A-96-01
II-A-668

OVERVIEW OF THE NOISE DECISION MODEL

-EXECUTIVE SUMMARY-

PREPARED FOR:

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26 May, 1983

Preface

Development of regulations concerned with the environment, energy, occupational health and safety, etc., that is the mandated responsibility of a particular federal or state regulatory authority is oft times an extremely complex problem. Many issues on matters relating to how society would benefit and at what cost must be addressed prior to promulgation of new regulations by federal regulatory agencies. Governing this determination process is Executive Order 12291.

The Environmental Protection Agency, Office of Noise Abatement and Control, has developed and extensively used a tool to assist them evaluate regulations controlling noise emissions of specific products. This tool, the Noise Decision Model, is a computerized cost-benefit model designed to integrate the results of technology assessment, cost and economic impact analysis, and health/welfare benefit analysis, into a consistent decision framework. The model has provided decision-makers in the EPA with a tool for the rapid computation and display of relevant data assessing the various anticipated costs, economic impacts and benefits associated with regulation.

The Noise Decision Model was designed and developed under the aegis of the Office of Noise Abatement and Control. Its conceptual framework and techniques used for problem-solving make it generically applicable to a broad range of regulatory programs. The modular structure of the model also provides the flexibility to easily adapt it to government regulations in other areas.

INTRODUCTION

The Environmental Protection Agency, Office of Noise Abatement and Control (EPA ONAC), developed and extensively used a tool to assist in the analysis and selection of regulatory options for all products identified and subject to noise emission regulations under the Noise Control Act. This tool, the Noise Decision Model (NDM), is a computerized model that provides a way of comparing alternative regulatory options under consideration by decision/policy-makers on the basis of benefits or effectiveness and cost. The model provides the Office with a tool for the rapid computation and display of relevant data required for selecting the preferred regulatory alternative. In addition, results obtained from executing this model are directly applicable to meeting regulatory review requirements for final rules under Executive Order 12291.

This report documents the salient features of the NDM. In addition, a brief statement on its origin is made.

BACKGROUND

A regulatory program generally consists of the following elements: a legislative mandate for regulation, the determination of benefits to be derived from regulation, the identification of the products or processes to be regulated, assessment of technology and their costs, and the analysis of regulatory options to determine optimum levels of regulation.

LEGISLATIVE MANDATE

The Congress establishes national policy and mandates regulatory programs through legislation. The identification of certain categories of products (e.g., construction equipment) to be regulated and the guidelines to be followed in establishing noise emission regulatory levels are specified in varying levels of detail. In some cases, the identification of products to be regulated is left to the regulatory agency, while in others, the types of products to be covered are laid out in the legislation. Similarly, the levels of regulation are sometimes specified, but generally become the responsibility of the regulatory agency.

In all cases, the regulations have to address a wide variety of technologies, benefits, costs, and economic impacts. The categorization and display of the options available for the decision-maker is in itself a bewildering task.

In order for the regulator to specify product regulations, he must consider many complex environmental, technological, societal, and economic issues. In today's economic environment the decision-maker cannot impose a stringent regulation simply because it is technologically feasible. The regulatory agency must carefully weigh the tradeoffs between the benefits and costs of regulation. The relative benefits of alternative regulations must be considered in relation to economic factors.

Therefore, there is a need for a decision methodology that provides a consistent and sound framework for assessing alternative regulatory options. It is difficult to be consistent in establishing regulations on products in a particular product category, if a formal decision framework is not adopted. Further, it should be recognized that through the use of a methodology like the NDM several positive effects on regulatory studies and the rulemaking process itself are achieved. These include the identification of specific quantitative data required for the decision process, various regulatory options or alternative levels of regulation, and results (model outputs) to compare the relative effectiveness among regulatory options.

SELECTION OF THE MODELING METHODOLOGY

As expressed earlier, this report describes an analytical, computerized model which was specifically designed to integrate relevant information on technology, benefit, economic and timing considerations into a decision-making framework. To develop this methodology it was necessary to study the needs of various regulatory programs, the scope and content of the information/data developed in studies supporting regulatory programs, and the nature of the decision problem to be solved. These studies provided the basis for developing criteria for evaluating several alternative modeling methodologies. A modeling methodology was then selected that would best satisfy the criteria.

Activities carried out as an integral part of the regulatory development process by the EPA ONAC include:

- Health and Welfare Analysis.
- Technology Studies.
- Cost and Economic Impact Analyses.
- Legal Review
- Preparation of Draft Environmental Impact Statement.

The information developed in some of these activities are listed below:

Health and Welfare Analysis

- Development of baseline data on the population exposed to product noise emissions.
- Development of information on the degree to which the population exposed to noise emissions (baseline case) changes with reductions in the noise emissions from certain product sources.
- Determination of measures to appropriately describe the adverse effect that noise emissions have on activities (e.g., speech or sleep) of the population exposed to such noise.

Technology

- Development of types, and classes within types of products on the market, and modifications required by regulation.
- Examination of methodologies for measuring product noise emission.
- Measurement of noise emission emitted by various products and classes of products.
- Determination of the technology (best available technology) to "quiet" the product.
- Determination of any deterioration of the utility of the products due to complying with regulation.
- Measurement of the variation in noise emissions among classes of products.

Cost and Economic Impact Analysis

- Economic snapshot concerning the identification of key structural relationships in the affected industry(s) and those areas most likely to be affected by the regulations, leading to an estimation of the elasticity of supply.
- Baseline forecast, without regulations, that consists of the development of a framework to forecast the expected industry sales growth for the future.
- Estimation of the elasticity of consumer demand with respect to increases in product prices.
- Identification of alternative possible time phases of regulation.
- Description of expected changes in the product's performance and the effect on noise emission levels.
- Identification of the cost implications of various abatement technologies on each class of product.

- Economic impact analysis that includes a detailed description of the differences between the baseline forecast and the forecast with regulations.

- Historical trend information of product sales over an appropriate timeframe.

- Impact of varying levels of regulation on unit costs of producing the product.

- Impact of increased operation and maintenance costs on product end-users.

- Investment by the industry in R&D and retooling to meet alternative noise emission levels by product type, class and basic model, as applicable.

- Average lifetime (obsolescence factor or rate of replacement) for each product class with and without regulation.

- Impact on unemployment and plant closings if sales and/or profits decrease due to regulation.

NEEDS OF THE REGULATORY PROGRAM

In order to meet the decision-making needs of a regulatory agency, a methodology for analyzing and selecting regulatory options must be considered. The methodology must be designed in such a manner that these problems are alleviated. To be useful, the methodology must also consider the constraints placed on the problem of selecting regulatory options for a variety of products, where differing data may be of significance in determining the optimal solution. In order to meet these needs, it is necessary to study and evaluate modeling techniques that would provide:

- Economically sound decision criteria.
- Methods for selecting the appropriate regulatory options.
- A consistent method for evaluating the appropriate regulatory options.
- Flexibility to analyze regulatory options for a variety of products and classes of products that may or may not have the same cost functions and benefit measures.

- A model that does not require unreasonably voluminous input data.

- A model that is able to rapidly analyze the data and generate feasible regulatory options on the basis of decision-maker criteria.

GENERAL COST/BENEFIT PROBLEM

Basically, the nature of the regulatory decision problem is that of trading off the benefits of the regulatory action against the cost of compliance. If the costs ($) of all possible regulations are greater than the respective benefits (expressed in dollars), then one should not impose a regulation. If the benefits ($) are greater than the costs ($) for some possible regulations, then one wants to choose the regulation that maximizes the ratio of benefits to costs. Using this classical economic cost/benefit approach, society can be assured of obtaining the greatest net benefit for the cost incurred due to complying with a particular government regulatory action.

Exhibit 1 presents this problem in the classical marginalist economic approach to cost/benefit analysis. Classical economic theory asserts that as some activity is pursued more intensively, a point will be reached where additional (marginal) benefits will begin to decline and additional (marginal) costs will begin to rise as shown in this Exhibit. For increasing levels of regulation, net benefits (B-C) increase. However, at the point A in Exhibit 1, the maximum net benefit occurs where the marginal (or incremental) benefits are equal to the marginal costs. This optimum point generally occurs where the costs are much lower than the benefits. At the optimum, a dollar value increase in cost would buy an additional dollar value of benefits. Pursuing the activity beyond this point would result in a waste of society's resources. The important point is to note that the optimal point A is neither the point of maximum benefit, nor minimum cost.

Under the general cost/benefit framework, the ideal method for evaluating regulatory options would be to place a dollar value on all the benefits and a dollar value on all the costs of compliance. The sum of costs subtracted from the sum of the benefits results in a single net benefit for each regulatory option. The regulatory option with the maximum net benefit would then be the best option.

There are, however, sometimes many problems in placing a dollar value on the benefits. For example, the benefits of noise regulation include people no longer adversely affected by long-term exposure to noise, people no longer impacted by a single event exposure, and wildlife no longer disrupted. To collapse these benefits into monetary terms (e.g., a single dollar sum) is a difficult task. At the present time, the knowledge and data do not exist to place a dollar value on each of these benefits. Therefore, analytical approaches to such problems allow benefits to be measured in any convenient unit, and deals with the ratio of benefits to costs rather than the difference between benefits and costs.

There can be problems in placing a dollar value on all the costs also to comply with regulation. The cost of compliance includes, for example, the changes in product prices, changes in regulated manufacturers' capital investment costs, changes in product operation and maintenance costs, plant closings, changes in regulated industry employment, effect on the Nations balance of trade. Most of these cost items can be combined into a single dollar value; however, some items such as employment, balance of trade, and plant closure, present technical problems of varying difficulty. These items can be considered as constraints. If the impact of one of these factors or the combined impacts of a number of these factors for a regulatory option are considered disruptive to the economy, then the regulatory agency should not choose that option as the regulation to be promulgated, independent of the cost/benefit analysis of the other factors.

Although a dollar value cannot be placed on the benefits, classical cost/benefit (or benefit/cost) economic analysis can still contribute much to the explanation of the nature of the problem. Consider the following hypothetical benefit/cost formulation of Exhibit 2. In this exhibit regulatory options are plotted against a benefit scale on the Y-axis and a cost scale on the X-axis. Each dot represents a possible regulatory option, which is defined by a set of time-phased sound intensity levels, dB(A), for an assumed product whose noise emissions are to be controlled via regulation. Several observations can be made about the nature of the decision problem on the basis of this example. Some of these observations include:

- More than one regulatory option may have approximately the same cost. This results in the existence of a set of options that are better than the other options no matter what dollar value is placed on the benefits. A convex envelope can be formed by drawing a line through the most cost-effective options.

- The maximum benefit/cost ratio for the case where there is a single unvalued benefit measure is the same point as it would be if the benefit was valued, no matter what dollar value was chosen.

- There is a direct relationship between the marginal costs for the formulation in Exhibit 2 and the optimal answer if a value is placed on the benefits. The marginal costs should be similar for different products and different classes of the same product in order to be economically consistent. In addition, point B represents the option having the maximum net benefit, i.e., benefit minus costs. The marginal cost in terms of dollars per unit of benefit of going from option B to option C is greater than the value placed on a unit of benefit. The net benefits in going from option A to option B are increasing faster than the costs, while in going further to option C, the costs are increasing faster than the net benefits.

MODELING METHODOLOGY SELECTION

Selection of the "optimal" modeling approach to meet EPA ONAC's decision-making needs involved a three pronged effort consisting of: the determination of the needs of the decision process; the identification and reviews of available information on the survey of the costs, benefits, and economic impacts due to complying with regulation; and the formulation of evaluation criteria pertinent to the requirements of the decision-making.

To facilitate selection of the "best" decision modeling methodology, a wide spectrum of alternative models was investigated. From the existing alternatives, several methodologies were selected for further evaluation; these included a general mathematical programming approach, a tabular enumeration procedure, and a graph-theoretic technique, which uses a regulatory option generator, to define the convex envelope of economically efficient regulatory strategies. Each model was then evaluated against the developed criteria.

The criteria developed to evaluate the modeling approaches are presented in Exhibit 3. The criteria were developed on the basis of the decision process requirements, including the availability of information on which to make the regulatory decisions, and the essential ingredients of sound decision-making.

Perhaps the most important attribute of any viable regulatory decision-making framework is its feasibility. To be useful and effective the model must be capable of integrating information on cost of compliance, benefits, and disruptive economic effects, that was developed for a variety of products. The model must then be able to assist the decision-maker in analyzing the effect of alternative noise emission regulatory options which may be in the form of time-phased standards over a specified decision horizon. In addition, a capacity must exist for evaluating distinct regulatory options for multiple equipment classifications within a single product category.

Inherent in the flexibility criterion is the ability of the model to develop consistent noise emission regulations for various products. Regardless of what objectives are considered in the decision process, each regulatory option should be considered in a consistent manner with regard to compliance costs, benefits, and economic disruptive effects. An economically sound regulatory decision framework should be based on the marginalist principles of economic theory (i.e., it must be able to locate the point at which marginal costs equal marginal benefits).

The decision model selected should be one that is easily implemented. The model should provide an output that is directly applicable to the decision process. Recommended regulatory strategies requiring discretion, or interpolation may produce infeasible, or suboptimal results. In addition, the methodology should provide the decision-maker with meaningful insight to the problem. The model should help to clarify, rather than obscure, the relationships among the decision variables.

Another major criterion, in the evaluation of a regulatory decision model, is the compatibility of the model's input requirements with existing studies on noise abatement technology and economic impacts due to regulation. The three major areas of information, which reflect the impact of a proposed regulatory option, are costs, benefits, and disruptive economic effects on industry and society. An effective, decision framework must be able to consider these impact areas as a possible objective or constraint within the model formulation. In addition, the amount of data required by a particular methodology may be excessive. Consideration must be given to the level of effort required of the technology and economic studies to generate the data inputs necessary for efficient operation of a specific model.

Finally, the computational efficiency of the model must be evaluated. Within the regulatory decision process, it may be necessary to evaluate a large number of possible decision alternatives. The model must be able to assist the decision-maker by suggesting those regulatory options which optimize various objectives within constraints. In addition, the model should be able to accommodate "quick reaction" demands of the regulatory agency. In all cases, a computerized model should be required to have a fast "turnaround" time so that immediate needs may be met, and analysis of new considerations may be dealt with effectively. The model should have the capability to test the sensitivity of regulatory options to changes in the costs of compliance, benefits, and economic impact data.

Alternatives

The first type of regulatory decision model considered was a general mathematical programming formulation. This approach would determine optimal regulatory options from the functional relationships of the decision variables level and year of compliance, and the dependent relationships would be obtained from the results of technology, and economic studies associated with the particular product under investigation. Depending on the form of the functions, optimal strategies would be obtained by classical Lagrangian, or variational calculus procedures. In light of the restrictive nature of the type of problem solvable by variational calculus, an alternative solution technique was also considered; that of dynamic programming using a high-speed digital computer. The formulation of the problem as an infinite stage dynamic program, which closely parallels the variational calculus approach, may provide greater flexibility and less stringent input requirements.

A second alternative considered was a tabular enumeration of various select decision options. Although, regulatory options may be generated as continuous functions, the discrete nature of their promulgation suggests consideration of various discrete variable formulations. Technology and economic studies would screen out certain possible regulatory options in light of cost, benefits, and economic impact considerations. The select group of "promising" alternatives would then be analyzed in depth. The results of these investigations then would be presented to the decision-makers in a convenient tabular form for the selection of the desired regulatory action.

The third approach extends the concept of a discrete enumeration procedure from the investigation of a select few regulatory options, and yields a decision modeling framework with the capability of analyzing all possible regulatory options. The significance of this capability may vary depending on the type of product, the number of levels to which the product may be regulated, and the time-phasing of regulations necessary to accommodate industry regulatory reaction times. A global graph-theoretic or network enumeration procedure would make use of data input generators to provide costs, benefits, and disruptive impact data for each possible regulatory option. With this analytic capability, a model could be programmed to generate economically efficient alternatives. The decision-maker might then use this set of efficient points and their sensitivities, as implied by the generated convex envelope, to select optimal regulatory alternatives using judgement and further analysis to eliminate points inconsistent with defined constraints. A summary of the three model alternatives is shown in Exhibit 4.

Evaluation of Alternatives Against Selection Criteria

To determine which of the three methodologies best meets the decision-maker's needs, each alternative was evaluated on the basis of the selection criteria. A summary of this evaluation is presented in Exhibit 5. Based on this evaluation, the graph-theoretic convex envelope method stands out as the most desirable, and was selected. The current level of sophistication in the EPA's decision process demands the flexibility and data processing capability provided by this approach over the other alternatives. The NDM in its computerized form, provides a useful and consistent framework for decision-making.

SPECIFICATION OF THE NOISE DECISION MODEL (NDM)

The subsequent discussion provides a detailed characterization of the NDM. This characterization is intended to be of sufficient descriptive detail to convey a general understanding of how the model operates.

DESCRIPTION OF THE BASIC MODEL COMPONENTS

The decision logic of the NDM, utilizing the graph-theoretic convex envelope methodology, requires interaction among several major model components.

The NDM was designed specifically to bring together certain key information on each product category that is routinely compiled during the regulatory development process into a consistent, unified decision-making framework.

Results derived from pertinent studies on noise abatement technology, health and welfare benefits, cost of noise abatement and control technology, and socioeconomic impacts due to product regulation, are used to develop the input data needed for this model.

The NDM consists of three distinct, but interconnected components. The first component summarizes the information and results from relevant product studies and generates a listing of all feasible regulatory options. The enumeration of these regulatory options considers discrete user inputs regarding the time-phasing of such regulations. Using the results of the cost and economic impact study, the health and welfare benefit analysis study, etc., the second component of the model computes the cost and benefit time-streams of various measures for each feasible regulatory option. The third and final component of the model, operates on each of the regulatory options according to user specified decision criteria and generates a rank ordering of these options on the basis of either benefit or effectiveness versus cost. Additionally, the model develops a scatter diagram plot of the benefit versus cost of the feasible options and then proceeds to construct a convex envelope containing only the most cost-effective combinations of noise abatement regulatory options. From this, the decision-maker can select the best combination of options for a product category within any defined compliance cost constraint.

A simplified flow diagram of the NDM is presented in Exhibit 6. A description of key components of the model is presented below.

Input Processor

The Input Processor accepts the inputs used to control the operation of the model. These inputs are generated by the user of the NDM. The model operates in four modes: (1) generation of options, (2) evaluation of options, (3) generation of the convex envelope, (4) mathematical optimization. The control inputs are read into the computer, checked against operational requirements and a status report generated. This status report includes a playback of all input data for the record. Specification of the model's input data requirements is shown in Exhibit 7.

Option Generator

The Option Generator enumerates all possible regulatory options over the range of alternatives specified by the user's entries to the Input Processor. The generated options are then used in the various modes of model operations to coordinate the evaluation of the alternative regulatory options.

The number of possible regulatory alternatives may be viewed as the number of possible paths through a regulatory option network. Exhibit 8 illustrates a regulatory option network for three regulatory levels and three decision years. Note that "no regulation" must be considered as a possible regulatory level also assuming that the regulatory severity of the option is a nondecreasing function over time. The regulatory option network is of special form, acyclic and triangular. The number of possible paths in such a network is related to the number of regulatory levels and the number of decision years.

That a great number of paths can be generated is seen by an example. Consider the case of three regulatory decision years and five possible product noise emission levels. Then the possible cases can be listed as shown in Exhibit 9. As seen, there are 35 possible paths for regulatory levels one through four.*

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*The general mathematical expression for the number of options is

$\frac{(L+Y-1)!}{Y!\ (L-1)!}$, where L = number of levels and Y = number of decision years.

This expression represents the number of combinations of (L-Y-1) things taken Y at a time.

The Option Generation mode of the NDM provides a listing without evaluation, of all possible regulatory options according to the decision years and regulatory levels specified by the user. The required inputs for the Option Generation mode consists of (1) number of decision years, (2) decision on calendar years and (3) number of regulatory levels. The processed and edited inputs are supplied to the Option Generator which produces an Option Listing Report.

It is useful to adopt the following convention for ordering the severity of regulatory options. Since regulatory alternatives are time-phased, ordering must accommodate multiple decision years and regulatory levels. A more restrictive regulatory level will be considered to be more stringent than a less restrictive level in the same decision year. For distinct decision years any regulatory level promulgated in an earlier decision year will be considered to be more stringent than any regulatory level in a later decision year. Hence, for purposes of option generation, if one would list in order of increasing severity, the possible regulatory options when considering two decision years: 1980 and 1985; and three regulatory levels: no regulation, 86 dB(A) and 80 dB(A), the list would appear as:

Decision Year	1980	1985
Least stringent	No Reg	No Reg
	No Reg	86
	No Reg	80
	86	86
	86	80
	86	80
Most stringent	80	80

The severity function of all regulatory options is assumed to be non-decreasing, i.e., a regulation never becomes less stringent at a future date.

The automated enumeration (triangulation) of the option alternative paths is performed by incrementing the regulatory levels in a sequence of nested DO-Loops. Exhibit 10 presents a flow diagram of the procedure in the case of three decision years.

Time Sequence Calculations

The user provides inputs to the NDM on such data as manufacturer's costs, benefits to the population (reduction in the number of people exposed to noise) and disruptive impacts (changes to regulated industry/ plant closings). The time sequence processor than computes the following quantities:

- Number of products replaced within each regulatory class.
- Number of sales for new regulated products, adjusted by the elasticity of demand.
- Cost increases to the manufacturer due to R&D, retooling, increased raw materials and production.
- Price increases to the end-user due to cost pass-throughs, adjusted by the elasticity of supply.
- Operation and maintenance costs to product end-users.
- Benefits (e.g. reduction in the population exposed to noise source emissions).
- Changes in regulated product manufacturers profit.
- Estimates of employment changes (up or down).
- Estimates of plant closings (or expansions).
- Discounted costs and benefits.

Optimization Algorithms

The NDM employs various algorithmic procedures. Using the information stored on the Intermediate Data File the optimization and decision algorithms provide the report generator with results for the decision reports.

The Procedure for generating the convex envelope of economically efficient points is a labelling algorithm. Assuming the origin to be the first labelled point, the computer routine scans the Intermediate Data File for the maximum benefit/cost ratio measured relative to the last efficient point labelled. Then, using this newly labelled point as the origin, the Intermediate Data File is scanned again for the maximum benefit/ cost ratio which then becomes the next labelled point. The procedure stops when the maximum benefit level is reached. Referring to Exhibit 2, the procedure can be visualized as the sweeping of the minute hand of a watch. If the hub of the watch is located at point A, for example, and pointing to 12 Noon, the first point that is swept by the minute hand as it turns clockwise would be point B. The watch is then moved to point B and the procedure locates C, etc.

Monotonically Increasing Benefits

In addition to finding the convex envelope, the computer routine also perform a graph-theoretic search which results in listing the options according to increasing benefits with costs. Exhibit 11 illustrates the concept. Points 1, 2, 3, 4 and 5 would be selected, while 6, 7 and 8 would not. Note that point 3 would be excluded from the convex envelope search routine which would proceed directly from point 2 to 4.

Report Generator

Finally the computer is programmed to print reports which rank the options according to increasing annualized costs, decreasing discounted benefits and decreasing benefit/cost ratios, respectively.

The Report Generator, for all intents and purposes, translates the required and other decision-maker input data to printed matter representing the output of a run of the NDM. One portion of the model's output, as indicated earlier, summarizes (or playsback) the input data parameters required to execute the model, as well as a display of the feasible regulatory options which will be subsequently analyzed individually. Another model product is a printout of computed information on benefits, manufacturer's costs of complying with regulation, economic impacts on affected industries, etc, for each year (time horizon) which was specified by the NDM's user. In addition, the Report Generator produces output summaries related to all of the regulatory options, including their rank order into terms of benefits, costs, etc., as well as those particular options lying on the convex envelope. A sample of typical reports are contained in Exhibits 12 and 13.

EXAMPLE: DEMONSTRATION OF THE NDM TO THE MEDIUM AND HEAVY TRUCK NOISE EMISSION REGULATION.

To illustrate the utility of the NDM as a useful tool in the regulatory decision process, an example related to the truck regulation is briefly described. The NDM, as indicated earlier in this report, is used by EPA decision-makers to evaluate alternative regulatory options on the basis of cost versus benefit or effectiveness data. During this phase of their deliberations, all information on health and welfare benefits, noise abatement technology, costs of compliance and economic impacts on affected industry manufacturers, etc., has already been analyzed. Using this existing data base, the user of the NDM develops the input data requirements for this model.

Option Generation

The first phase of the NDM is the generation of all feasible regulatory options through the network procedure. Exhibit 14, presents the network defining all possible regulatory options using the regulatory levels and decision years considered in the truck regulation. Each possible path through the network corresponds to a possible regulatory option. It is assumed that all regulatory alternatives are promulgated from the same initial state and that the severity of any proposed time-phased regulation is a nondecreasing function over time. Although technological considerations may render some regulatory options infeasible (e.g., all options requiring 75 dB(A) before 1983 may be technically infeasible), the total number of possible options is given by an expression in the number of regulatory levels and the number of decision years. If we let, N, equal the number of regulatory levels and, d, equal the number of decision years, then

$$\text{The Number of Possible Regulatory options} = \frac{\prod_{i=1}^{d} (N-i-1)}{d!}$$

For the truck regulations, with N=5 regulatory levels, and d=5 decision years, the total number of possible regulatory options is equal to:

$$\text{Number of Possible Regulatory Options In the Truck Study} = \frac{\prod_{i=1}^{5} (N+i-1)}{5!}$$

$$= \frac{(5)\ (6)\ (7)\ (8)\ (9)}{(5)\ (4)\ (3)\ (2)\ (1)}$$

$$= 126$$

Exhibit 15 presents a partial enumeration of the possible regulatory options which could have been considered in the truck study. The table illustrates only those regulatory options which impose a regulatory level of at least 83 dB(A) in decision year 1987. It is noted that 9 of the 10 regulatory options considered in the truck study are among the options listed. This exhibit also illustrates those options of at least 83 dB(A) that were not considered.

Data Generation and Input

The second phase of the model is the generation of the cost, health/welfare, and disruptive economic impact data, for each feasible regulatory option. The input data on compliance cost for each option were developed outside of the NDM. The health/welfare input data were obtained from information developed by an EPA health/welfare model which is external to this model also. The input data concerning economic impacts due to regulation were developed using the available data from the Background Document for Medium and Heavy Trucks.* The regulatory options for which data were directly available included the nine lettered options of Exhibit 12 plus the data for the no-regulatory case. The equivalent annual cost for each regulatory option was based on the stream of yearly costs from 1977 to 1990 with a 10 percent discount rate. In a similar manner the equivalent annual health/welfare benefit was measured in terms of equivalent annual population no longer exposed to noise based on the stream from 1977 to 1990 with a 10 percent discount rate. Based on the information obtained from the referenced Background Document, the disruptive effects were negligible for the regulatory options considered. The results of these calculations are summarized in Exhibit 16. These points are displayed graphically in Exhibit 17.

Generation of Convex Envelope

Optimization is the final phase of the NDM. In its marginalist economic mode, the model scans the feasible regulatory options and identifies the convex envelope of economically efficient points. The economically efficient points are those which provide a maximum benefit for a specified cost. The convex envelope of the ten regulatory options considered in the Background Document for Medium and Heavy Trucks is illustrated in Exhibit 17. Given the convex envelope of efficient points one may then consider the marginal implications of moving from one efficient point to the next. These marginal costs per equivalent annualized person no longer exposed to truck noise emission are listed below.

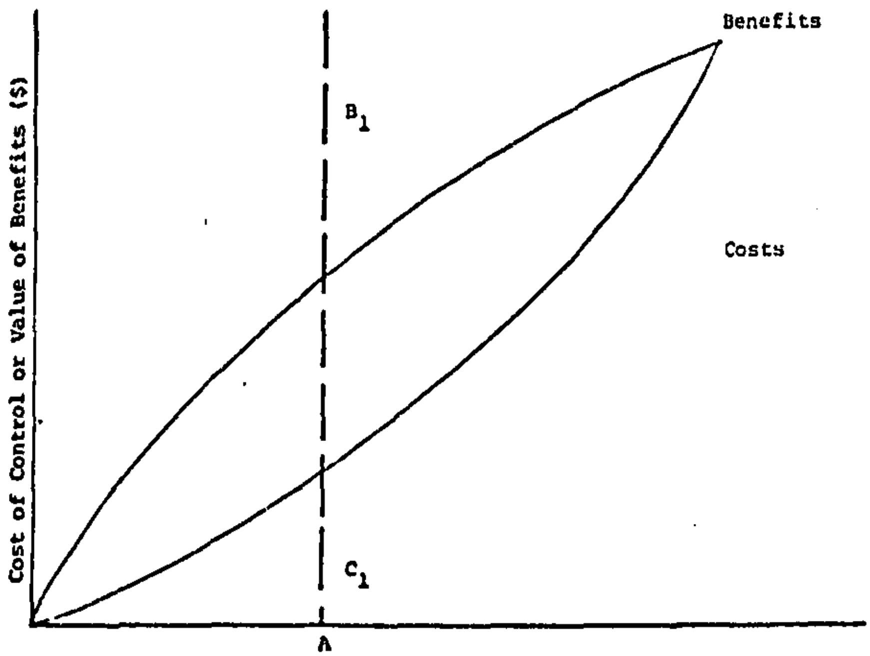
PRODUCT	OPTION (Levels in dB(A))	Marginal** Annualized Cost ($ Millions)
TRUCKS	Present-G (86-83)	$ 77
	G-E (83-80)	110
	E-C (80-78)	429
	C-A (78-75)	$727

**Marginal cost represents the difference in cost of the two regulatory levels specified.

*Background Document for Medium and Heavy Truck Noise Emission Regulations, U.S. Environmental Protection Agency, Washington, D.C. EPA-550/9-76-008, March, 1976.

If, for example, a minimum of $250 cost/equivalent annualized person removed from such emissions and a maximum of a $400 cost/equivalent annualized person removed from truck noise was dictated by consistency with other regulations, regulatory option E would be considered most favorably. In its optimization mode, the model determines the regulatory option which maximizes total benefit subject to specified cost considerations. Exhibit 16 shows that alternative F provides the maximum number of equivalent annual population removed from noise harassment subject to the constraint that the annual costs be less than 300 million dollars.

EXHIBITS



Level of Regulatory Activity

EXHIBIT 1 CLASSICAL MARGINAL COST/BENEFIT ANALYSIS

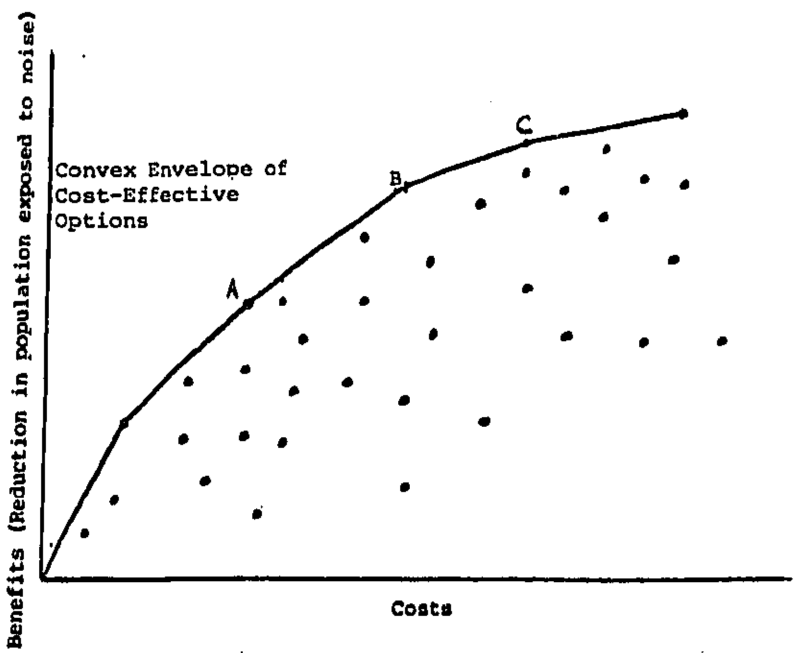


EXHIBIT 2 BENEFITS VS. COSTS

EXHIBIT 3 EVALUATION CRITERIA FOR SELECTION OF A METHODOLOGY

- Flexibility
  - Easily adapts to other equipment
  - Integrates costs, benefits, and disruptive impact data
  - Handles time phased regulations
- Validity and Consistency
  - Is based on economically sound decision framework
  - Develops consistent regulations over a variety of products
- Implementation Usefulness
  - Applies directly to decision process
  - Provides meaningful insight to problem
- Reasonable Input Requirements
  - No restrictive assumptions necessary
  - No excessive data requirements
- Computational Efficiency
  - Quick turnaround
  - Allows sensitivity tests of input data

EXHIBIT 4

DECISION MODEL ALTERNATIVES

GENERAL DESCRIPTION	BASIC OPTIMIZATION TECHNIQUES	INPUT REQUIREMENTS	OUTPUT
General Mathematical Programming Approach	Non-Linear Programming; Lagrangian Procedures; Calculus of Variations	Functional Relationships Among all Decision Variables	"Optimal" Function of Regulatory Level And Time
Tabular Enumeration of a Select Group of Options	Comparison of Ratios Between Options	Data Required For a Few Select Options	List of Costs and Benefits for Each Option
Enumeration of Convex Envelope of Efficient Points	Graph Theory; Marginalist Considerations	Discrete Data "Generators" Required	Convex Envelope of All Economically Efficient Regulatory Options

EXHIBIT 5

SUMMARY OF THE CRITERIA USED TO EVALUATE THE MODEL ALTERNATIVES

Model Evaluation Criteria	Mathematical Programming	Tabular Enumeration	Convex Envelope
Easily adapted to other equipments	No	Yes	Yes
Integrates all data	Yes	Yes	Yes
Handles time phasing	Yes	Yes	Yes
Economically sound	Yes	No	Yes
Consistent	Yes	No	Yes
Directly applicable	No	Yes	Yes
Provides meaningful insight	No	No	Yes
No restrictive assumptions	No	Yes	Yes
No excessive data requirements	No	Yes	Yes
Quick turnaround	Yes	No	Yes
Sensitivity analysis of inputs	Yes	No	Yes

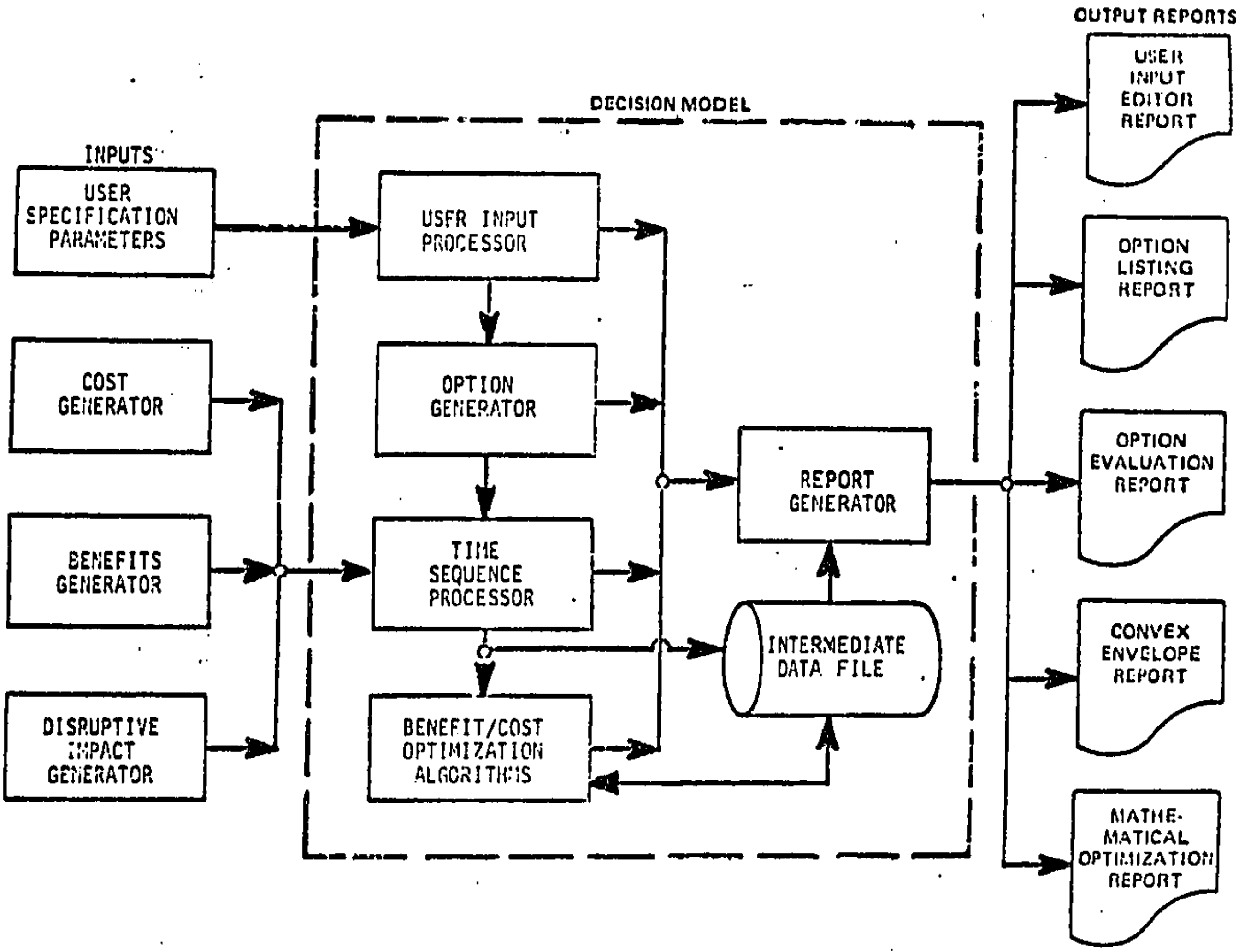


EXHIBIT 6. SIMPLIFIED FLOW DIAGRAM OF THE GRAPH THEORETIC CONVEX ENVELOPE DECISION MODEL

EXHIBIT 7. NDM INPUT DATA DESCRIPTIONS

LINE #	DESCRIPTION
100	Product Identification
200	Growth type: 1=linear, 2=exponential, 3=tabular.
300	Rate of growth of shipments
400	Unregulated noise level
500	Number of products replaced in year of timestream start (line 1100)
600	Number of regulated noise levels
700	Regulated noise levels
800	Number of lead times for each regulated noise level
900	Total price, total operating and maintenance cost in year of timestream start
1000	Product fleet size in year of timestream start
1100	Timestream start year, total number of years in the timestream, purchase finance period
1200	Benefit discount rate, cost discount rate, unemployment discount rate, profit rate
1300	Announcement year for regulation
	The following set of entries, from lead times to unemployment, is repeated once for each regulated noise level. Entries correspond to lead times.
1400	Lead times
1500	Fraction of sales
1600	User price increase
1700	User operating and maintenance cost increase
1800	Fraction of products scrapped (Product replacement rate)
1900	Manufacturer's capital investment increase
2000	Number of plant closings
2100	Health/welfare benefits
2200	Number of people unemployed
5000	Benefit weights for each year in the timestream
5100	Unemployment weights for each year in the timestream
5200	Baseline forecast of units sold assuming no regulation

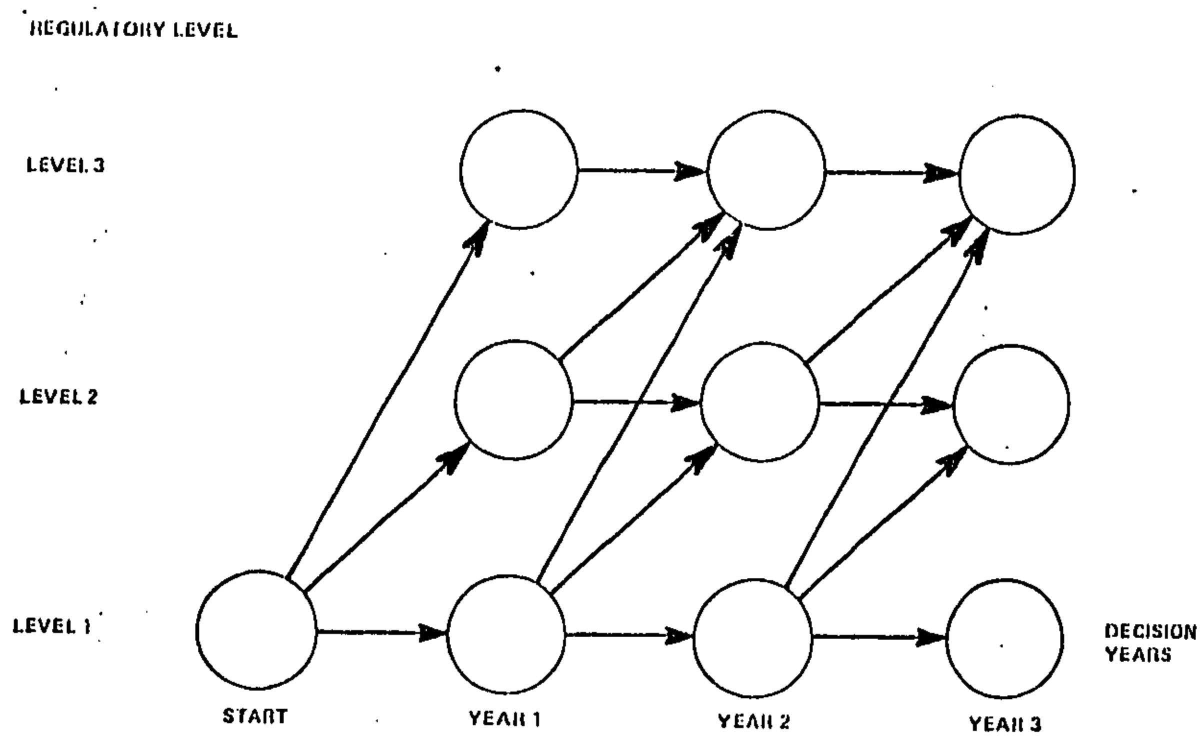


EXHIBIT 8. REGULATORY OPTION NETWORK

Exhibit 9. Number of Possible Regulatory Levels

Option	Years 1	2	3
1	0	0	0
2	0	0	1
3	0	0	2
4	0	0	3
5	0	0	4
6	0	1	1
7	0	1	2
8	0	1	3
9	0	1	4
10	0	2	2
11	0	2	3
12	0	2	4
13	0	3	3
14	0	3	4
15	0	4	4
16	1	1	1
17	1	1	2
18	1	1	3
19	1	1	4
20	1	2	2
21	1	2	3
22	1	2	4
23	1	3	3
24	1	3	4
25	1	4	4
26	2	2	2
27	2	2	3
28	2	2	4
29	2	3	3
30	2	3	4
31	2	4	4
32	3	3	3
33	3	3	4
34	3	4	4
35	4	4	4

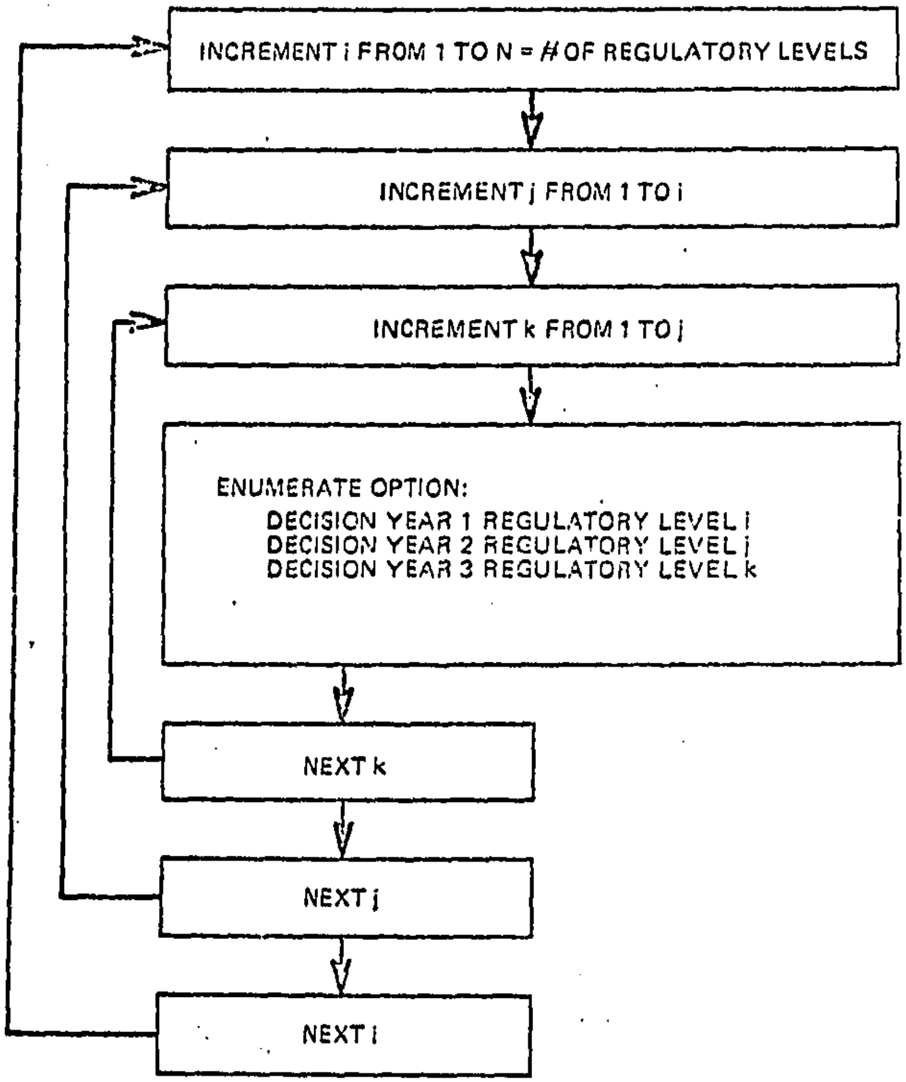


DIAGRAM 10. FLOW DIAGRAM OPTION ENUMERATION PROCEDURE

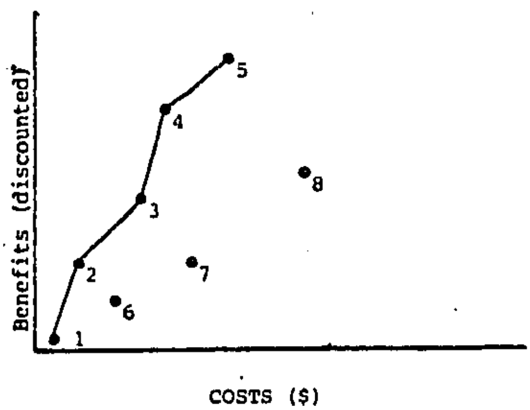


EXHIBIT 11. Monotonically Increasing Benefits Versus Costs

TIMESTREAM FOR OPTION 22

YEAR	BENEFIT	COST	UNEMPLOYMENT	MANUFACTURERS CAPITAL INVESTMENT COSTS
1979	9.1	80.000	10.0	30.0
1980	18.2	110.000	10.0	5.0
1981	27.3	140.000	10.0	5.0
1982	36.4	170.000	10.0	5.0
1983	45.5	200.000	10.0	5.0
1984	63.6	257.000	35.0	5.0
1985	81.8	292.000	35.0	0.0
1986	100.0	327.000	35.0	0.0
1987	118.2	362.000	35.0	0.0
1988	136.4	397.000	35.0	0.0
1989	154.5	432.000	35.0	0.0
1990	163.6	437.000	35.0	0.0
1991	172.7	442.000	35.0	0.0
1992	181.8	447.000	35.0	0.0
1993	190.9	452.000	35.0	0.0
1994	200.0	457.000	0.0	0.0
1995	200.0	457.000	0.0	0.0
1996	200.0	457.000	0.0	0.0
1997	200.0	457.000	0.0	0.0
1998	200.0	457.000	0.0	0.0
1999	200.0	457.000	0.0	0.0
2000	200.0	457.000	0.0	0.0

Timestream of Costs, Economic Impacts & Benefits of Specific Regulatory Options

EXHIBIT 12

OPTIONS ON BENEFIT/COST CONVEX ENVELOPE

OPTION	BENEFIT	COST	BENEFIT/COST	MARGINAL COST INCREASE PER UNIT INCREASE IN BENEFIT
14	40.3	147.6	0.273	3.662
8	54.5	207.7	0.262	4.246
7	59.7	249.6	0.239	7.981
16	79.8	421.4	0.189	8.552
17	80.3	437.9	0.183	31.425
18	82.3	610.2	0.135	85.514

Regulatory Options on Convex Envelope

EXHIBIT 13

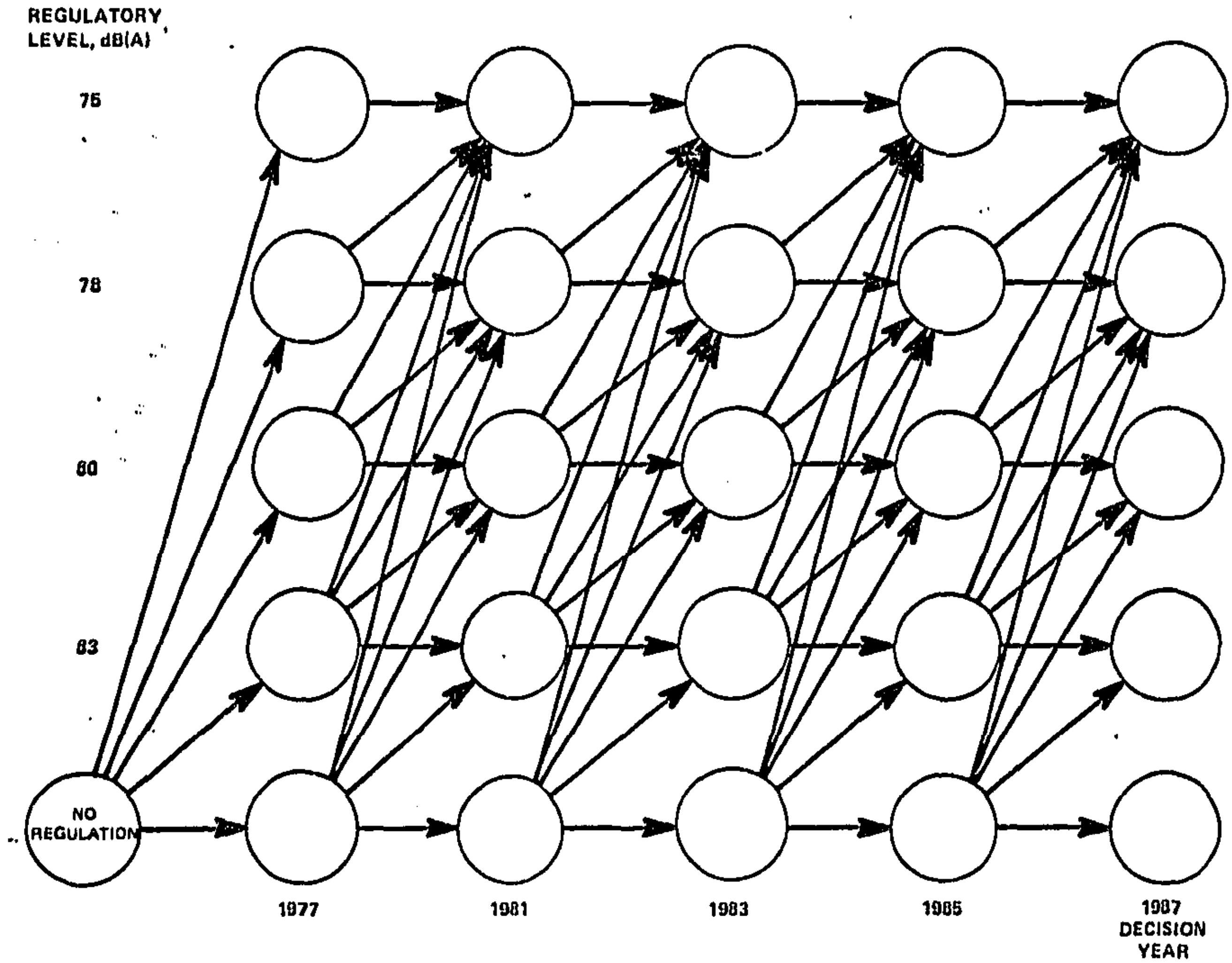


EXHIBIT 14. NETWORK DEFINING ALL POSSIBLE REGULATORY OPTIONS

EXHIBIT 15

POSSIBLE REGULATORY OPTIONS

	1977	1981	1983	1985	1987
G	83	-	-	-	-
	83	-	-	-	80
	83	-	-	-	78
	83	-	-	-	75
	83	-	-	80	-
	83	-	-	80	78
	83	-	-	80	75
	83	-	-	78	-
	83	-	-	78	75
J	83	-	-	75	-
F	83	-	80	-	-
	83	-	80	-	78
I	83	-	80	-	75
	83	-	80	78	-
	83	-	80	78	75
	83	-	80	75	-
D	83	-	78	-	-
	83	-	78	-	75
	83	-	78	75	-
	83	-	75	-	-
E	83	80	-	-	-
	83	80	-	-	78
	83	80	-	-	75
	83	80	-	78	-
	83	80	-	78	75
B	83	80	-	75	-
C	83	80	78	-	-
	83	80	78	-	75
	83	80	78	75	-
A	83	80	75	-	-
	83	78	-	-	-
	83	78	-	-	75
	83	78	-	75	-
	83	78	75	-	-
	83	75	-	-	-

1977	1981	1983	1985	1987
80	-	-	-	-
80	-	-	-	78
80	-	-	-	75
80	-	-	78	-
80	-	-	78	75
80	-	-	75	-
80	-	78	-	-
80	-	78	-	75
80	-	78	75	-
80	-	75	-	-
80	78	-	-	-
80	78	-	-	75
80	78	-	75	-
80	78	75	-	-
80	75	-	-	-
78	-	-	-	-
78	-	-	-	75
78	-	-	75	-
78	-	75	-	-
78	75	-	-	-
75	-	-	-	-

EXHIBIT 16

EQUIVALENT ANNUAL COST VS. EQUIVALENT ANNUAL PEOPLE REMOVED FROM TRUCK NOISE EMISSIONS a,b,c,

ITEM		TRUCKS									
Noise Emission Regulatory Options/dBA		A/75	B/75	C/78	D/75	E/80	F/80	G/83	H/-	1/75	J/75
Cost ($/Millions)	Without Fan Savings	574	482	419	359	349	289	168	-0-	353	373
Population no Longer Exposed to Truck Noise Emissions (Millions)		3.38	3.20	3.16	2.90	2.99	2.65	2.19	-0-	2.80	2.60

a. Cost and population (equivalent) are based on the stream from 1977 to 1990 with a 10% discount rate.

b. Population (equivalent) is adjusted by subtracting people removed with no regulation (option H).

c. Population (equivalent) assumes no other non-truck noise regulations.

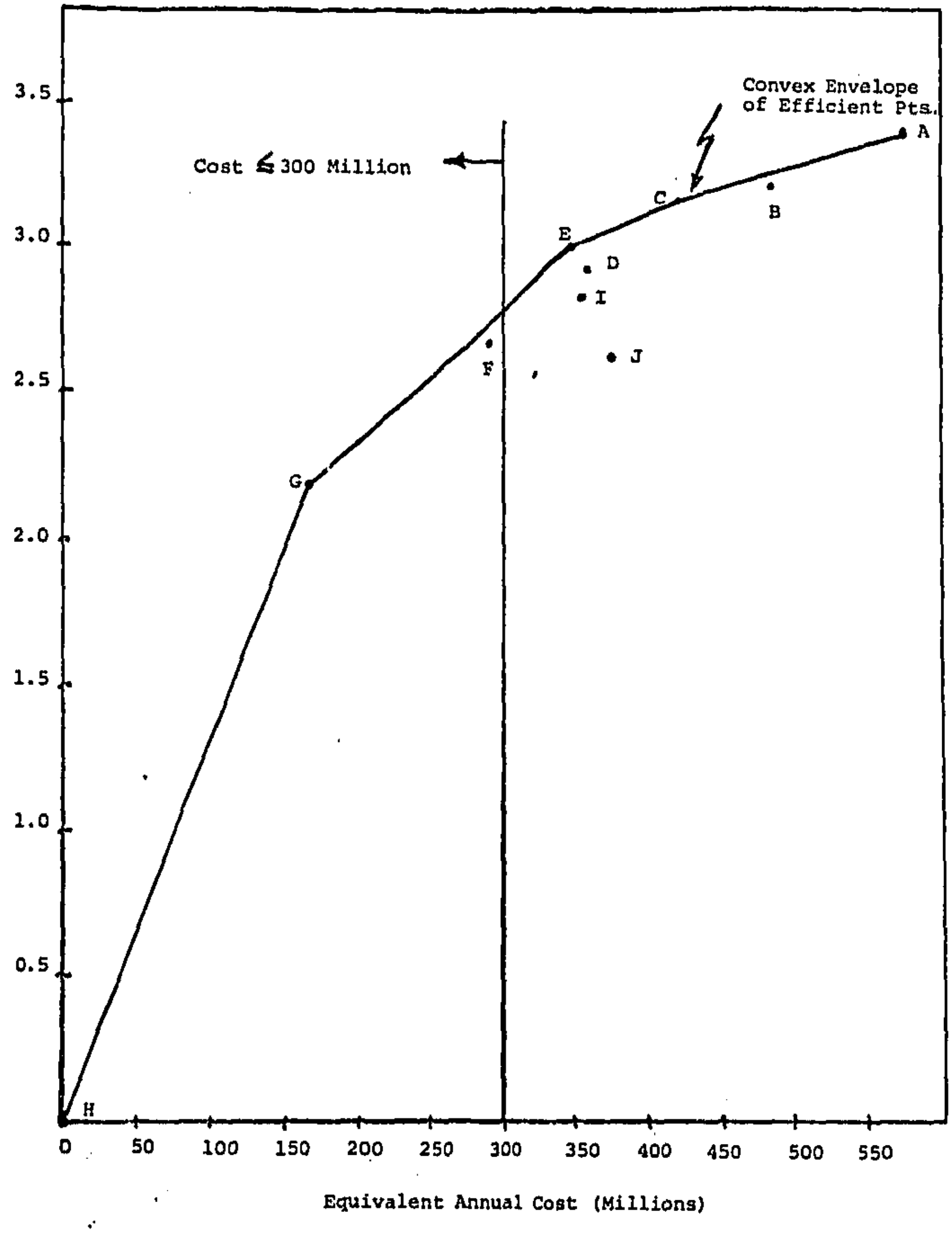


EXHIBIT 17. EQUIVALENT ANNUAL COST VS. EQUIVALENT ANNUAL POPULATION NO LONGER EXPOSED TO NOISE EMISSION