ESTRUCTURADOS EN UN ARBOL DE DECISION, CUYOS COMPONENTES PRINCIPALES Y SECUNDARIOS, ASI COMO SU PONDERACION RESPECTIVA, FUERON EL RESULTADO DE UNA SERIE DE REUNIONES DE CONSULTA DE EXPERTOS EN LOS MESES DE MAYO Y JULIO DE 1990, EN LA QUE PARTICIPARON ESPECIALISTAS E INVESTIGADORES DEL DDF, LA SEDUE, LA COMISION NACIONAL DE ECOLOGIA, EL LABORATORIO NACIONAL DE LOS ALAMOS (E.U.), PEMEX Y EL IMP.

LOS CRITERIOS GENERALES DE EVALUACION SON: EL TECNICO, EL ECONOMICO, EL AMBIENTAL Y EL SOCIAL-POLITICO E INSTITUCIONAL; LOS CUALES FUERON JERARQUIZADOS Y DESGLOSADOS EN SUS RESPECTIVOS ATRIBUTOS O CRITERIOS ESPECIFICOS QUE, A SU VEZ, SE ASOCIAN CON FUNCIONES O MEDIDAS DE UTILIDAD, LAS CUALES SON LA BASE DE LA EVALUACION GLOBAL.

Analisis de Estrategias

LAS ESTRATEGIAS SELECCIONADAS, MISMAS QUE YA SE HAN IMPLEMENTADO, SE CARACTERIZAN POR ENFOCARSE A DOS DE LAS MAS IMPORTANTES FUENTES DE CONTAMINACION, LO QUE JUSTIFICA Y FACILITA SU ESTUDIO. LAS EMISIONES VEHICULARES REPRESENTAN EL 76% DEL TOTAL DE CONTAMINANTES EMITIDOS A LA ATMOSFERA DE LA ZMCM Y LOS AUTOS PARTICULARES SON RESPONSABLES DE MAS DE LA MITAD DE DICHA

CONTAMINACION, LA CUAL INCLUYE PRINCIPALMENTE CO, HC Y NO_X. POR OTRO LADO, LAS TERMOELECTRICAS JORGE LUQUE Y DEL VALLE DE MEXICO, ARROJAN COMO RESULTADO DE SU OPERACION MAS DEL 28% DEL SO_2 Y EL 3.7% DE NO_X.

LA INVESTIGACION DOCUMENTAL REALIZADA SE PLASMO EN DOCUMENTOS DE APOYO QUE DIERON UN PANORAMA GLOBAL DE LA PROBLEMATICA ASOCIADA CON AMBAS ESTRATEGIAS Y QUE ADEMAS, SIRVIO PARA ESTRUCTURAR UN CUESTIONARIO QUE SE UTILIZO PARA DOS ENTREVISTAS DIRECTAS CON FUNCIONARIOS DE LA INDUSTRIA AUTOMOTRIZ Y DE ENSAMBLADORAS DE CONVERTIDORES CATALITICOS(C.C.). EN LAS SIGUIENTES EMPRESAS: GENERAL MOTORS DE MEXICO; NISSAN MEXICANA; FORD MOTORS COMPANY; CHRYSLER DE MEXICO; VOLKSWAGEN DE MEXICO; A.P. DE MEXICO; NACK.; AGENCIA DE VENTAS DE FORD Y CHRYSLER Y ASOCIACION MEXICANA DE LA INDUSTRIA AUTOMOTRIZ; ASIMISMO EN LAS DOS TERMOELECTRICAS CITADAS JORGE LUQUE Y DEL VALLE DE MEXICO.

Convertidores Cataliticos

- A PARTIR DE 1991 TODOS LOS AUTOMOVILES TENDRAN C.C. DE FABRICA, PERO NINGUNA EMPRESA AUTOMOTRIZ LO PRODUCE EN MEXICO POR LO QUE SERAN DE IMPORTACION Y AQUI SERAN ENLATADOS Y POSTERIORMENTE ENSAMBLADOS COMO UNA AUTOPARTE.
- LA EFICIENCIA PARA REDUCIR LA EMISION DE CONTAMINANTES SE DETERMINA POR LA GENERACION DEL C.C. A LA QUE PERTENEZCA, EN ESTE CASO SE INTRODUCIRAN DUALES O DE PRIMERA GENERACION Y DE TRES VIAS QUE SON LOS MAS DESARROLLADOS ACTUALMENTE. EL DUAL REDUCE 80-90% DE HC, 80-90% DE CO Y 65-75% DE NO_X; EL DE TRES VIAS REDUCE EL 90% DE LOS TRES CONTAMINANTES.
- EL C.C. TIENE UNA VIDA UTIL PROMEDIO DE 80,000 KILOMETROS, CON UN COSTO DE ENTRE 2 Y 3 MILLONES DE PESOS QUE INCLUYE EL RESTO DEL SISTEMA NECESARIO PARA SU FUNCIONAMIENTO. NO SE LES PUEDE DAR MANTENIMIENTO POR LO QUE AL TERMINAR SU VIDA UTIL TIENEN QUE SER REEMPLAZADOS.
- LA CHRYSLER Y NISSAN INTRODUJERON C.C. DUALES MIENTRAS QUE LAS DEMAS MARCAS INCORPORAN DESDE 1991 EL C.C. DE TRES VIAS.
- EMPRESAS LIDERES COMO DEGUSSA, ENGELHARD Y J. MATTHEY.P., TIENEN PRACTICAMENTE CONTROLADO EL MERCADO INTERNACIONAL DE C.C.
- EL C.C. REQUIERE DE GASOLINA SIN PLOMO Y UN SISTEMA "FUEL INJECTION", POR LO QUE SU INTRODUCCION PERMITE TAMBIEN REDUCIR LAS EMISIONES DE DICHO CONTAMINANTE ASI COMO MANTENER EL APROVECHAMIENTO DEL COMBUSTIBLE.
- LA ADAPTACION DEL C.C. A VEHICULOS DE MODELOS ANTERIORES A 1991 TIENE FUERTES DIFICULTADES TECNICAS Y UN ALTO COSTO ECONOMICO.

- ACTUALMENTE, SE CONSIDERA QUE NO HAY MEJOR ALTERNATIVA QUE EL C.C. PARA REDUCIR LAS EMISIONES DE LOS VEHICULOS AUTOMOTORES.
- LA TENDENCIA HISTORICA Y LA ESTIMACION DE LAS VENTAS DE VEHICULOS ENTRE 1991 Y 1993 UBICADAS EN ALREDEDOR DE 350 MIL UNIDADES ANUALES, MUESTRAN QUE EL IMPACTO INICIAL SOBRE EL TOTAL DEL PARQUE VEHICULAR ES PEQUEÑO, POR LO QUE ES NECESARIO ACELERAR LA RENOVACION DE DICHO PARQUE.
- PEMEX TIENE LA CAPACIDAD PARA SATISFACER LA DEMANDA DE GASOLINA MAGNA-SIN A CORTO PLAZO Y YA EXISTEN PROYECTOS PARA INCREMENTAR SU CAPACIDAD DE PRODUCCION A LARGO PLAZO HASTA LLEGAR A ALREDEDOR DE 100 MIL BARRILES DIARIOS.

Substitucion de Combustoleo por Gas Natural en Termoelectricas

- LA MEDIDA DE SUSTITUIR COMBUSTOLEO POR GAS NATURAL EN LAS TERMOELECTRICAS DE LA ZMCM NO ES NUEVA; DESDE 1986 SE APLICO EN FORMA TEMPORAL (EN EPOCAS INVERNALES) Y PARA 1990 SE IMPLEMENTO DE FORMA PERMANENTE. DADAS LAS LIMITACIONES EN EL ABASTO DE ESTOS ENERGETICOS, SE MANTENDRA LA MEDIDA HASTA CONTAR CON COMBUSTOLEO DE MAYOR CALIDAD, ES DECIR CON MENOR CONTENIDO DE AZUFRE.
- EL DISEÑO DE AMBAS PLANTAS, DEL VALLE DE MEXICO Y JORGE LUQUE, PERMITE QUEMAR COMBUSTOLEO Y GAS NATURAL INDISTINTAMENTE, SIN QUE HAYA RESTRICCIONES DE TIPO TECNOLOGICO.
- NO SE CUENTA CON SISTEMAS EN LOS QUEMADORES, QUE PERMITAN CONTROLAR EL NO_X DADAS LAS CARACTERISTICAS DEL DISEÑO Y EL HECHO DE QUE NO SE USAN ADITIVOS PARA QUEMAR EL COMBUSTOLEO.
- EL COSTO POR KCAL DE GAS NATURAL ES 75% MAYOR QUE EL DE COMBUSTOLEO.

Termoelectrica Jorge Luque

- CAPACIDAD NOMINAL DE GENERACION 224 MW.
- EXPECTATIVAS DE GENERACION ENTRE 1991 Y 1993 ES DE 101 MW*AÑO.
- CONSUMO DE COMBUSTIBLES

	1988	1990
COMBUSTOLEO (M^3)	358,366	37,955
GAS NATURAL (Miles M^3)	596.9	173,491.6

- COSTO POR CONSUMO DE COMBUSTIBLE EN EL CASO DE SUSTITUCION AL 100%.

CAPACIDAD:	DISEÑO (224 MW)	REAL (128 MW)
COMBUSTIBLES	MILLONES $/AÑO	MILLONES $/AÑO
COMBUSTOLEO	3,141.41	47,509.39
GAS NATURAL	142,847.50	81,627.03
AUMENTO EN COSTO POR USO DE GAS NATURAL	59,706.09	34,117.64

Termoelectrica "Valle de Mexico"

- CAPACIDAD NOMINAL DE GENERACION 766 MW.

- EXPECTATIVAS DE GENERACION DE ENERGIA ELECTRICA.

AÑO	1991	1992	1993
MW	464.7	489.1	491.2

- CONSUMO DE COMBUSTIBLES.

	1988	1990
COMBUSTOLEO (M^3)	667,531.0	88,065.1
GAS NATURAL (Miles M^3)	494,945.3	902,664.1

- ESTIMACION DE CONTAMINANTES EMITIDOS EN DIVERSOS CASOS.

	CONTAMINANTES			
CASOS	PST	SO_2	CO	NO_X
COMBUSTOLEO 100%(KG/M^3)	5.0	72.0	0.5	8.0
G. NATURAL 100%(KG/10^6M^3)	N.R	N.R	300.0	10,000
MEZ.G.NAT/COMB 90/10 (KG/M3 TOT)	0.15	0.10	0.01	0.036

- COSTO POR CONSUMO DE COMBUSTIBLES EN EL CASO DE SUSTITUCION AL 100%.

CAPACIDAD:	DISEÑO (766 MW)	REAL (490 MW)
COMBUSTIBLES	MILLONES $/AÑO	MILLONES $/AÑO
COMBUSTOLEO	284,314	181,871
GAS NATURAL	488,486	312,478
DIFERENCIA EN COSTO	204,172	130,478

ADICIONALMENTE, PARA COMPLEMENTAR LA INFORMACION RELATIVA A LA SUSTITUCION DE COMBUSTOLEO POR GAS NATURAL EN LAS TERMOELECTRICAS SE REALIZO UN ESTUDIO DEL ESTADO ACTUAL DE LOS METODOS PARA PRODUCIR MEJORES COMBUSTOLEOS O SUSTITUTOS DE GAS NATURAL, ASI COMO DEL PROCESAMIENTO DEL GAS EN MEXICO. EN EL PRIMER CASO, SE TIENE, POR EJEMPLO, QUE LA TECNOLOGIA DE HIDRODESULFURACION DE RESIDUALES (H.OIL) PERMITE LA PRODUCCION DE COMBUSTOLEO CON MENOS DE 1% EN PESO DE AZUFRE; MIENTRAS QUE POR OTRO LADO, LA TECNOLOGIA DE GASIFICACION PERMITE OBTENER GAS DE SINTESIS QUE PUEDE SUSTITUIR AL GAS NATURAL. EN AMBOS CASOS, LA DESVENTAJA APARENTE ES EL ALTO COSTO DE LAS PLANTAS QUE SE REQUIEREN PARA SU PRODUCCION, PERO ELLO SE COMPENSA POR EL ALTO VOLUMEN DE PRODUCTOS QUE SE PUEDEN OBTENER.

POR LO QUE RESPECTA AL PROCESAMIENTO DE GAS, SE TIENE QUE LAS RESERVAS PROBADAS DE GAS NATURAL EXPERIMENTARON UNA DISMINUCION DE ALREDEDOR DEL 1% ANUAL EN EL ULTIMO QUINQUENIO, MIENTRAS QUE LA PRODUCCION TAMBIEN DECRECIO EN 0.2%; POR OTRO LADO, LAS IMPORTACIONES HAN VENIDO AUMENTADO CONSIDERABLEMENTE, PERO SU PARTICIPACION EN LA PRODUCCION NACIONAL SOLO REPRESENTA ALREDEDOR DEL 1%; POR LO QUE LA PROBLEMATICA PRINCIPAL SI BIEN TIENE QUE VER CON LA MAGNITUD DE LAS RESERVAS, SE UBICA TAMBIEN EN LA FALTA DE CAPACIDAD DE APROVECHAMIENTO.

Las Funciones de Utilidad

CON BASE EN LA INFORMACION RECABADA SE REALIZARON EJERCICIOS DE LAS FUNCIONES DE UTILIDAD DE LAS ESTRATEGIAS SELECCIONADAS, A TRES NIVELES: GLOBAL, POR CRITERIO Y POR ATRIBUTO. MAS QUE UN RESULTADO DEFINITIVO LO QUE SE PUEDE APRECIAR SON LOS RANGOS EN LOS QUE SE UBICA LA BONDAD DE LOS CRITERIOS TECNICO, ECONOMICO, AMBIENTAL Y SOCIO-POLITICO DE CADA ESTRATEGIA, ASI COMO LAS CONVENIENCIAS O PROBLEMAS QUE PRESENTA LA METODOLOGIA PARA CAPTAR ALGUNAS PARTICULARIDADES DE LAS ESTRATEGIAS EVALUADAS.

A NIVEL GLOBAL, LA INTRODUCCION DEL C.C. ALCANZO UN PUNTAJE ACUMULADO MAYOR QUE LA SUSTITUCION DE COMBUSTOLEO POR GAS NATURAL, BASADO EN CALIFICACIONES ALTAS PARA LOS ASPECTOS TECNICOS, ECONOMICOS Y SOCIAL-POLITICOS, MIENTRAS QUE EL CRITERIO AMBIENTAL QUEDO ABAJO; AUNQUE LA SEGUNDA ESTRATEGIA TIENE MENOR PUNTAJE, EL CRITERIO DEL BENEFICIO AMBIENTAL SUPERO AL DE LA PRIMERA ESTRATEGIA.

EN EL ASPECTO TECNICO, LA DESVENTAJA DEL USO DEL GAS NATURAL ESTRIBO FUNDAMENTALMENTE EN SU BAJA DISPONIBILIDAD. EN EL CRITERIO ECONOMICO LA BAJA INVERSION REQUERIDA Y EL TRASLADO DEL COSTO DE LOS C.C. AL CONSUMIDOR

FAVORECIERON A LA PRIMERA ESTRATEGIA, MIENTRAS QUE LOS ALTOS COSTOS Y LA FORMA SUBSIDIADA DE LA SEGUNDA LA AFECTARON NEGATIVAMENTE. POR LO QUE RESPECTA AL CRITERIO SOCIAL-POLITICO EL HECHO DE QUE LA SUSTITUCION DE COMBUSTOLEO POR GAS NATURAL FUERA UNA PROPUESTA GUBERNAMENTAL REALIZADA PRACTICAMENTE POR DECRETO, LA AFECTO NEGATIVAMENTE. FINALMENTE, POR LO QUE RESPECTA A LA CUESTION AMBIENTAL, EL LENTO IMPACTO QUE TENDRA LA INTRODUCCION DEL C.C. LA AFECTO DESFAVORABLEMENTE, MIENTRAS QUE LA MAGNITUD DEL IMPACTO Y EL EFECTO PRACTICAMENTE INSTANTANEO QUE TUVO LA QUEMA DE GAS NATURAL EN TERMOELECTRICAS FAVORECIO ESTA ESTRATEGIA.

SE OBSERVO QUE ALGUNAS DE ESTAS CALIFICACIONES ESTAN DESVIRTUADAS POR EL HECHO DE QUE LA METODOLOGIA PRIVILEGIO MAS LO PRIVADO QUE LO PUBLICO EN ALGUNOS ATRIBUTOS Y, POR LO TANTO, SE DEBE PRECISAR SU VALORACION SOBRE TODO EN EL CRITERIO TECNICO, EN EL ECONOMICO Y EN EL SOCIAL- POLITICO. ASIMISMO, LA NATURALEZA DE LAS ESTRATEGIAS OBLIGA A REDISEÑAR ALGUNAS FORMAS DE MEDICION DE LOS ATRIBUTOS CUANDO, POR EJEMPLO, SE TIENE QUE CONSIDERAR VARIOS PRODUCTOS O SERVICIOS QUE CONTROLAN PORCIONES DIFERENTES DE UN MISMO MERCADO COMO EL DE LOS AUTOMOVILES O LAS DIFERENTES CAPACIDADES Y EFICIENCIAS DE PRODUCCION DE LAS TERMOELECTRICAS DE LA ZMCM.

POR OTRO LADO, SE DETECTO Y ESTIMO QUE AL CRITERIO AMBIENTAL SE LE ASIGNO UN FACTOR DE POCO PESO Y, POR OTRO, QUE ES NECESARIO HACER UNA DIFERENCIACION ENTRE LOS DISTINTOS TIPOS DE CONTAMINANTES.

ADEMAS, HAY QUE RESALTAR QUE EN LOS CRITERIOS GENERALES ES NECESARIO DEFINIR PLAZOS EN EL TIEMPO, YA QUE INDEPENDIENTEMENTE DE LOS VALORES OBTENIDOS EN OTRAS FUNCIONES DE UTILIDAD, ESTO PUEDE ALTERAR LA VIABILIDAD DE UNA MEDIDA.

DATE FILMED

7/8/94

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