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Analysis of Control Strategies to Attain the National Ambient Air Quality Standard for Nitrogen Dioxide

Presented by

John Crenshaw, Allen Basala
Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

ABSTRACT

This paper discusses the methodology and conclusions of an analysis that evaluated alternative air pollution control strategies that achieve the National Ambient Air Quality Standard (NAAQS) for NO_2 (nitrogen dioxide). The analysis was undertaken by the Environmental Protection Agency (EPA) in the summer of 1973 to determine the level of NO_x (nitrogen oxides) emission control from mobile and stationary sources required to achieve the standard.

The primary objective of the analysis was to determine an efficient air pollution control strategy that would attain and maintain the annual NO_2 standard of 100 $\mu g/m^3$ despite the rapid growth of NO_x sources. A proportional model was used to simulate air quality data at five-year intervals out to 1990. The model used current air quality data, six categories of NO_x sources (light, medium, and heavy duty vehicles, industrial processes, area sources, and power plants), five sets of growth rates for each source category, two levels of stationary source control, and four NO_x automotive emission standards. A proportional relationship was assumed between total annual NO_x emissions and annual average NO_2 concentrations. Control costs were calculated for each strategy. Fuel penalty costs were calculated for each level of mobile source control.

From the analysis, EPA concluded and recommended that the 1977 automotive standard of 0.4 grams/mile should be revised to 2.0 grams/mile. In addition, more stringent emission control should be placed on new and existing stationary sources in regions with high NO_2 concentrations. If adopted, this recommendation would change the national

NO_2 control strategy. The recommendation was made after evaluating projected air quality, control costs, and fuel penalty costs.

BACKGROUND

The Clean Air Act of 1970 requires that the Administrator of EPA establish ambient air quality standards for any pollutant which, in his judgement, adversely effects the public health and welfare. An ambient air quality standard implies that at no location in the nation may a parcel of air contain more than a specified concentration of the pollutant. Air quality standards are expressed in micrograms per cubic meter ($\mu g/m^3$) or parts per million by volume (ppm). In addition to requiring air quality standards, Congress, through the Clean Air Act, set emission standards for new automobiles. Based on 1970 NO_2 measurements, Congress estimated that only through 90% control of NO_x[1] emissions on new cars would the public be adequately protected from the adverse health effects of NO_2. Congress, therefore, wrote into the Clean Air Act the requirement that automotive emissions of NO_x be reduced by 90% by 1976.

In 1971, EPA promulgated National Ambient Air Quality Standards (NAAQS) for NO_2 and five other pollutants. The standard for NO_2 is

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[1] Nitrogen oxides are emitted into the air a nitric oxide (NO) and nitrogen dioxide (NO_2). By far, NO is emitted in larger quantities. Once in the air, NO is converted to NO_2. Therefore, to control NO_2 in the ambient air, emissions of NO_2 and its precursor, NO, must be controlled. By convention, NO_x represents the sum of NO and NO_2. In this paper, NO_x refers to the emissions of NO and NO_2. NO_2 refers to atmospheric concentrations of nitrogen dioxide.

100 μg/m^3 annual average. The national control strategy for attaining the NO_2 standard was to meet the mandated 90% control of NO_x emissions from automobiles, to apply the available NO_x control technology to stationary sources, and then, if certain areas do not meet the standard, to place further controls on transportation sources. Transportation controls include reducing vehicle miles traveled, retrofitting existing automobiles, and restricting downtown parking.

After the Clean Air Act was enacted, EPA discovered that the analytical method that was being used to measure ambient NO_2 was overestimating NO_2 levels in many cases. Using other analytical techniques, EPA remeasured air quality in the 47 regions of the country where the standards were suspected of being violated. The results showed that only 2-5 regions of the country were in violation of the standard. Thus, the Administrator suspected and alerted Congress to the possibility that our national control strategy for attaining the NO_2 standard might be overly restrictive on the automobile.

The Office of Air Quality Planning and Standards (OAQPS) was asked to study the NO_2 problem and, if appropriate, to recommend a new national control strategy for NO_2 based on the more recent air quality measurements. The problem was to determine the balance of NO_x emission control between mobile and stationary sources that would achieve the NAAQS at the least cost to society. The general approach to the problem was to formulate a set of strategies, predict future air quality for each strategy, associate a cost to each strategy, and then recommend a control strategy based on future air quality, costs and energy considerations (gasoline consumption).

AIR QUALITY SIMULATION

The Modified Rollback Model was used to simulate NO_2 concentrations in the future. The model was developed by Roger Morris and Noel deNevers of EPA. The model will not be explained in detail because the model per se is not the major subject of this paper. The model assumes that in a region air concentrations of a pollutant are proportional to the emissions of that pollutant. The basic equation from which the model was derived is

$$AQ_F = B + (AQ_o - B) \left[\frac{\Sigma E_F}{\Sigma E_o} \right]$$

where AQ_F = Predicted pollutant concentration at a future date ($\mu g/m^3$)

B = Natural background concentration ($\mu g/m^3$)

AQ_o = Baseline pollutant concentration ($\mu g/m^3$)

E_F = Total emissions (Tons/year) at a future date

E_o = Baseline emissions (Tons/year)

The equation states that (future concentrations of a pollutant) = (background concentration) + (that portion of baseline air quality contributed by man) x (the ratio of future emissions to baseline emissions).

The ratio $\left[\frac{\Sigma E_F}{\Sigma E_P} \right]$ is a summation of E_F and E_P for six categories of NO_x emission sources. The calculation of ΣE_F and ΣE_P begins with the baseline emissions (Tons/year) from each source category. The following parameters were considered in the calculation. (a) Present and future emission factors. Emission factors represent the rate of emission into the environment per a unit of production. For example, an emission factor for the automobile is expressed in grams/mile. An industrial boiler would be expressed in pounds/10^6 BTU. (b) Weighting factors represent the percent contribution of NO_x emissions from sub-categories within each emission category. Since the combustion of different fuels releases different amounts of NO_x into the air, the power plant category was divided into coal, oil and gas-fired units. Industrial emissions were divided into coal, oil, and gas-fired boilers, nitric acid plants, and solid waste disposal. (c) Stack height factors considered the effect of stack height on ground level NO_2 concentrations. (d) Growth rates were derived for all six categories. (e) Speed factors adjusted emission factors of mobile sources according to average vehicle speeds. (f) Deterioration factors accounted for the decrease in effectiveness of control equipment (i.e. increased emissions) as vehicles grew older. (g) Distribution factors were applied to consider the contribution of emissions from each model year vehicle during a given calendar year. Appendix A shows the expansion of the basic rollback equation that considers six emission source categories and breaks down emissions by new and existing sources.

Future air quality was simulated for the ten cities shown in Table 3. These cities were selected because they represented a wide variety of NO_2 concentrations and NO_x emission sources.

Emissions data were taken from the National Emissions Data System (NEDS) which is maintained by EPA with data provided by each state. For the analysis, data were divided into the following six categories--light-duty vehicles, medium-duty vehicles, heavy-duty vehicles, power plants, industrial sources, and area sources (small emitting sources of less than 100 Tons/year each). Air quality data were taken from the National Air Surveillance Network (NASN) which is a network of air monitors operated by EPA. Air quality was measured in the central business district of each city. The baseline year for all data was 1972.

Growth rates were derived for each source category. For each category several sets of growth rates were derived using different economic indicators from the Department of Commerce. The model was run with each set of growth rates to determine whether small variations in growth rates would significantly affect future air quality. The variations were not significant (usually <4 $\mu g/m^3$). Therefore, the growth rates selected for the analysis were those derived from what were felt to be the best economic indicators.

STRATEGY FORMULATION

The general approach to formulating strategies was to select various future automotive standards and test them at different levels of stationary source control. The current NO_x emission standard for light-duty vehicles is 0.4 grams/mile to be achieved in 1977. The interim standards are 3.1 grams/mile in 1973 and 2.0 grams/mile in 1976. EPA's Mobile Source Testing Lab recommended four emission levels that should be considered for future standards: 0.4, 1.0, 1.5, and 2.0 grams/mile. Each standard represents a distinct level of technology and cost. Each of these potential standards was assumed to be met in 1977 after the interim standards were met in 1973 and 1976. Standards for medium and heavy-duty vehicles were assumed in 1980 at a level expected to represent best available control technology at that time. These standards remained constant throughout the simulations. Each of the four automotive strategies was simulated with two levels of stationary source control. Both stationary source strategies assign a level of control to new and existing emission sources within each category and sub-category of NO_x sources.

CSST - Current stationary source technology represents emission reductions that will occur as a result of the current Federal and State air pollution control regulations.

MSST - Maximum stationary source technology represents emission reductions that would be feasible beginning in 1980 if EPA pursues an intensive research and development program for the control of NO_2. The MSST strategy was derived from emission estimates by EPA's Control Systems Laboratory.

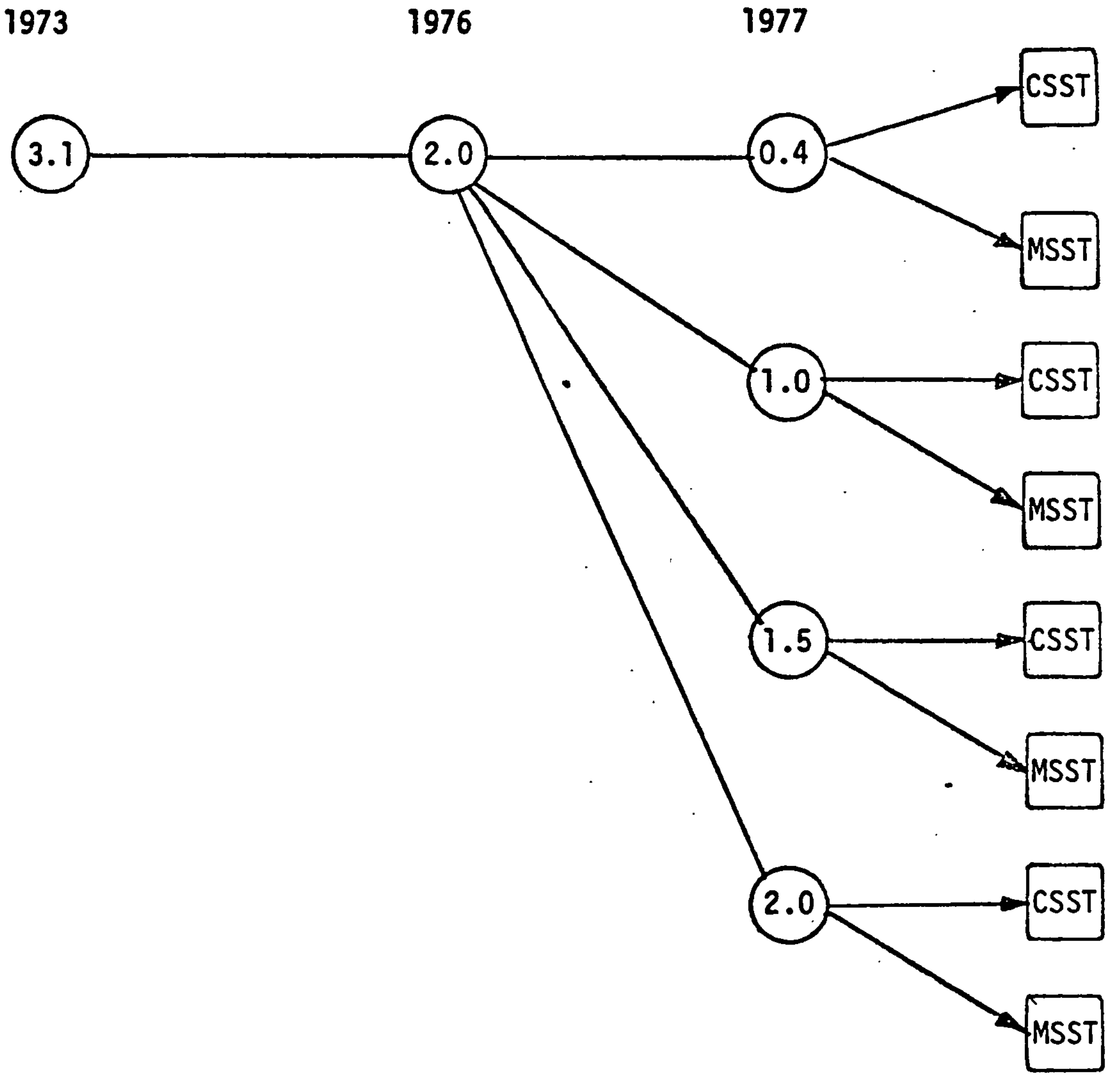
Figure 1 graphically represents the eight control strategies that were considered. For each strategy future air quality concentrations were simulated (on the Modified Rollback Model) for the years 1975, 1977, 1980, 1985, and 1990.

DEVELOPMENT OF COSTS

For the purpose of recommending a control strategy, the air quality simulations alone were not conclusive. Several strategies appeared to attain and maintain the air quality standard adequately. Cost estimates would provide a measure of the resource requirements for each strategy. A strategy could then be selected which achieved and maintained the air

Figure 1

SIMULATED STRATEGIES



CSST = Current Stationary Source Technology

MSST = Maximum Stationary Source Technology quality standard while efficiently utilizing resources. Therefore, costs were calculated for each of the eight simulated strategies.

No formal model existed relating NO_x emissions to air quality and cost. The relationship between emissions and air quality could be simulated with the Modified Rollback Model. But a method for linking costs to emissions had to be developed.

The following assumptions were employed in developing costs. Constant costs were assumed for each source affected by a simulated regulation. Economies and diseconomies of scale were not considered. In certain instances, cost was projected beyond the useful life of a device. This action implied replacement of the control device. Costs were presented in annualized form for each of the simulated time periods. The annualized form was believed to be an adequate representation of costs since the ordinal ranking of projected air quality and cost for every strategy did not change over the time periods.

Cost Development. In the analysis, cost represented the annualized control cost required to achieve a strategy in a particular time period and region. For consistency, each strategy cost was developed with the same emissions and growth rates used in the air quality simulations.

Each strategy cost was developed in the following sequence. The affected sources were designated and categorized. The control techniques were determined. Model plant costs were developed. The number of affected sources in each category was determined. Finally, the model plant costs and the numbers of affected sources were multiplied and their products summed to yield the total strategy cost. Each step of cost development is described in more detail below.

Affected Sources. The affected sources were designated by comparing the current and projected emissions inventory with the emission reduction requirements for each strategy. For example, consider a regulation applying to NO_x emissions from stationary source coal combustion under CSST. A search of the current and projected emissions inventory found coal-fired boilers in the industrial category and in the power plant category. The emission source categories and the applicable affected sources are displayed in Table 1.

Control Techniques. After the affected sources were selected, the control techniques that would achieve the required emission reductions were determined. The criterion for selection of a control technique was least cost subject to demonstrated reliability or development potential. Given the affected sources, the required emission reductions, and the criterion, the applicable control techniques were determined. Although appearing to be a large chore, this task was relatively easy, because NO_x control techniques for stationary and mobile sources are few. The selected control techniques for the mobile and stationary source categories are given in Table 2-1 and Table 2-2, respectively.

Model Plant Cost. Given each affected source and the applicable control technique, a model plant was specified. A model plant is a typical source within a source category. For the mobile source category, the model plant was defined by the affected source designation. In the industrial, power plant, and area source categories a model plant had

TABLE 1. Affected Sources

Emission Source Category	Affected Sources	
	CSST	MSST
Area	None	New residential oil-fired sources
Industrial	New and existing coal, oil, gas fired boilers. Existing nitric acid plants.	New and existing coal, oil, gas fired boilers.
Power Plant	New and existing coal, oil, gas-fired plants	Coal, oil, gas-fired plants
Light-duty vehicle	New	New
Medium-duty vehicle	New	New
Heavy-duty vehicle	New	New

TABLE 2-1.

Control Techniques for Mobile Sources

Affected Sources	Emission Reduction Requirement	Control Technique
Light-Duty Vehicle	2.0 grams/mile	Proportional Exhaust Gas Recirculation (PEGR)
	1.5 grams/mile	PEGR
	1.0 grams/mile	PEGR + 3-way Catalyst
	0.4 grams/mile	PEGR + 3-way Catalyst
Medium-Duty Vehicle	3.1 grams/mile	Exhaust Gas Recirculation
	2.0 grams/mile	Proportional Exhaust Gas Recirculation
Heavy-Duty Vehicle		
gasoline	7.0 grams/mile	Exhaust gas recirculation
diesel	7.0 grams/mile	Engine Modification by Redesign

TABLE 2-2.

Control Techniques for Stationary Sources

Affected Sources	Current Stationary Source Technology (CSST)	Maximum Stationary Source Technology (MSST)
Power Plants		
coal-fired	Low Excess Air Firing plus two stage firing	Flue Gas Recirculation
oil-fired	Low Excess Air Firing plus two stage firing	Flue Gas Recirculation
gas-fired	Low Excess Air Firing plus two stage firing	Flue Gas Recirculation
Industrial Sources		
coal-fired	Low Excess Air Firing	Flue Gas Recirculation
oil-fired	Low Excess Air Firing	Flue Gas Recirculation
gas-fired	Low Excess Air Firing	Flue Gas Rhcirculation
HNO_3 Plants	Catalytic Reduction	
Area Sources		
Residential oil-fired heaters	Not Applicable	Low Excess Air Firing plus Flue Gas Recirculation

to be specified. The model plants in these instances were composite plants whose characteristics were determined considering the current and projected size distribution of the affected sources.

Characteristics such as operating time, life of the control device, investment cost, interest, and maintenance cost were then calculated for each model plant. The validity of each characteristic was documented by published cost/engineering studies and expert opinion. Given the model plants, the characteristics, the required emission reductions, and the control techniques, the annualized costs for each model plant were developed. Two examples, one from the industrial category and one from the mobile source category are given below. The examples display the sequence of model plant cost development.

1. Source category -- Mobile
2. Regulatory strategy element -- 2.0 grams NO_x per mile
3. Affected Source -- light-duty vehicles (less than 6000 pounds)
4. Control Technique -- Proportional exhaust gas recirculation
5. Model Plant -- light-duty vehicle
6. Characteristics:

    Vehicle Age and Annual Mileage -- 4 years old; 11,400 miles
    Miles per gallon -- 13.5 mpg
    Fuel Cost -- $.40/gal
    Control Investment -- $32.00
    Depreciation period -- 10 years
    Interest -- 8%
    Maintenance -- $4.00/year
    Fuel penalty factor -- 6%
    Operating cost --

$$\text{Annual fuel penalty cost} = \left(\frac{\text{miles}}{\text{year}}\right)\left(\frac{\text{gallons}}{\text{mile}}\right)\left(\frac{\$}{\text{gallon}}\right)\left(\begin{array}{c}\text{fuel penalty}\\ \text{factor}\end{array}\right)$$

$$= (11{,}400)\ (.0741)\ (\$.40)\ (.06)$$

$$= \$20.27/\text{year}$$

7. Annualized Model Plant Cost -- $29.00

1. Source Category -- Industrial
2. Regulatory Strategy Element -- MSST
3. Affected Source -- Coal Fuel Combustion
4. Control TUchnique -- Flue Gas Recirculation
5. Model Plant -- Boiler producing 190,000 pounds of steam per hour
6. Characteristics:

Fuel Consumption -- 9 tons of coal per hour
Operating Time -- ~~4560~~ 5700 hours per year
Fuel Cost -- $.18 per 10^6 BTU
Combustion Efficiency Factor -- 80 percent
Excess Air, pre control -- 25 percent
Excess Air, past control -- 5 percent
Fuel Savings Factor -- 1 percent
Control Investment -- $141,000
Depreciation Period -- 10 years
Interest -- 8 percent
Maintenance -- 8.6 percent of investment
Operating Costs

Electricity and Labor -- $700

$$\text{Fuel Savings} = \text{pounds steam} \times \frac{\text{BTUs per pound steam}}{\text{combustion efficiency factor}} \times \text{fuel savings factor} \times \frac{\text{fuel cost}}{10^6\ \text{BTU}} \times \text{operating time}$$

$$= 190{,}000 \times \frac{1000}{.80} \times .01 \times \frac{.18}{10^6} \times 5700$$

$$= \$2437$$

7. Annualized Model Plant Cost -- $22,443

<u>Affected Number of Sources</u>. The number of affected sources was calculated in the following manner. The annual emissions per model plant were determined. NO_x emissions for each of the affected sources were projected for each region and time period. Then, the projected annual emissions were divided by annual model plant emissions to determine the affected number of sources. An example is given below.

1. Emissions per model unit
   a. Emission factor: 18 pounds of NO_x per ton of coal consumed
   b. Annual Coal consumption --
      - hourly consumption x annual operating time
      - 9 tons per hour x ~~4560~~ 5700 hours per year = ~~4~~51300 tons per year
   c. Annual unit NO_x emissions --
      - emission factor x annual coal consumption
      - 18 pounds of NO_x per ton of coal x 51300 coal tons per year = 923,400 pounds of NO_x per year = 460 tons of NO_x per year
2. AQCR emission of NO_x from new industrial -- coal fuel combustion in the year 1980, regulation effective in 1980
   a. total 1980 emissions
      (1) Base emissions; growth rate; projection period given
      (2) 1980 total emissions = $(1 + \text{growth rate})^{10}$ x 1970 emissions
   b. 1980 new source emissions
      (1) 1979 total emissions
      (2) 1980 emissions = 1980 total - 1979 total
3. Number of new industrial fuel combustion sources in 1980
   New sources in 1980 = 1980 emissions from new sources divided by annual unit emissions

Total Strategy Cost. Total strategy cost was developed by multiplying the number of affected sources by the model plant cost for a given source for each time period and region. An example of this product would be the annualized cost for oil-fired power plants to meet the MSST requirements in New York City in 1985. The costs of each source were then summed to yield the total strategy cost for a given time period and region. An example of the total strategy cost would be the cost for the 1.0 gram/mile strategy with CSST for Chicago in 1980 (depicted in Table 4).

FACTORS INFLUENCING COST

The relative magnitudes of strategy cost are not always apparent from the regulatory aspects of a strategy. Factors that influence the magnitude of costs include growth rates of the affected sources, the distribution of emissions among the various mobile and stationary source categories, control techniques, age of the source, and phasing of control. Of course, there are other factors influencing cost. For NO_x control, one of the most important factors is the relationship of emission reduction to fuel use. This factor is unique in its affect upon cost. For some sources, there is an indirect relationship between emission reduction requirements and fuel use. For other sources, there is a direct relationship between fuel use and emission reduction requirements.

For stationary fuel combustion, required emission reductions are achieved by boiler modifications that reduce excess air during combustion. This modification reduces waste heat losses to the stack and thus saves fuel. The fuel savings were considered in calculating the costs for both the CSST and MSST strategies.

For light, medium, and heavy-duty gasoline propelled vehicles emission reductions down to 1.5 grams/mile are achieved by lowering combustion temperatures through exhaust gas recirculation (EGR). Exhaust gas recirculation suppresses NO_x formation, but engine efficiency is also suppressed, resulting in the expenditure of more fuel. Emission reductions and fuel use increase as the flow rate through the EGR device is increased. Emission reductions below 1.5 grams/mile are achieved by also installing a catalytic muffler. Fuel penalties, however, are still controlled by the EGR specifications. Fuel penalties increase as automotive emissions are reduced from 3.0 to 2.0 to 0.4 grams/mile. In comparing strategies, the fuel penalty was found to be the dominant factor influencing the relative magnitudes of cost. Note in Table 4 that the cost of the 1.0 gram/mile strategies is less than the cost of the 1.5 gram/mile strategies. The explanation lies in the fuel penalties associated with 1.0 and 1.5 gram/mile emissions. Although fuel penalties usually increase as NO_x emissions are reduced, this is not the case as NO_x emissions are reduced from 1.5 to 1.0 grams/mile. A change in control techniques account for a decrease in fuel penalty between 1.5 and 1.0 grams/mile. Emission reductions to 3.1, 2.0, and 1.5 grams/mile are achieved by exhaust gas recirculation (EGR). At 1.5 grams/mile, the EGR device is operating at its limit and the fuel penalty is severe. Other control methods could potentially achieve 1.5 gram/mile emissions, but the exhaust gas recirculation device was selected because none of the other methods had been demonstrated and the potential for development was not considered adequate ~~within the required time.~~ To reduce emissions to 1.0 gram/mile exhaust gas recirculation has to be augmented with a catalytic muffler. At 1.0 gram/mile, the catalyst eases the emission reduction burden on the EGR device so that the flow rate through the EGR (which determines fuel penalties) can be reduced to the same level that is required for an emissions reduction to 2.0 grams/mile. Note in Table 5 that the fuel penalty for 1.0 gram/mile and 2.0 grams/mile is identical.

Thus, the fuel penalty associated with the 1.0 gram/mile standard is far less than the fuel penalty associated with the 1.5 gram/mile standard (Table 5). The fuel penalty has such an overwhelming influence on cost that the total cost of the 1.0 gram/mile strategies was less, in all cases than the total cost of the 1.5 gram/mile strategies.

RESULTS AND CONCLUSIONS

The results of the air quality simulation are presented in Table 3. For the analysis, the assumption was made that a city within ± 10 $\mu g/m^3$ of the standard will marginally achieve the standard. The model was not considered sufficiently precise to conclude that a city with a predicted air quality of 104 $\mu g/m^3$ in 1985 would, in fact, violate the standard in 1985 or that a city with a predicted air quality of 98 $\mu g/m^3$ would meet the standard. Table 3 shows that each strategy affected various cities differently. The cities fell into three classes: (1) cities (e.g. Phoenix, San Francisco, Salt Lake City) that adequately maintain the standard under any strategy; (2) borderline cities (e.g. Chicago, Baltimore) where the model cannot predict with confidence if the standard will be met or fail to be met; (3) Los Angeles where only through maximum control of both stationary and mobile sources will the standard be met.

Although each city's air quality reacted differently to a given strategy, one trend was apparent in all cases--that air quality was affected more by stationary source control than by mobile source control. For example, consider one of the borderline cities--Philadelphia. Air quality (AQ) in 1972 was 83 $\mu g/m^3$. By 1985, if the interim 2.0 gram/mile standard is retained, AQ = 106. If the automotive standard is reduced to 0.4 grams/mile in 1977, AQ = 102 $\mu g/m^3$ by 1985. If the 2.0 gram/mile is retained in 1977 and more control is placed on stationary sources, then AQ = 87 $\mu g/m^3$ by 1985. The conclusion was drawn that the 2.0 gram/mile strategy with MSST will give comparable or even better air quality than the current strategy of 0.4 grams/mile with CSST. Further, MSST may not be required except in a few cities. 2.0 grams/mile with CSST may adequately maintain the standard in all cities except Los Angeles and Chicago.

Table 4 presents the cost of each strategy. The data clearly show that the 2.0 gram/mile strategy with MSST costs less than any strategy with CSST and more strict control of the automobile. The main reason is because of the fuel penalties attributable to the control of NO_x from mobile sources. Table 6 shows the cost of extra gasoline consumption that is associated with each level of automotive control.

From this analysis, and after other considerations, the Administrator of EPA has recommended that the 1977 NO_x emission standard for automobiles be changed from 0.4 gram/mile to 2.0 grams/mile and that cities requiring more NO_x control to maintain the standard achieve that control through further emission reductions from stationary sources. Table 6 summarizes data from Tables 3, 4, and 5 for New York City for the current NO_2 strategy and the recommended strategy. The table shows an example of how the recommended strategy results in better air quality for the city, costs the public less, and requires less gasoline consumption.

ACKNOWLEDGEMENT

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Table 3

Projected Air Quality ($\mu g/m^3$)
For Various Standards

CSST
MSST

Standard / AQCR	2 g/mi			1.5 g/mi			1 g/mi			.4 g/mi		
	1977	1980	1985	1977	1980	1985	1977	1980	1985	1977	1980	1985
1. Phoenix	66 66	69 61	72 63	65 65	65 59	70 60	65 66	65 60	69 59	65 65	65 58	66 66
2. Los Angeles	119 119	122 112	135 123	116 116	117 106	124 112	117 117	113 102	120 107	116 116	108 97	110 94
3. San Francisco	70 70	73 66	83 74	69 69	72 64	80 72	69 69	71 63	79 71	70 70	70 62	76 68
4. Denver	81 81	85 74	99 85	81 81	84 73	98 83	80 80	83 72	97 83	80 80	83 72	95 81
5. New York	91 91	95 78	95 77	90 90	93 76	91 74	90 90	87 74	89 72	90 90	90 74	86 68
6. Philadelphia	89 89	95 79	106 87	89 89	94 78	104 85	88 88	93 77	104 84	88 88	93 77	102 82
7. Washington, D.C.	87 87	101 72	98 71	87 87	97 71	95 69	87 87	97 69	94 68	87 87	97 69	89 64
8. Chicago	119 119	114 102	122 104	119 119	112 100	118 99	119 119	109 97	112 98	119 119	109 97	111 93
9. Baltimore	101 101	99 88	101 90	101 101	98 86	96 85	101 101	95 84	94 84	101 101	95 84	88 78
10. Salt Lake City	59 59	59 58	56 55	59 59	57 57	52 51	59 59	55 54	50 50	59 59	55 54	46 45

Table 4

Annualized Costs of Projected Air Quality ($\$10^6$)

CSST / MSST

Standard AQCR	2 g/mi			1.5 g/mi			1 g/mi			.4 g/mi		
	1977	1980	1985	1977	1980	1985	1977	1980	1985	1977	1980	1985
1. Phoenix	16.8 16.8	27.1 28.4	44.7 46.0	18.4 18.4	37.2 38.5	65.8 70.1	18.0 18.0	32.3 33.5	56.4 57.8	18.9 18.9	38.0 39.3	68.5 69.9
2. Los Angeles	112.2 112.2	172.0 174.0	249.5 252.1	123.1 123.1	237.1 239.1	377.1 379.7	120.0 120.0	205.1 207.0	320.5 323.1	126.2 126.2	242.3 244.3	393.4 396.0
3. San Francisco	49.3 49.3	75.5 78.1	110.7 115.7	54.1 54.1	103.9 106.5	166.5 170.5	52.7 52.7	89.9 92.5	141.2 146.2	55.5 55.5	106.1 108.8	172.5 177.5
4. Denver	14.6 14.6	22.3 35.8	32.7 49.4	16.0 16.0	30.8 44.3	49.4 66.1	15.6 15.6	26.6 40.1	42.0 58.7	16.4 16.4	31.5 45.0	51.2 68.2
5. New York	128.7 128.7	196.5 194.7	291.7 320.6	141.2 141.2	270.2 268.4	431.8 460.7	137.6 137.6	234.0 232.1	369.6 398.5	144.8 144.8	276.0 274.2	457.0 478.6
6. Philadelphia	52.0 52.0	79.0 80.5	113.5 117.2	57.1 57.1	109.2 110.6	172.0 175.7	55.7 55.7	94.4 95.8	146.0 149.8	58.6 58.6	111.6 113.0	179.5 183.2
7. Washington, D.C.	26.9 26.9	41.3 42.6	63.4 66.5	29.6 29.6	57.5 58.8	96.1 99.2	28.8 28.8	49.5 50.8	81.6 84.7	28.3 28.3	58.7 60.1	100.3 103.4
8. Chicago	66.2 66.2	99.4 106.8	149.4 160.8	72.7 72.7	137.4 145.4	224.3 235.7	70.8 70.8	119.0 126.4	191.1 202.4	74.5 74.5	141.0 148.0	233.8 245.2
9. Baltimore	23.0 23.0	38.9 40.8	72.4 76.6	25.3 25.3	54.4 56.2	109.6 113.4	24.6 24.6	46.8 48.6	93.1 97.3	25.9 25.9	55.6 57.4	114.3 118.5
10. Salt Lake City	9.7 9.7	15.8 16.0	25.7 25.9	10.7 10.7	21.7 22.0	38.3 38.5	10.4 10.4	18.8 19.0	32.7 32.9	10.9 10.9	22.2 22.4	39.9 40.1

Table 5

Annualized Fuel Penalties ($\$10^6$)

AQCR \ Standard	2 g/mi			1.5 g/mi			1 g/mi			.4 g/mi		
	1977	1980	1985	1977	1980	1985	1977	1980	1985	1977	1980	1985
1. Phoenix	7.9	12.8	19.9	9.5	22.9	41.1	7.9	12.8	19.9	8.8	18.5	32.0
2. Los Angeles	52.5	82.1	120.3	63.4	147.2	247.9	52.5	82.1	120.3	58.8	119.3	193.2
3. San Francisco	23.1	35.8	51.7	27.9	64.1	106.5	23.1	35.8	51.7	25.8	52.0	83.0
4. Denver	6.8	10.7	15.7	8.2	19.1	32.4	6.8	10.7	15.7	7.6	15.5	25.3
5. New York	60.5	92.8	132.1	73.0	166.5	272.2	60.5	92.8	132.1	67.6	134.9	212.2
6. Philadelphia	24.5	38.0	55.2	29.6	68.2	113.8	24.5	38.0	55.2	27.4	55.3	88.7
7. Washington D.C.	12.8	20.4	30.8	15.5	36.6	63.5	12.8	20.4	30.8	14.4	29.7	49.5
8. Chicago	31.3	48.6	70.6	37.8	87.2	145.5	31.3	48.6	70.6	35.0	70.7	113.4
9. Baltimore	11.0	19.4	35.1	113.3	34.8	72.2	11.0	19.4	35.1	12.3	28.2	56.3
10. Salt Lake City	4.6	7.5	11.9	5.5	13.4	24.5	4.6	7.5	11.9	5.1	10.9	19.1

Table 6

COMPARING NO_x CONTROL STRATEGIES
(NEW YORK)

Strategy	Annual Air Quality (ug/m^3)				Annual Control Cost (10^6 \$)				Annual Fuel Penalty (10^6 \$)			
	1977	1980	1985	1990	1977	1980	1985	1990	1977	1980	1985	1990
Automotive standard of 0.4 grams/mile and Moderate Stationary Source Control.	90	90	86	96	144.8	276.0	457.0	510.1	67.6	134.9	212.2	227.9
Automotive standard of 2.0 grams/mile and Maximum Stationary Source Control.	91	78	77	87	128.7	194.7	320.6	377.4	60.5	92.8	132.1	136.7

Appendix A: MODEL USED FOR AIR QUALITY PREDICTIONS

$$\frac{c_{max-future} - b}{c_{max-base} - b} = - - -$$

$$\frac{(e \cdot gf \cdot ef)_{LDV} + (e \cdot gf \cdot ef)_{MDV} + (e \cdot gf \cdot ef)_{HDV}}{(k \cdot e)_{LDV} + (k \cdot e)_{MDV} + (k \cdot e)_{HDV}} - - -$$

$$\frac{[k \cdot e\ (ef_1 + (gf - 1)ef_2)]_{pp} + [k \cdot e\ (ef_1 + (gf - 1)ef_2]_{I} + [k \cdot e\ (ef_1 + (gf - 1)ef_2]_{A}}{+ (k \cdot e)_{pp} + (k \cdot e)_{I} + (k \cdot e)_{A}}$$

where e = baseline emissions in Tons/year

k = emission height factor (unitless)

ef_1 = emission factor ratio for existing sources

ef_2 = emission factor ratio for new sources

gf = growth factor (unitless)

c = air concentration ($\mu g/m^3$)

b = background concentration ($\mu g/m^3$)