Procedures for the Establishment of Standards

Final Report Volume 1

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PREFACE

This final report summarizes two years of research on analyzing procedures for the establishment of standards. The research was sponsored by the Volkswagenwerk Foundation and jointly carried out at the International Institute for Applied Systems Analysis at Laxenburg and the Kernforschungszentrum Karlsruhe. The final report is meant to be both a problem-oriented review of related work in the area of environmental standard setting and an executive summary of the main research done during the contract period. The final report is accompanied by eleven technical reports which describe studies and findings performed under the contract in more detail, and which have been either published as IIASA Research Memoranda or as outside publications, or were especially written for this report. These technical reports are structured in four parts:

- policy analyses of standard setting procedures;
- decision and game theoretic models for standard setting;
- applications of decision game theoretic models to specific standard setting problems;
- biological basis for standard setting.

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INTRODUCTION

Environmental Decision Making: A Time for Reevaluation

As a veteran of the Japanese environmental administration recently noted in a discussion*, the 1950s and early 1960s were "polluter's heaven" in Japan and in probably most industrialized countries of the world. "The Environment" had not yet become an issue of public debate. Government actions to control industry and new technological developments consisted largely of ex post facto measures in cases of obvious damage or of individual plans for the conservation of special areas (coastal zones, national parks). High economic growth was the driving force behind government planning, and industrial polluters had to pay a small price or none for the burden they put on the environment. Following again the vivid description of this Japanese official, the late sixties marked the end of "polluter's heaven" and the beginning of "the stormy days". Initiated through accidents and environmental damage of a scale recently unprecedented (e.g. the Torrey Canyon accident, the Miniamata disease, PCB poisoning), public concern about environmental pollution increased drastically. Several court cases were resolved in favor of plaintiffs claiming damages from environmental pollution against industry and government. In most industrialized countries legislative action was taken to respond to the increased public pressure to reduce pollution and to preserve environmental conditions. The U.S. Environmental Protection Act (NEPA) of 1969 is a prominent example which has been followed by many other countries. Environmental agencies, such as the EPA in the United States, the State Pollution Control Authority in Norway, the Central Unit on Environmental Pollution in the United Kingdom, and the Environment Agency in Japan, were set up to mediate in the growing conflict between environment and development interests.

But the stormy days only marked the beginning of what should eventually become "polluter's hell", characterized by the rise of citizens' movements, zealous administrative action, and involvement of radical political groups in environmental protests against large-scale governmental and industrial programs and operations. In this period a multitude of environmental law suits were initiated, new and often stiff environmental legislation, standards, and zoning decisions were made, and environmental impact statement requirements were introduced. Laws against strip mining, severe limits on SO_2 emissions from fossil fuel power plants, radiation standards, car emission standards began to put a heavy burden on the industry and

*M. Hashimoto, Director of the Air Preservation Bureau, Environment Agency, Japan, in a discussion with IIASA members on October 10, 1977.

eventually on the economy as a whole as highlighted particularly during the energy crisis. With standards set on car emissions on the basis of environmental and health considerations, fuel consumption of cars increased. Requirements of environmental impact statements put considerable organizational and financial burden on industrial and governmental institutions and led to time delays in planning and operating new plants, particularly in the energy sector. Inconsistencies in environmental regulations were found after the initially zealous period of administrative action: Restricting one pollution source sometimes would tend to produce more pollution of another kind (e.g. restricting carbon monoxide and hydrocarbon emissions from cars increases sulfuric acid mist). Reduction in risks of one kind could lead to increased risks of another (e.g. reducing population risks from operating power plants may lead to higher occupational risks).

When in the mid-seventies these effects of environmental regulations became felt, governmental officials, environmental researchers and administrators began to ask themselves some new challenging questions: How well does environmental decision making fulfill its task of mediating between environment and development interests? How much does environmental regulation actually cost? How much does the public actually benefit from regulation?

Attempts at answering these questions bring up some fundamental problems of governmental regulation and environmental decision making:

- problems of the role of regulation as such: How much power should be given to regulatory agencies?

- problems of scale: How do economic benefits of scale compare with the often unprecedented risks and hazards of large technologies?

- problems of uncertainty in planning: How can the risks and uncertainties in environmental decision making be accounted for if the complexity and scale of consequences prohibit traditional experimental or incremental approaches?

- problems of planning and regulations in the light of conflicting opinions: How can scientific data, their conflicting interpretations by experts, and public beliefs be integrated in regulatory decision making?

- problems of conflicting interests and goals: How can the variety of interest groups and their conflicting objectives and values be taken into account in environmental regulation?

Recognition of these problem areas in environmental regulation and decision making seemed to have changed the initial ambition of environmental researchers and decision makers, and attempts at reevaluating environmental decision making are now underway. The Congress of the United States, for example, has issued through EPA a series of studies on exactly these questions, including studies on the implications of environmental regulations upon energy production and consumption (NRC, 1977, VI), on the quality of environmental decision making in the EPA (NRC, 1977, II), and on environmental monitoring (NRC, 1977, IV).

It is in this context of reevaluation of environmental decision making that IIASA's research on standard setting procedures has to be seen. Although standard setting is only one of many environmental policy tools, it is used in this study as a vehicle for analyzing some basic decision problems of environmental decision making and for developing new methodologies to aid environmental decision makers. The fundamental questions that have motivated this research are these: How are standards set at present? What are the main problem areas in standard setting procedures? How can standard setting procedures be improved?

Origin, Purpose, and Overview over IIASA's Research on Standard Setting

While we can now put the study on standard setting procedures reported here in a wider context of national studies for the evaluation of environmental decision making, our original interest in standards was triggered off by a series of modeling efforts in IIASA's Energy Systems Program (for an overall description, see Häfele, 1976). Within the Program so-called energy models have been developed to analyze present and future supply and demand structures. Especially the nuclear option was studied in greater detail (see Häfele and Manne, 1977). As part of these studies an attempt was made to analyze all (normal operating and accidental) risks and hazards involved in the large-scale use of nuclear energy (see Avenhaus, Häfele, and McGrath, 1977). This necessarily led to the question which environmental burden from such an energy system could be tolerated, and what the criteria for limiting these (individual or societal) burdens should be.

In addition mixed (i.e. nuclear and non-nuclear) energy strategies were analyzed in which environmental constraints were taken into account. Nordhaus (1975) developed a two-sector model with a constraint for the upper limit of the global carbon dioxide content. Agnew, Schrattenholzer, and Voss (1978) analyzed the consequences of different standards for SO_2, NO_x, and others on the cost of alternative energy systems. At that level nothing was said about the appropriate, i.e. socially acceptable, numerical inputs in the form of standards or the like as constraints for such models. They were simply treated as parameters of the problem as was done by other modeling groups (see, for example, Hoffmann, 1973).

It was quite natural not to stop at that point, and to determine equilibrium states and cost optimal strategies for parametrically fixed constraints. The question was how to reach such equilibrium states under given social conditions, considering the institutional and political realities of environmental decision making and regulations, and in particular, the realities of standards and standard setting procedures. On this path we ended up with virtually the same types of issues and questions of environmental decision making as described earlier.

It was clear from the beginning that investigation of the political and social nature of standard setting required new analytical tools. Under study was a problem of public policy making under uncertainty and with conflicting interest groups and objectives, with risks and impacts of a large scale, and with only limited possibilities for traditional experimental and incremental approaches. The initial literature survey on analytical approaches and procedures for standard setting suggested possible research directions:

- policy analyses;
- environmental economics;
- cost-benefit approaches;
- simulation gaming approaches;
- decision theoretic approaches;
- game theoretic approaches.

These approaches are discussed briefly in the next section of this report. Here it is sufficient to say that, based on the expertise of the researchers involved in IIASA's standard setting studies, and based on our judgement of the possible limits and benefits of the different analytical study approaches, several initial decisions were made. First of all, it was decided to closely study the standard setting procedures at the hand of *actual cases*, and as far as possible in an interaction with real decision makers. Secondly, two main lines of case-oriented research evolved: *policy analyses* of ongoing or past standard setting processes with a largely *problem-oriented* and *descriptive* focus; and *decision* and *game theoretic models* with a more *normative* emphasis on aiding regulatory decision makers in standard setting tasks.

The policy analyses were meant to provide the case material, to describe how standards are set at present, to identify problem areas in standard setting, and to provide inputs into the decision and game theoretic modeling efforts. A policy analysis framework was elaborated by Fischer (1978, TR-2*) and applied to two standard setting cases: the United Kingdom and Norwegian standards for chronic oil discharges for North Sea production platforms, and the Japanese noise standards for superrapid trains, such as the Shinkansen (see Fischer and v. Winterfeldt, TR-3; v. Winterfeldt, 1978, TR-4). In each case in-depth interviews were held with the parties involved in the standard setting process, including members of the environmental agencies, other governmental agencies and ministries, industrial representatives, and environmentalists.

Besides these largely problem-oriented and qualitative policy analyses, decision and game theoretic models were developed. Decision theory and game theory both are appropriate analytical tools for problems with multiple decision makers, uncertainty, and multiple objectives. A decision theoretic model for emission and safety standards setting was developed by v. Winterfeldt (1978, TR-5,6), which comprises the decision making of a regulator, developer (producer), and impactee. The purpose of the model was to provide both a structure and quantification possibilities for the regulator to perform his information processing and evaluation tasks when setting standards. The model was applied to the chronic oil discharge case using some of the policy analyses inputs from the case study (see v. Winterfeldt, 1978, TR-8). The multistage nature of the standard setting process, possible feedbacks between the decision making units, and the learning process involved let to an extension of the static three decision makers model. Höpfinger and Avenhaus (1978, TR-7) extended the decision theoretic model into a multistage game theoretic model. The purpose of this model was to parametrically explore the possible futures of a dynamic standard setting process in which several decision makers with different interests and objectives interact. In this model transitions from one stage of the decision process to another are uncertain, either because of an uncertain environment or because of the unpredictability of the responses of the decision makers involved. Such models can be mainly descriptive in character (i.e. they can simulate a sequence of decisions), or normative if a given solution concept is being provided, e.g. equilibrium points or Pareto optimal solutions. The game theoretic models were applied to noise standards for Shinkansen trains and CO_2 standards (see Höpfinger and v. Winterfeldt, 1978, TR-10; and Höpfinger, 1978, TR-9).

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*All reports designated TR- are contained in Volume II of this report, "Procedures for the Establishment of Standards, Technical Reports".

It should be mentioned that during the two years of work not all original ideas could be realized. For example, only normal operating losses (in connection with emission standards) were studied in detail, while questions of risks and safety standards were only touched upon in the decision theoretic model. Also, more general questions of environmental regulations, such as the statutory framework, alternative analytical methods for standard setting procedures, or institutional aspects of standard setting were only considered in the initial review phase of the study (see Majone, 1978, TR-1).

STANDARD SETTING: PROBLEMS AND ANALYTICAL APPROACHES

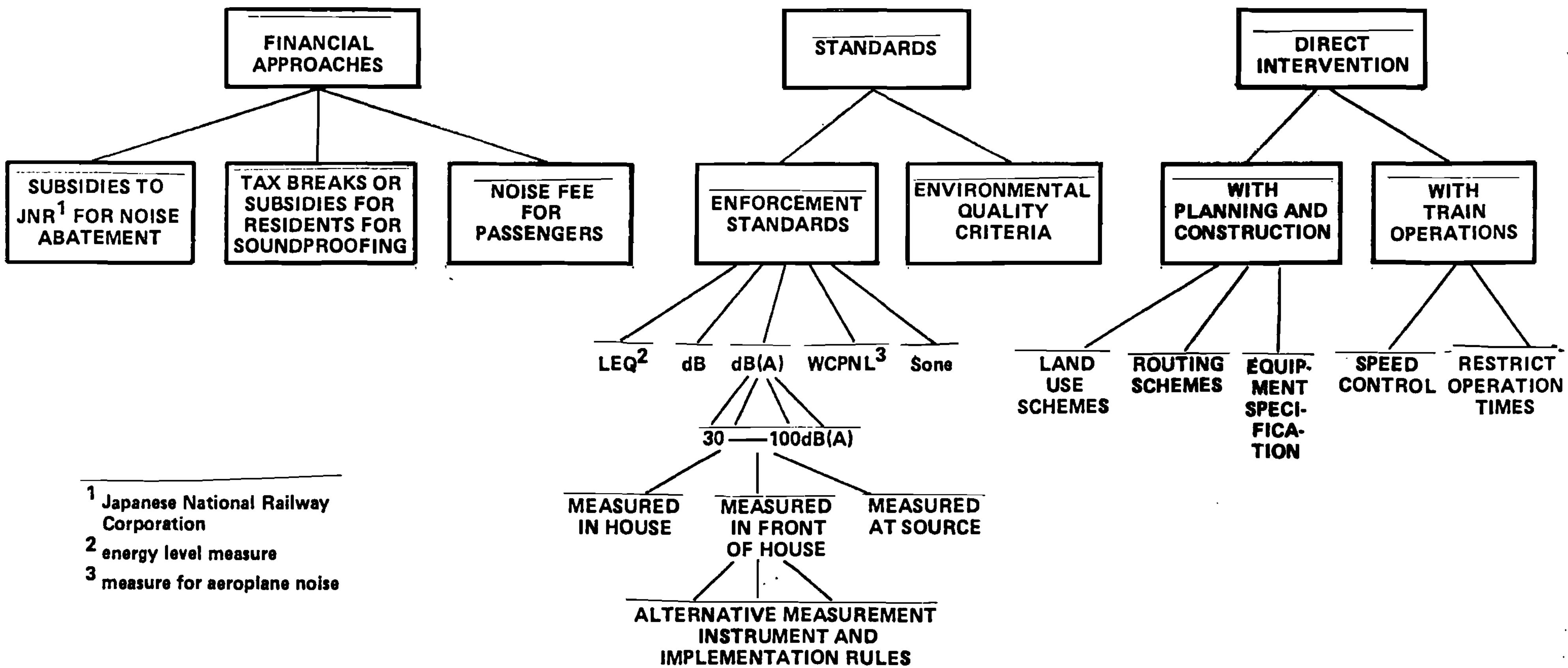
Standards and Alternative Environmental Policy Tools

Before going into the detailed discussion of standards and standard setting procedures, it is useful to back up a little and consider the variety of environmental policy tools of which standard setting is only a small, but important, part. Environmental policy tools range from banning products or operations, over emission taxes, incentives, subsidies, emission and ambient standards, zoning, to procedural rules (contained in environmental impact statements, for example), and institutional rules (concerning, for instance, public participation). An example of this range of alternatives was provided in v. Winterfeldt's (1978, TR-4) study of noise regulation for high speed trains. Figure 1 presents some logical alternatives for setting noise standards. These alternatives alone are only a small segment of the full range of regulatory means and interventions to reduce railway noise. Just an attempt at putting all of these together would have quickly made a bushy mess out of the tree in Figure 1.

Also, there are different types of standards. To name only a few:

- environmental quality standards (usually ambient concentrations or population doses);
- enforcement standards (mainly emission standards);
- safety standards (usually engineering design criteria);
- product performance standards (e.g. milage limitations for cars);
- product design standards (e.g. seat belts);
- work practice standards (e.g. factory temperature).

Out of this range of alternatives this study is mainly concerned with emission standards and only touches on ambient and safety standards. In a review of environmental policy



[1] Japanese National Railway Corporation
[2] energy level measure
[3] measure for aeroplane noise

Figure 1. Regulatory alternatives for Shinkansen noise pollution.

tools and their evaluation, Majone (1978), however, covered a wider range. He classified such policy tools into three categories:

- market approaches (taxes, incentives);
- regulation (standards, licensing, zoning);
- direct intervention (construction of public sewage facilities, banning of certain activities).

Majone critically discussed and evaluated these different types of environmental policy tools, considering their efficiency, equity, and institutional feasibility. In less technical terms, the questions he addressed were: Are the tools cost-effective? Do they distribute costs and benefits in a fair way? Are they adapted to institutional or political reality? Some of Majone's conclusions are worth summarizing here:

- There are no fail-safe policy tools, whose performance may be assessed solely on the basis of their technical-economic properties. The actual outcomes of environmental policies are influenced more by the institutional arrangements, and by people's attempts to manipulate them in their own interests, than by the technical characteristics of the instrument used. Standards and other types of regulatory policy have been criticized for being amenable to bargaining and political compromise. The closed model of environmental decision making shows that the same or similar behavior patterns can be expected to be present, and have in fact been observed, where market approaches to pollution control are used.

- There is no way of reconciling equity with efficiency considerations. The multiplicity of equity constraints rules out the possibility of first-best solutions (emission taxes or effluent charges); and it is even difficult to perceive the distinguishing features of the second best position (the approach of combined standards and charges comes closest to such a characterization).

- Direct regulation is, and will remain, an essential component of environmental policies. This statement can be supported by at least three groups of considerations: institutional, informational, and administrative. Institutionally, the process of standard setting is well adapted to political and administrative realities, in a way in which pollution charges and rights, for example, are not.

From the point of view of information requirements standards--being essentially empirical guidelines that summarize the scientific and economic evidence available--can be used without the precise knowledge of costs, damage, and benefits that is required by more sophisticated methods.

Administratively, direct regulation is unavoidable when quick action must be taken in response to sudden emergencies or to environmental situations that may result in irreparable damage, or to avoid unfavorable long-run developments that could not be checked on the basis of simple cost-benefit considerations.

- Standard setting is a political process, constrained by requirements of internal consistency, and of compatability with known scientific and economic facts. Recognition of the political character of the process does not rule out the possibility of improvement through analysis. It does imply, however, that the relevant analysis must be different from that which is applicable to the paradigm of individual decision making. Specifically, the goal of the analysis can no longer be the search for optimal decisions, by algorithms or other means, but should be the design of improved procedures for argumentation and collective decision making. If it is true that "the most formidable barrier to controlling pollution is probably not technology, population, or public attitudes but the politics of power" (Freeman, Haveman, and Kneese, 1973, page 170), it seems rather pointless to advocate policies that essentially deny the political character of environmental problems.

In short, the study of standard setting procedures began with the precepts that:

- standards are one of the most commonly used regulatory tools, well adapted to the institutional realities;
- standard setting is an inherently political process;
- methods for improving standards are needed and require new methodological and institutional approaches.

Before we discuss some such approaches, the next section will first look into the actual tasks and problems a regulatory decision maker typically faces when setting emission, ambient, or safety standards.

Standard Setting Tasks and Difficulties

Let us consider for a moment an administrator in an environmental agency who has recognized that new production platforms for offshore oil production involve the hazards of operational oily water emissions of a scale and concentration which may endanger the balance of the marine ecology and lead to mortality and chronic toxity of fish and possibly even to an accumulation of hydrocarbons in the food chain. This regulator has just completed the first task in the long chain of tasks when setting a standard: he has identified the hazard, its source, and surveyed its potential impacts. But there still is a long road ahead of him (a rough estimate of two years of study is probably not exaggerated) before he finally can issue an order in which standards are specified.

First of all, there is the question of sources and amounts of pollution. This is a relatively easy task in the chronic oil case (see also Fischer and v. Winterfeldt, 1978, TR-2), but one has only to consider oxidants or carbon dioxide to realize that the problem of amounts and sources is no trivial matter. (See Environment Agency, 1976; Williams, 1978). Polluters are quick to point to other sources of comparable or larger impacts (for example natural hydrocarbon seepage in the seas). Amount estimates vary from expert to expert and between government, industry, and independent researchers. In the chronic oil case estimates of total amounts of oil entering the North Sea from chronic oil pollution differed by a factor of 5. The regulator for the first time faces a problem which he will encounter over and over again in the following months: conflicting opinions, conflicting assumptions, conflicting probabilities, and conflicting estimates.

Next, the problem of pollution abatement technology, and the question of its cost and performance arises. The regulator quickly sees the limits of his own (and not infrequently of the inhouse governmental) research capability. In technological questions he usually has to rely on equipment manufacturers and on industrial sources. Again he faces conflicting data: Manufacturers cite good performance and low costs, often neglecting costs for installing peripheral equipment. Industrial representatives tend to give high cost estimates, cite worse equipment performance, and question the feasibility of equipment. A typical case is again derived from the North Sea study: Manufacturers cited performance figures of oily water treatment which often were lower by a factor of 2 than those of the field studies of the industry and environmental agencies.

Next comes the question of effects and impacts. At this stage the regulator may find himself in one of several binds. If the problem is setting safety regulations (for instance, for preventing blowouts from oil production and drilling platforms), the task becomes one of estimating low probabilities of failures and accidents and of assessing the range of consequences of these accidents. Here the main uncertainties are in the initial event, and to a lesser degree in the impacts. In normal operating losses of industrial operations the uncertainties are reversed: The initiating event is known, but the fate and turnover, synergistic effects, and cumulative long-term effects of low concentration pollution on the affected environment and ultimately on human health may be very uncertain (see also Sagan and Affifi, 1978, TR-11). Chronic oil discharges are again a good example. Although the regulatory agencies in the United Kingdom and Norway know the levels of oil pollution from production platforms, they have only vague ideas about the effects of oil on the marine environment. An example of a double bind is CO_2 emission, which leads to the possibility of a catastrophic climatic change (see e.g. Williams, 1978). In this case neither the probabilities of such an event nor the ultimate nature or consequences of the climatic changes are well known.

Now let us assume that our hypothetical regulator has muddled through the previous tasks of identifying the sources and amounts of pollution, covering a range of possible hazards and risks, and estimating possible effects on the environment. The next step is most critical: to evaluate alternative policy tools, standard measures, and standard levels, within light of his (explicit or implicit) objectives. In the rational paradigm of decision making, this task involves complete specification of objectives and possible alternatives to achieve them. The regulator may consider the availability and performance of equipment as a main criterion of choice among standards (as is very often done; see, for example, CUEP, 1976; EPA, 1975) to rely on pollution equipment control for what technologies are available. On the other hand he may decide to solely rely on environmental or health criteria for selecting a standard in cases where good knowledge about the dose-response relationship exists. This in fact is the idea behind "environmental quality standards", which are usually ambient standards considered as environmental targets. Besides such technical and environmental criteria, the regulator may also consider equipment costs or larger scale economic impacts of regulation.

But often more than just environmental, economic and engineering aspects are to be considered. The international community may exert pressure on the regulator to enforce strict standards because the pollution he intends to limit also affects other countries (this was certainly the case with the chronic oil discharge standards; other examples are: the Rhine pollution, sulfur dioxide pollution which carries across borders, the Mediterranean, etc.). The regulator may be bound by the national governmental policy (e.g. high national economic growth) or the statutory framework defining environmental policy (for example, by asking for the "best practicable" or "best technical" means for pollution control). And, to conclude this list of potential political objectives, the regulator may be concerned about actions and responses from industry and from environmentalists. For example, in the noise regulation case of the Japanese Environment Agency, one main concern was to reduce the number of complaints about train noise. This case also provided a wide range of possible objectives. In the policy analysis study by v. Winterfeldt (1978, TR-4) an attempt was made to delineate all the objectives that the environment agency might have considered when setting noise standards. These include nine objectives reflecting the railway side (e.g. maintain speed, comfort, safety and reliability of trains, minimize investment and operation cost), six environmental objectives (e.g. minimize disturbance to residential areas, minimize direct harmful effects such as aggravation of existing illnesses), and finally, five political objectives of the nature discussed in the previous paragraph (e.g. reduce the number of complaints about noise, meet international standards, fit into national environmental policy framework).

Given these objectives, what are the regulatory means to achieve them? One could think in terms of standards that the regulator merely has to select a numerical value which characterizes the upper limits of emission, ambient concentrations of a chemical or of noise, etc. But there are many more alternatives in standard setting as the noise regulation case (see Figure 1) has shown. The regulator has to take a series of crucial decisions, among which the actual numerical level of the standard is only one of many. The first step is to define one or more quantities (measures) indicative of the pollution level. For example:

- emission concentration averaged over a month;
- maximum emission level on a single day;
- average ambient concentration at a certain distance from a source;
- composition measures such as basic oxygen demand;
- individual or population doses.

Next he has to determine an analytical procedure for measuring pollution levels. This is no trivial matter either. Noise metering instruments can have quite different readings depending on their technical characteristics, even if they are meant to measure the same quantity, e.g. decibel. In the chronic oil pollution study the regulator had recognized that different devices for measuring oil concentration in the effluent could result in readings differing by more than ten percent. In the nuclear industry, standards for permissible plutonium concentrations in air and water had been set which could, for a long time, not be measured at all.

Next the standard level has to be considered. But a simple numerical level does not do. The regulator has to define the limit. For example, it can mean that the average readings of one month based on four daily samples are not to exceed a given limit. Or it can mean that no single sample on any day may exceed the limit. The study of chronic oil discharges clearly demonstrated the influence of such definitions on the industry's decision making in the decision theoretic model (see v. Winterfeldt, 1978, TR-8).

Furthermore, the regulator has alternative means for implementing standards by defining monitoring and inspection procedures, sanctions, and enforcement schemes. It makes no sense to set a standard and not to enforce it. Standards are set to change the operations of an industrial polluter or to reduce the risks of some technology. If there is no inspection or no enforcement, little will change. Again this effect showed very clearly both in the policy study on chronic oil pollution and in the decision theoretic model, which made this aspect a crucial part of the analysis.

Usually not all possible alternatives and objectives are considered in standard setting, and those which remain are seldom spelled out explicitly. In any case, the crucial final task has to then be performed in the light of the information available, the objectives, and alternatives: the evaluation of alternative standards and the final agreement on a standard. This task involves many problems:

- some objectives cannot be operationalized;
- some consequences may not be commensurable;
- trade-offs among conflicting interests and objectives are extremely difficult to make;
- conflicting probabilities and opinions have to be taken into account;
- trade-offs have to be made between short-term benefits and costs and long-term impacts of regulation.

All this has to be done under often severe time pressure, with lobbyists and interest groups at the front door, and experts still fighting over the interpretation of their studies. Will it be a "rational" decision?

Analytical Approaches to Standard Setting

Most likely it will not. Recognition of the inadequacies of environmental regulatory decision making has therefore led to several attempts at analytically studying standard setting procedures and to suggest formal or institutional innovations for improving standard setting. Among these are:

- policy analyses;
- environmental economics;
- cost-benefit analyses;
- simulation gaming approaches;
- decision theoretic approaches;
- game theoretic approaches.

Since policy analysis approaches and the decision and game theoretic approaches--the study tools selected in this research--will be treated in detail later, we will only briefly touch on the alternative tools not explored in detail, i.e., economic analyses, cost-benefit analyses, and simulation games.

Economic analyses are divided into two main study approaches: theoretical studies on the efficiency of alternative pollution control measures (e.g. Baumol and Oates, 1975; Kneese and Bower, 1968; Oates, 1972; Mäler, 1974) and actual studies on the national economic impacts of environmental regulation (e.g. NRC, 1977, VI; Environment Agency, 1977). In his review for this report (TR-1), Majone discusses the first type of studies, some of the results, and the limits of the economic analysis of the pollution problem. To give a simplified version of the economic approach, consider the decision making of a firm under free competition. Since the firm's decision making is oriented towards minimizing investment and operational costs, and the determination of optimal production schemes under free competition, it will neglect the costs and burden its production will impose on the environment (and its users) unless these costs and burdens are internalized into the investment and operational costs. To follow Majone again, consider the case of a chemical factory producing product P and discharging its waste into a nearby river, or polluting the air. These discharges reduce the quality of the environment and its suitability for a number of alternative uses. Since water and air are common property, their services (in this case the services of carrying off wastes) are not sold. The cost of reduced environmental quality is thus overlooked by the price system, and failure to account for such cost leads to an oversupply of P and an undersupply of the benefits which are reduced by pollution. This is the *efficiency* problem. If the damage cost of pollution were internalized, resources would be used more efficiently: the price of P would be higher, less P would be produced, and pollution would be abated.

The solution environmental economists offer to the efficiency problem is to internalize pollution cost to the firm by imposing adequate taxation schemes or by providing pollution rights. The regulatory agency would set a charge or price equal to the marginal damage for each unit of waste, thus forcing polluters to decrease their waste flows as long as the marginal cost of doing so was less than the price for discharging, settling at the optimum where marginal treatment costs are equal to the charge.

Majone points out several problems with this approach, both on the theoretical side and with respect to practical implementation. Perhaps the most persuasive implementation problems can be illustrated in the following (not totally hypothetical) example. A city council imposes effluent charges on a firm emitting a flow of pollutant X. After some years of adjusting its production according to the taxation scheme, the firm develops a new technology which would allow it to drastically reduce the rate of pollution, with the reduction in taxation making up for the investment and operation costs of the new equipment. But rather than maintaining the charges scheme (which should be independent of technologies and only consider marginal damage from pollution), the city council now fears to lose a substantial amount of revenue and quickly reduces its charges. After this reduction, it is no more cost efficient for the firm to install the new equipment. It will continue with the previous production scheme, the same amounts of pollution, but reduced charges.

This may be a somewhat drastic example, but it illustrates some of the difficulties with the charge systems. Other difficulties are, of course, the setting of the charge scheme itself, the estimation of the net damage, taking into account uncertainties, etc. For these reasons environmental economists have attempted to develop "second best" solutions, e.g. the charge and standard approach (see, e.g. Baumol and Oates, 1975). Such schemes assume standards and attempt to set a price system by which to achieve these standards rather than basing them on unknown damage functions (see Majone, 1977). For a discussion of these second best approaches and of alternative studies on environmental economics, we refer here only to the literature cited (see also Pethig, 1978).

Several attempts have been made in recent years to estimate the economic consequences of regulations and standards. In particular, studies have been performed to determine the investment and operation costs of governments regulation, impacts on GNP and employment, etc. Good examples are studies of the U.S. National Research Council (1977, VI) and the Japanese Environment Agency (1977). The general framework for such an analysis is given in Figure 2. The NRC study estimated "incremental annual expenditures made pursuant to Federal pollution control legislation relating to health and environment to be 14 to 30 billion (1974) dollars for 1975 or one to two percent of the GNP". In Japan similar estimates also lie

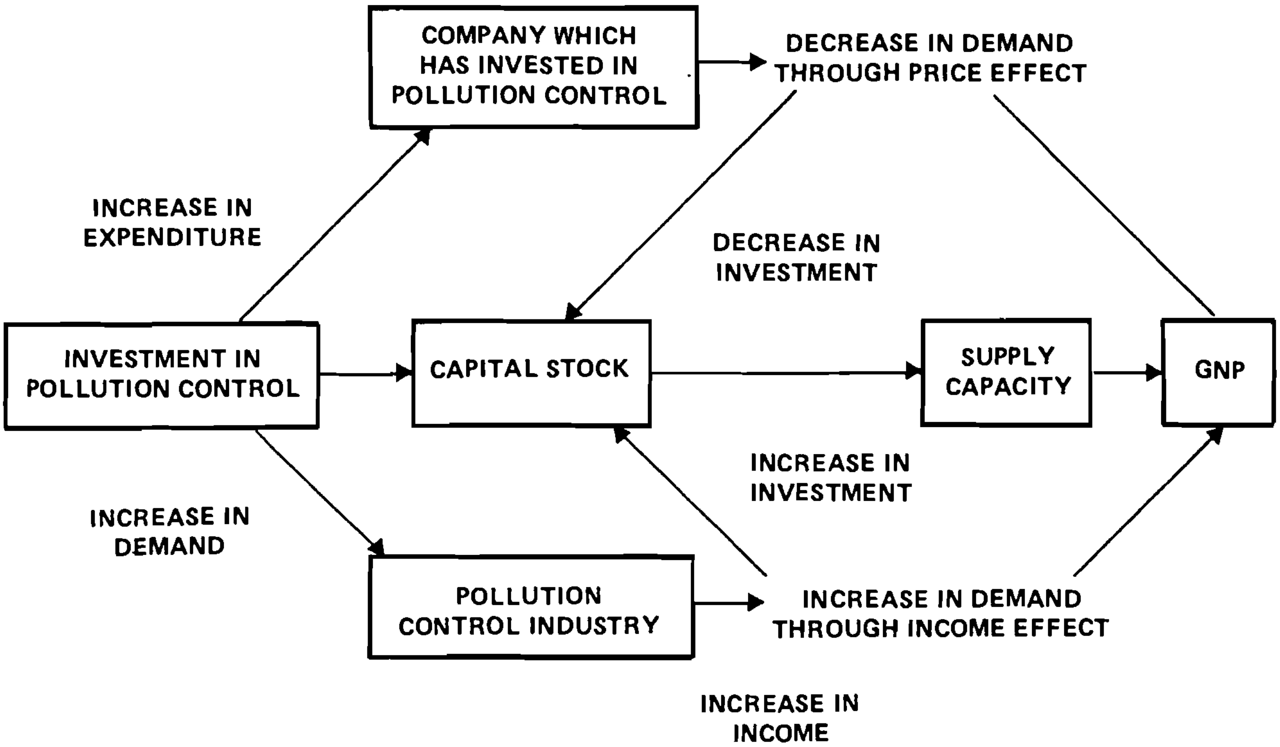


Figure 2. Framework for analysis of the economic impact of environmental regulativ.

Source: Environment Agency, 1977

in the area of one to two percent of the GNP. With respect to the full impact of environmental regulation on national economic growth, the Japanese study comes to a very interesting conclusion: "As the increase in demand resulting from the income effect of the pollution abatement investments is expected to cancel the demand decrease to be caused by its price effects, the pollution abatement investments are expected to have no substantial impact on the average national economic growth..." These numbers say little, of course, about the financial burden put on various industrial sectors. Here, the picture for the next ten years, for example in Japan, may look a little dimmer. For example, the Environment Agency estimates that in 1975 pollution abatement investments accounted for 8.7 percent of the total private investment, and that particularly the petroleum and the coal industry may be affected in the future by environmental regulation. For 1985 the two industries are estimated to have a pollution abatement stock of 34 percent as compared to the total private investment stock, followed by the pulp and paper industry (32 percent) and the ceramics industry (22 percent).

Whether these figures are typical is not the question here. They are meant to illustrate the overall macroeconomic approach to analyzing the effects of environmental control and regulations on the national economy.

Cost-benefit analysis. Cost-benefit analysis is a more practical approach in evaluating environmental decision making that grew out of environmental economics. In its most traditional form, cost-benefit analysis would determine all the costs accruing from, say, standards (for example, investment cost of treatment, operation costs) and the benefits resulting from regulation (for example in reducing health hazards, risks, effects on ecology, etc). Criteria of choice among policy tools are then cost-benefit ratios or the like. Examples of environmental cost-benefit analyses are Dorfman and Jacoby (1975) for water pollution abatement decisions; North and Merkhofer (1975) for regulations for coal-fired power plants; Templeton, McAuliffe, and Murphy for oil discharge regulations (1977); and various other applications in Karam and Morgan (1975).

While the cost of regulations is usually relatively easy to quantify in monetary terms, the quantification of the benefits of regulation (or the damage from pollution) is by no means easy. Quantification approaches include the willingness-to-pay approach or other revealed or expressed trade-off approaches. These are critically reviewed, for instance, in Fischoff (1977), and Pearce (1976). Other limits of cost-benefit analysis are that it does not take into account uncertainties and risks (see Pearce, 1976), and that it cannot incorporate distributional effects and equity considerations.

A study of the National Academy of Sciences (1975) therefore concluded that:

"There is no scientific formula for making regulatory decisions...There is no satisfactory way to summarize all the costs and benefits of regulatory options in dollars or other terms which can be added, subtracted, or compared. In short, there is no substitute for experienced decision makers exercising good judgment." (page 2)

The same report, however, expressed cautious optimism with respect to the less rigid applications of formal analysis as possible decision aids for regulatory agencies:

"However, the techniques developed by decision theory and benefit-cost analysis can provide the decision maker with a useful framework and language for describing and discussing trade-offs, noncommensurabilities, and uncertainty. They can also help to clarify the existence of alternatives, decision points, gaps in information, and value judgments concerning trade-offs." (page 3)

Gaming is one such approach to overcome the problem that regulatory decision makers have little chance of testing their ideas before taking major decisions. This problem will be urgent when trial and error methods are too disruptive and too costly. Other approaches are given by simulation and game theory. A simulation involves the representation of a system by another system that purports to have a relevant similarity to the original system. The simulator is usually simpler than the system being simulated and more amenable to analysis and manipulation. Thus a simulation is a model giving answers to specialized sets of questions about the behavior of the system.

Gaming, in constrast to simulation, employs human beings in some actual or simulated role. Furthermore, players may be experimental subjects under observation or they may be participating in the exercise for instruction or training. An illustrative example is business gaming which is an instructional vehicle based on situations specifically designed to represent the actual business world conditions. It enables the participant to test his decisions within a realistic and often competitive environment since most structures make use of teams or have individuals compete to increase sales, cut costs, etc. Game theory, furthermore, provides the language for describing conscious goal-oriented decision making processes involving more than one individual.

Since the effects of special pollution and the scope of its regulation can often be understood only in a broad context, it seems worthwhile to provide the staff of regulating authorities and perhaps managers in industry with a special training on pollution and its regulation, which of course can be done with a gaming model.

For example, a gaming model on pollution was developed by the firm "Industrianlagen-Betriebsgesellschaft m.b.H." in Ottobrunn, FRG. The result was "Remus: Rechnergestütztes Entscheidungsmodell zur Umweltsimulation" (a computerized decision model on environmental simulation) by Birr et al (1975). It serves as an aid to deciding on regulatory measure. Furthermore, it should demonstrate the effects of measures, scheduled or already carried out, on environment, economy, and on public enterprise. It is planned as a general regional model in which spatial units such as rivers, agricultural regions, and regions of high population density are part of the system. It also considers economic activities in interaction with pollution.

Remus is a multistage model with at most 20 stages. A stage represents one year. There are three groups of players:

- industry;
- governmental planning unit;
- governmental decision unit.

During each stage the three groups choose measures concerning that stage only. These measures relate to four sections: industry, government, population, and environment; the sections "industry" and "government" are represented by groups of players. The groups' objectives are not formulated as utility functions defined on the consequences or action.

Population changes are represented by numerical changes, including migration, which is governed by an index of attractiveness of a region. The main components are environment, infrastructure, state of local labor market, state of recreation facilities, and habitat.

During one stage the industry groups and the governmental groups choose their measures independently, whereas in the governmental group first the planning unit and then the decision unit make their choice. The developers of the model intend to elaborate the various levels of decision makers within government and population and to improve the information obtained during gaming.

The approach chosen by Birr et al is, of course, only one of many gaming approaches. An alternative which relies more on human judgment and on structuring the environment-development problem, for example, is the simulation gaimng approach developed by Helmer (1978). (For an overall review of gaming and simulation gaming approaches, see Shubik, 1975a and b).

While gaming can explore futures of environmental decision making and their consequences directly involving other decision makers or "players", it says little about:

- the structure of environmental decision problems;
- the source and nature of conflicting opinions and values of players;
- possible optimal solutions to environmental regulation in the light of uncertainty and value conflicts.

But in a situation such as standard setting, which apart from different active "players", also involves experts, exogenous pressures, and uncertainties, one may wish to explore in more detail the problems of the decision making processes in regulation, the sources of opinion and value conflicts, and possible solution strategies. For exactly these reasons our studies concentrated on the three remaining analytical approaches:

- *policy analysis* for problem identification, and identification of major actors, values, and alternatives in standard setting problems, with the main goal of structuring the environmental decision process;
- *decision theory and decision analysis* for quantifying the major decision variables, uncertainties, and values in standard setting with the main goal of analyzing the sensitivities in regulatory decision making;
- and finally, *game theory* to explore in a multistage process different solution concepts for regulation.

POLICY ANALYSIS OF STANDARD SETTING PROBLEMS

A Policy Analysis Framework for Standard Setting

The policy analysis framework used in this study was developed by Fischer (1978, TR-2) in a refinement of an approach used in previous studies of environment-development decision making (see Keith and Fischer, 1976). These refinements consisted largely in an adaptation of the original policy analysis framework to standard setting and in the use of some structural tools from decision theory, namely goal trees (see Keeney and Raiffa, 1976) and decision trees (see Raiffa, 1968).

The purpose of this policy analysis approach is to *understand* a specific decision making process in standard setting. This includes a structuring of the decision makers and actors involved in standard setting, their organization, information interlinkages (both formal and informal), the objectives and values of the actors, and their alternative means and instruments for achieving these objectives. Besides providing an understanding of environment-development decision making systems policy analysis also can provide a framework for comparing the decision making in different countries (as was done in the North Sea study by Fischer and v. Winterfeldt, 1978, TR-3), and to some degree also help evaluate the decision making process. Interviews and background literature provide the main data base for such policy analysis.

Fischer's policy analysis framework begins with a definition of the *concept of actors*. In application to standard setting processes, the policy analysis uncovered several generic actor groupings which can be characterized as follows:

Development Actors

objective: profit or service potential;
reason for involvement: generation of energy or products via approved technology.

Regulatory Actors

objective: assimilate opposing demands and approve technology;
reason for involvement: legislative/administrative authority.

Environmental Expert Actors

objective: professional and personal interests;
reason for involvement: recognition of impacts.

Impactees

objective: preservation of environment/livelihood;
reason for involvement: dissatisfaction with potential outcome of development.

Exogeneous Actors

objective: preservation of environment/energy systems;
reason for involvement: treaty, international influence.

A convenient way of initially structuring the interrelationships between actors was found to be a representation of these five actor groups as shown in Figure 3.

The actual organizational setup is the next step of the policy analysis. Here the main formal and informal interconnections between the actor groups identified are constructed. Figure 4 presents an example of the organizations and actors involved in the standard setting process for chronic oil discharges from North Sea production platforms. Interconnections represent lines of advice, information exchange, approval, and control. Following the definition of actors, their organizations, and their interlinks, the next step of the policy analysis is to structure the potential values and objectives of the three main actor groups--the regulator, the developer, and the impactee--by means of goal trees. Finally, the policy analysis attempts to outline possible alternative strategies

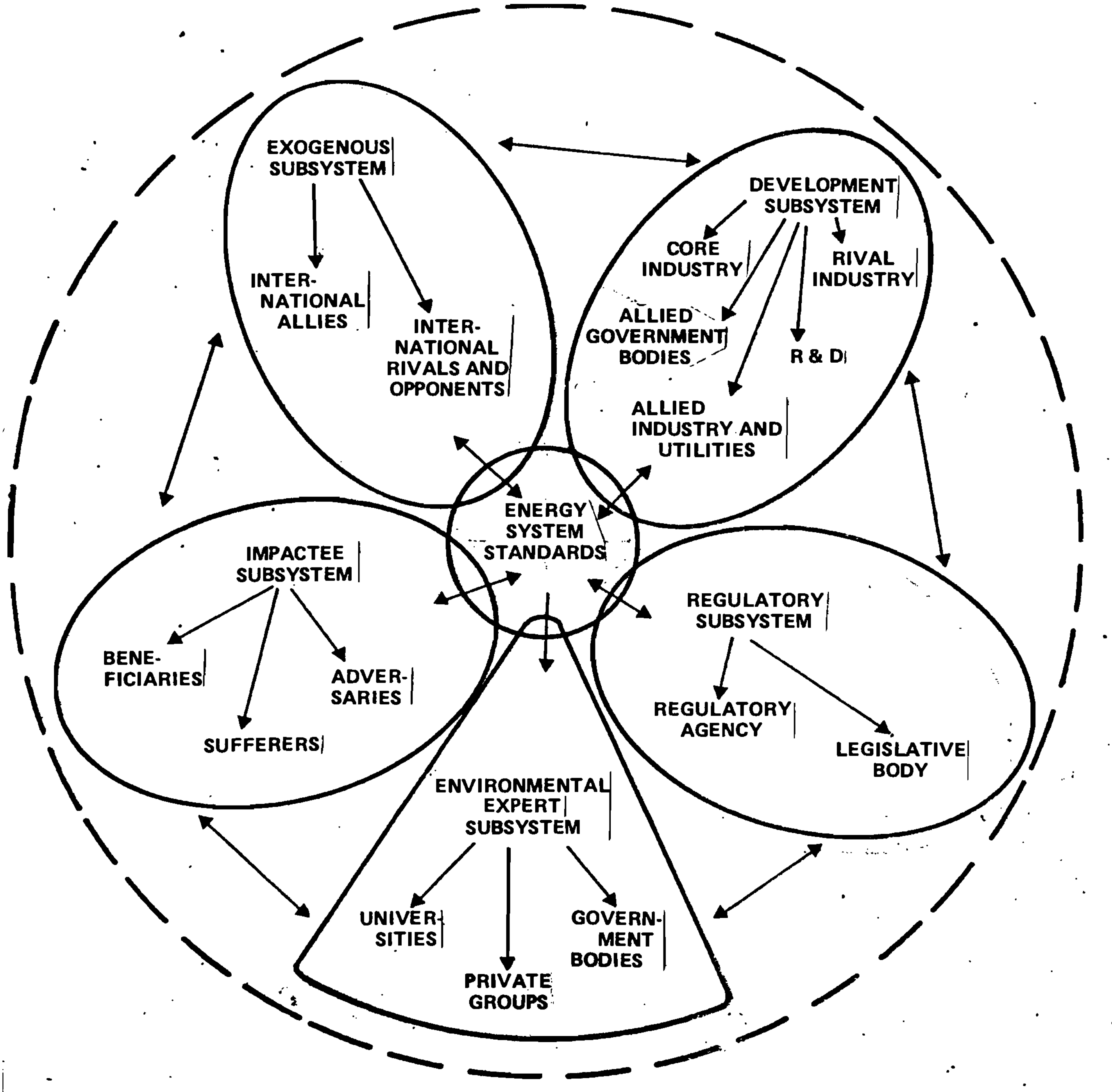
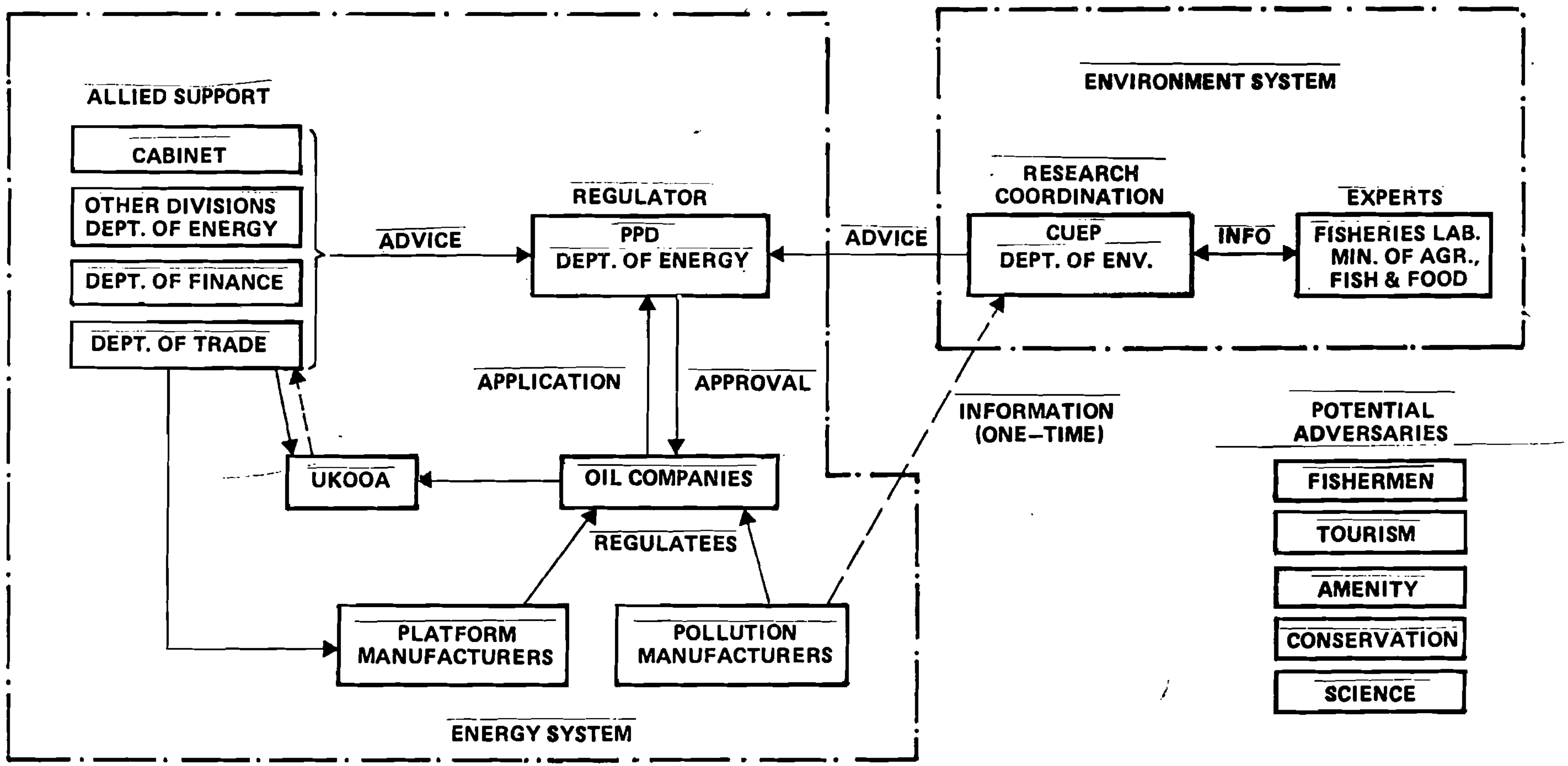


Figure 3. The actor subgroups involved in standard setting for energy systems.



UKOOA: UK Offshore Operators Association
CUEP: Central Unit on Environmental Pollution
PPP: Petroleum Production Division

Figure 4. An assessment of the energy-environment interface in the UK for setting standards for offshore chronic oil discharges.

and instruments of these three actor groups by menas of alternative or decision trees.

The previous steps of the policy analysis framework for standard setting defined the *elements* of the standard setting process, and are an attempt to cover a *wide span* of *possible* actors, objectives, and alternatives. The final analysis attempts to first describe in detail the actual information collection, processing, and evaluation in standard setting and to reflect this real process against the outlined objectives, alternatives, and actors. Questions raised here are:

- Which actors were included in the decision making process and how?
- Which actors were excluded and why?
- Which objectives (of those outlines in the tree) were actually considered, and with what priority?
- Which alternatives (of those spanned in the tree) were actually considered and how?
- Which alternatives were excluded and why?
- Which information was used for standard setting?

Attempts can be made on that basis to reflect on the possible inconsistencies, lack of information use, lack of information exchange, exclusion of certain actors or alternatives in the standard setting process. These can then be useful to compare across different countries and to provide a basis for further evaluation within a given country.

The policy analysis approach is qualitative and problem oriented with a non-rigid methodology. It helps the analyst to quickly orient himself in a real world problem and gives a rough structure of the situation. However, it should be noted that such an analysis can never do more than portraying a qualitative picture of the standard setting process perhaps tainted through the perceptions of the interviewees and the analysts. There is no assurance that a different analyst who takes up the same analysis will end up with the same results and conclusions. This lack of intersubjectivity is both a strength and a weakness. It is a strength because it allows a deeper understanding through the direct involvement of the analyst, a flexible approach, and a possibly more perceptive and insightful analysis which could not be provided by standardized questionaires or data collection methods. It is a weakness because it opens itself to numerous judgments and biases on the side of those interviewed and of the analyst, who then in turn will have to face criticisms of silent assumptions, biases, or misunderstandings. Both these strengths and weaknesses fully applied in the two following policy analyses of chronic oil discharge and noise regulation. Particularly in the chronic oil discharge case, the United Kingdom representatives argued quite strongly against some of the evalutions and comparisons between Norway and the United Kingdom. One should therefore read the following summaries of these studies, keeping in mind both the strengths and the weaknesses of the policy analysis framework.

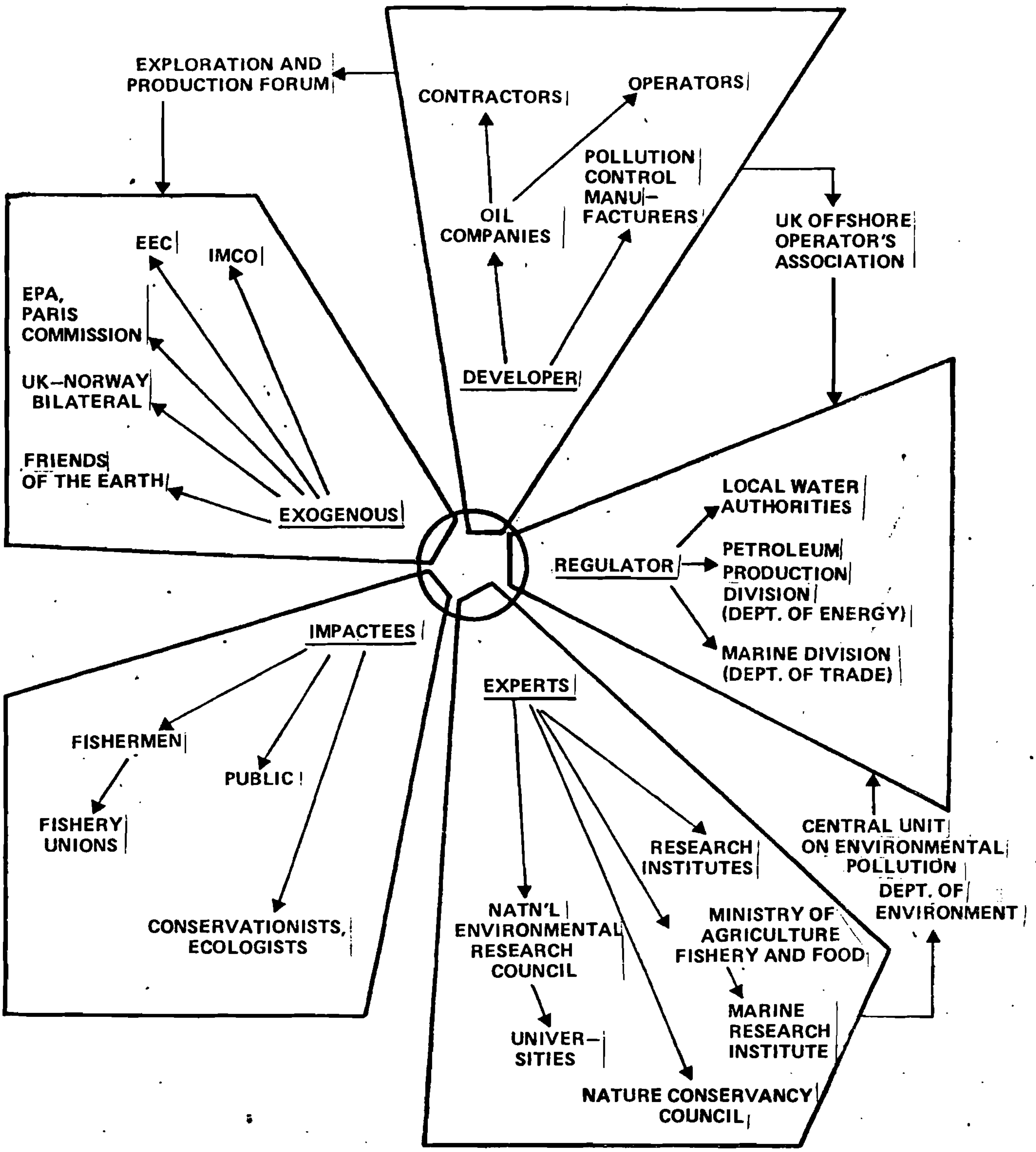
The Chronic Oil Discharge Study

The study of chronic (operational) oil discharges from North Sea production platforms was the more detailed policy analysis of this project. In-depth interviews were held with members of the departments of energy and environment in the United Kingdom and Norway and with industry representatives and researchers, and close contacts were established between the IIASA team and the regulatory agencies. The IIASA team visited the United Kingdom and Norway twice during this study, and delegations of the United Kingdom and Norwegian regulators came to IIASA during a workshop held partly on the issue of operational oil discharges.

The problem of chronic oil discharges from North Sea production platforms arose with the growing oil development in the North Sea. Production platforms discharge, as part of their routine operations, certain amounts of oily water (up to 200,000 barrels a day) with an oil content of up to 100 ppm (parts per million). Both the United Kingdom and Norwegian governments were in the process of setting discharge standards on oil concentration when in December 1976 the IIASA study team began to look into the problem.

Figures 5 and 6 show the first step of our analysis, the determination of the actor configurations in the United Kingdom and Norway. Although many organizational units are identical but have different names, one difference appears quite obvious: in the United Kingdom the standard setting for chronic oil discharges is put in the hands of the Department of Energy, while in Norway it rests within the Department of Environment.

Figure 7 presents an example of an alternative tree that shows the developer's choices for treating chronic oil discharges. To give an example of the goal tree structuring approach, Figure 8 illustrates the goals for protecting the marine environment under the explicit formulations of the United Kingdom Central Unit on Environmental Pollution. Objectives of the developers were mainly cost oriented, while the regulator appeared to have objectives (or rather: constraints) determined by international and national legislation and other standards (for example, agreements by the Paris Convention on Oil Pollution).



IMCO: Intergovernmental Maritime Consultative Organization

Figure 5. Potential actor configuration in setting standards for offshore chronic oil discharges in the UK.

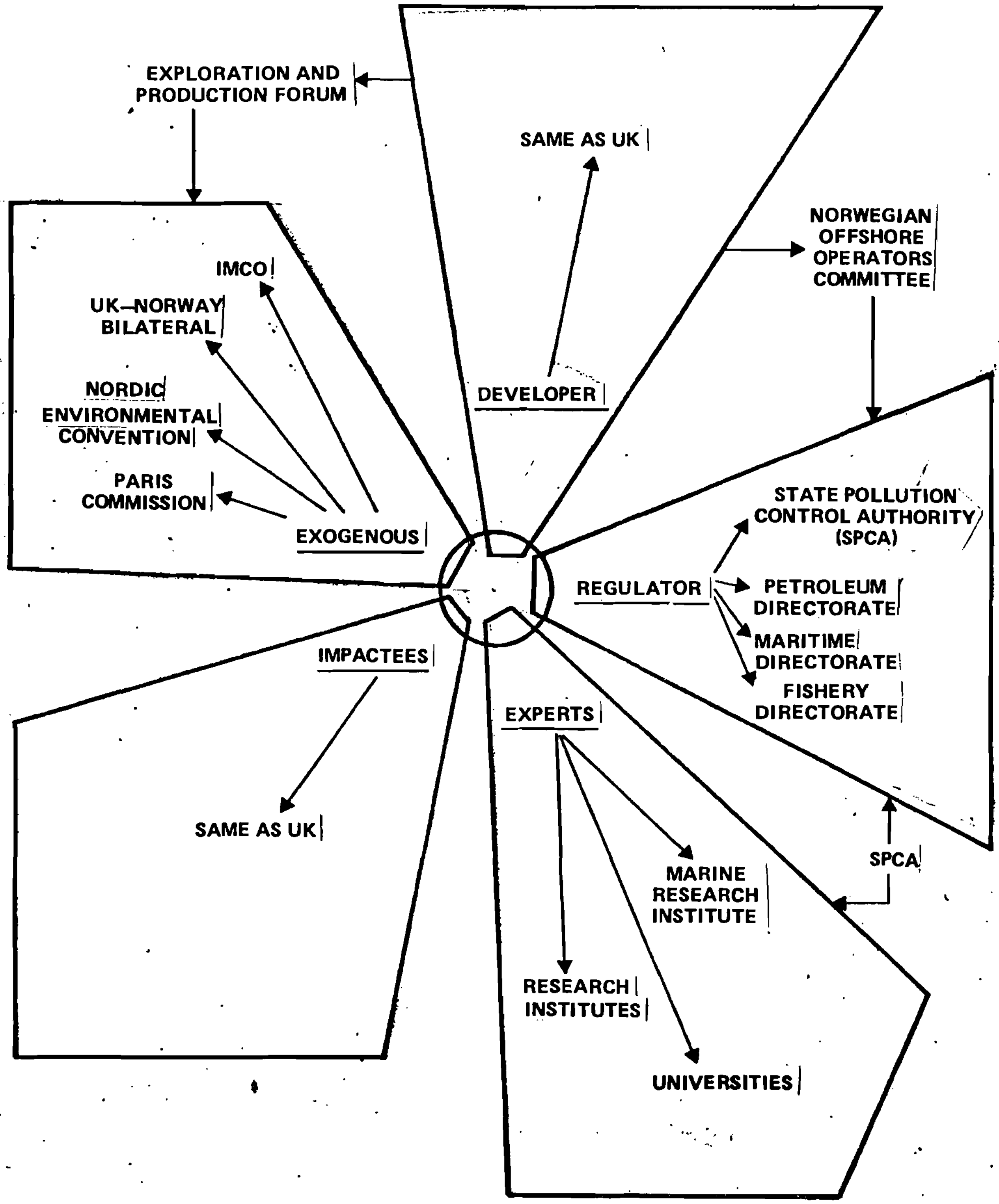


Figure 6. Potential actors configuration in setting standards for offshore chronic oil discharges in Norway.

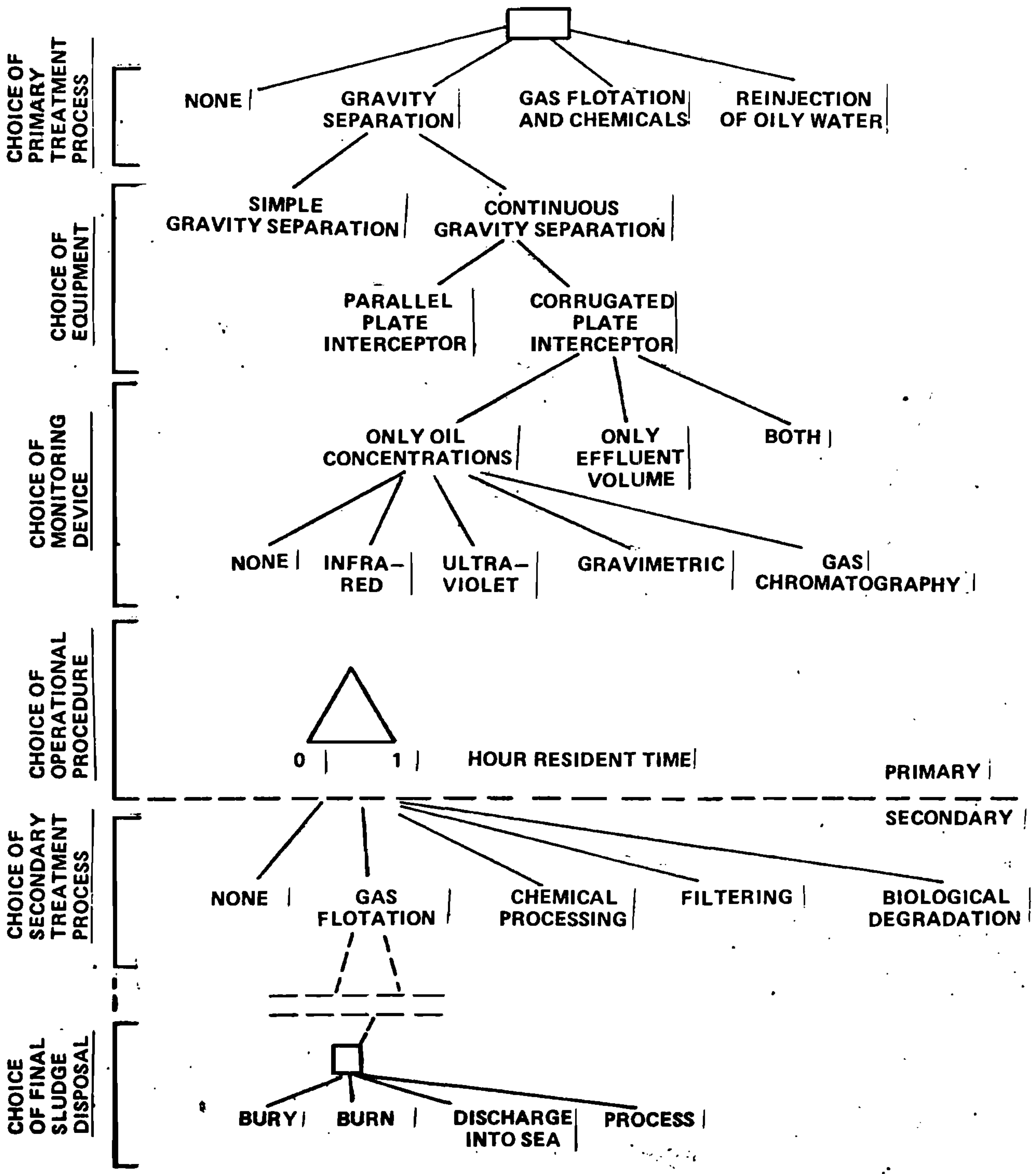


Figure 7. Some branches of a developer's tree of oily water treatment alternatives.

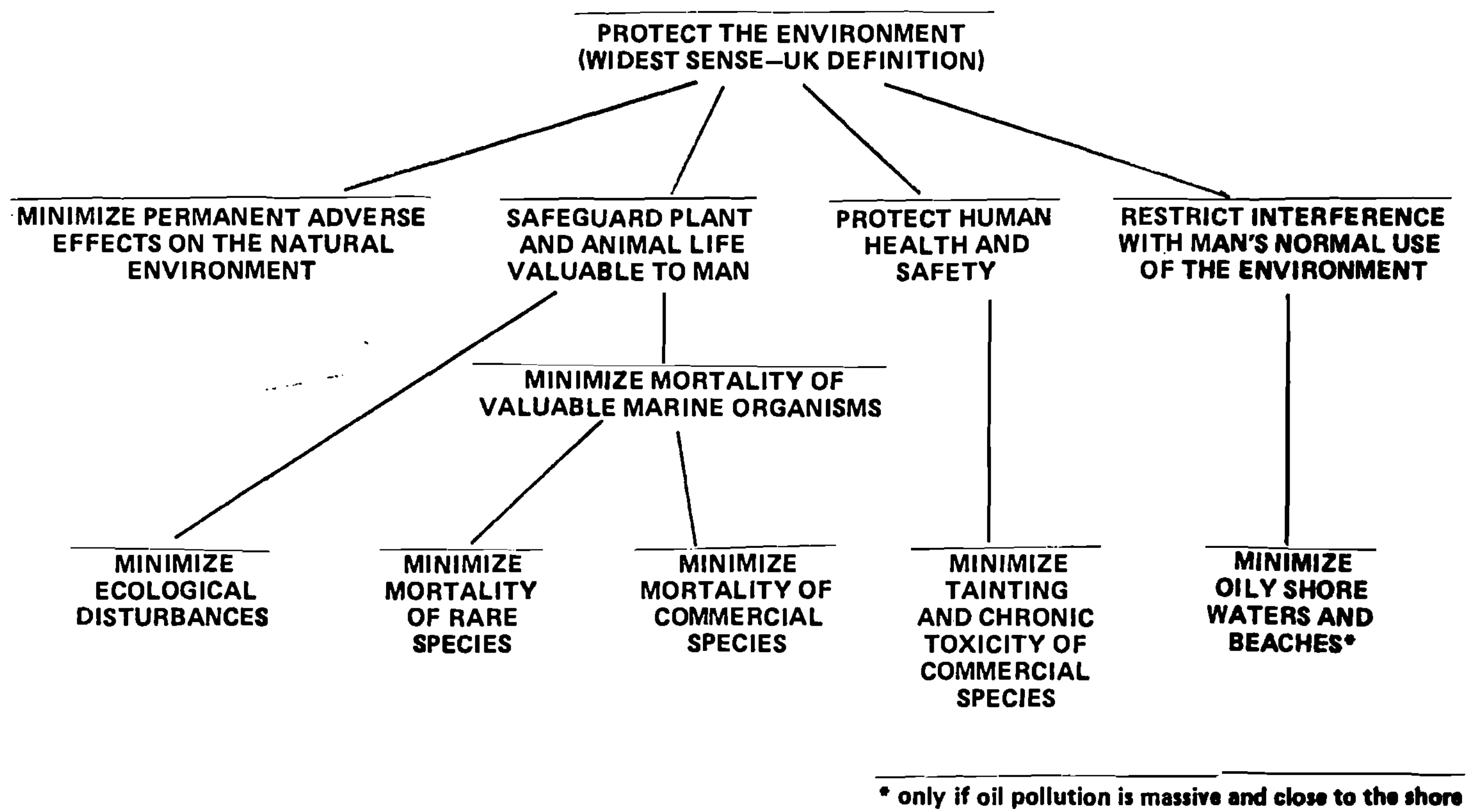


Figure 8. Goal tree for impactees concerned about chronic oil pollution.

Standard setting in the United Kingdom was actually done in two steps. First guideline standards (40 to 50 ppm) were elaborated by the Central Unit on Environmental Pollution (see CUEP, 1976). Because of a lack of biological information (see National Academy of Sciences, 1975; National Research Council, 1974) these guideline standards were set largely on the basis of treatment availability, cost, and performance considerations. Extreme regulatory solutions (for example zero discharge) were never seriously considered, as extreme treatment solutions (reinjection of oily water into an empty reservoir, or biological treatment) were considered infeasible or too costly. The Petroleum Production Division of the Department of Energy handles the day-to-day operations of setting and enforcing standards. In Norway there were no guideline standards, but standards were set on a case by case basis. Starting from the middle of 1978, however, the guideline standard will be between 25 and 30 ppm. These numbers have to be interpreted with much care, however, since it turns out that the specific definitions of sampling period, sample sizes, and the number of exemptions from standards play an important role in the implication of the actual numerical value of a standard (see v. Winterfeldt, 1978, TR-8).

The policy analysis allowed us to draw certain comparisons and suggested recommendations for further improvement of standard setting. Similarities between the United Kingdom and Norway include for example:

- The emphasis is on treatment equipment;
- Standards are set on a case by case basis;
- There are attempts to work with industry in the design stage;
- Monitoring is tied to discharge permits;
- Responsibility to monitor rest with the company;
- Standards are set in the vicinity of 40 ppm;
- Energy unit inspects platforms.

The main differneces between the two countries are summarized in Table 1.

The recommendations included:

- improvement of inhouse (governmental) expertise on oil treatment equipment to remove dependence on industry assessments;
- improvement of research on effects of low-concentration oily water around production platforms;

Table 1 COMPARISON OF REGULATORS OF OIL DISCHARGES CONNECTED WITH OFFSHORE PLATFORMS IN THE NORTH SEA

DIFFERENCES BETWEEN NORWAY AND UK	
NORWAY	UK
• regulator is pollution control authority with emphasis on environment	• regulator is petroleum production unit with emphasis on energy
• regulator had to create regulatory structure	• regulator had to redesign regulatory structure
• impactees asked for comments	• impactees not asked for comments
• regulator open with information	• regulator keeps information confidential
• problem viewed as environmental with emphasis on fish impacts	• problem viewed as political and technical
• no research on treatment alternatives	• published one paper on treatment alternatives
• pessimistic estimates of total amount of oil discharges	• optimistic estimates of total amount of oil discharges

- improvement of the process of circulation and information gathering for discharge applications (to include impactees, and to provide a more useful response format).

The Shinkansen Noise Standards Study

The noise standards study was a part of a larger study by IIASA's Management and Technology Area on the management of the superrapid Shinkansen trains in Japan. As it turns out, noise pollution is one of the most severe environmental impacts of the Shinkansen. The information used for the standard setting study on noise pollution was based on a conference held at IIASA, where Japanese representatives participated and part of which dealt with the noise issue. In-depth interviews were held in Japan during a IIASA field study, mainly with representatives of the Environment Agency, the Japanese National Railway Corporation, and a lawyer's association representing residents who suffer from noise pollution.

The problem of noise pollution is one of the most severe pollution problems in Japan. Over 24,000 complaints reached the Japanese Environment Agency on noise issues in 1975 alone. Complaints over trains are a relatively small fraction, but there exists a strong and organized opposition against Shinkansen noise. When the IIASA study team became involved in the noise pollution problem, standards for Shinkansen trains had already been set. The bulk of the study was therefore restricted to a retrospective analysis of how the Environment Agency had set noise standards. However, one part of the analysis dealt with the ongoing law suit of residents against the Japanese National Railway (JNR) to reduce noise pollution.

The main actors in the noise standard setting were the Environment Agency with its advisory body, the Council for Pollution Control as the regulator, the JNR as the developer, and the residents along the line as the impactees. A particular impactee group, the "Nagoya Association Against Shinkansen Public Nuisance" was identified as a prototypical organization of impacted residents. A broader actor spectrum is represented in Figure 9.

Figures 10 and 11 present the goal tree and the alternative tree for the JNR as examples of the analysis. The possible regulatory actions of the Environment Agency were already outlined on page 6 . Actions of the impacted residents could include:

- complaints by individuals;

- petitions by groups to prefectures, the JNR, or the Environment Agency;

- organization of residents;

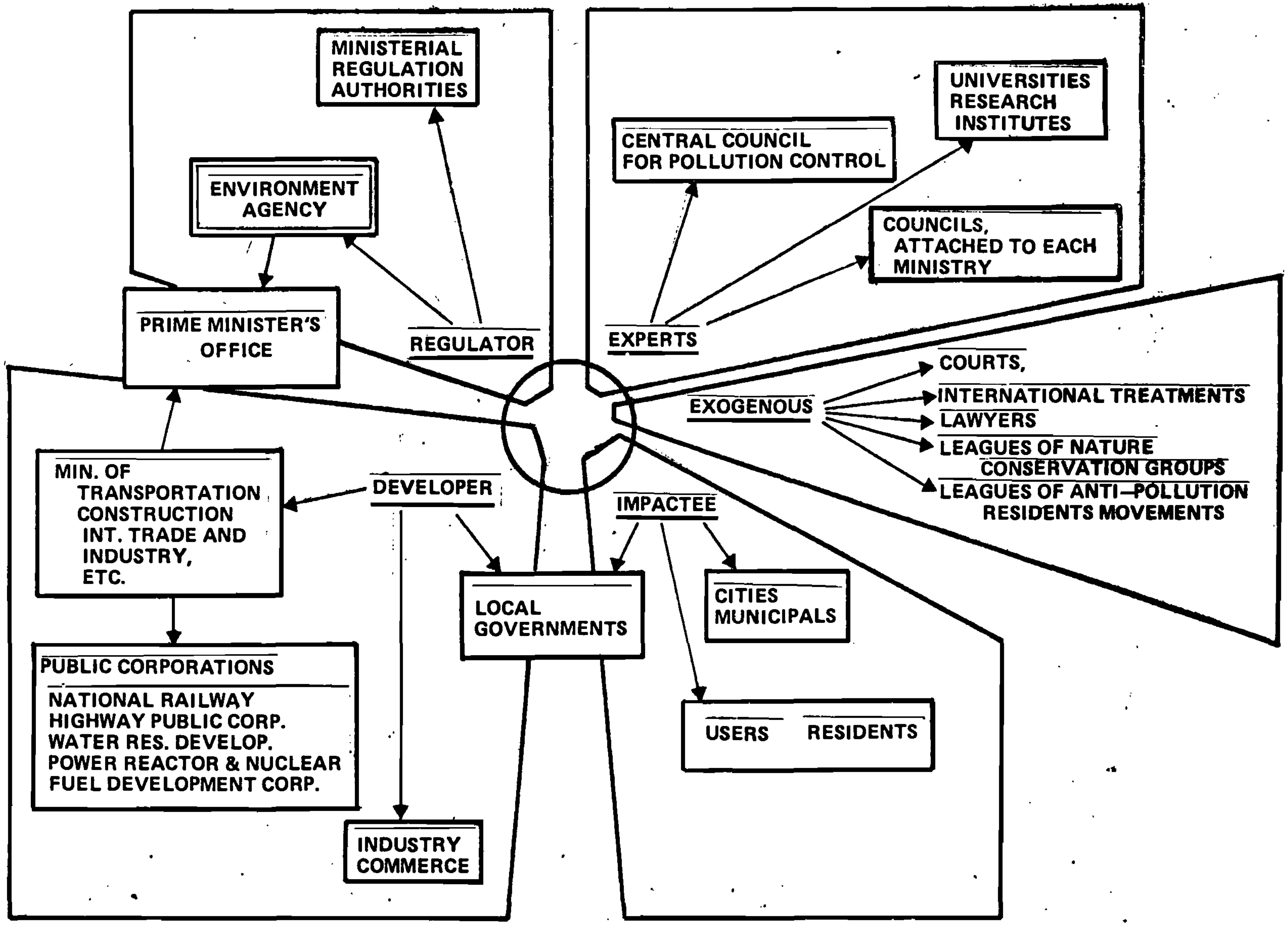


Figure 9. Actors involved in Shinkansen noise standard setting.

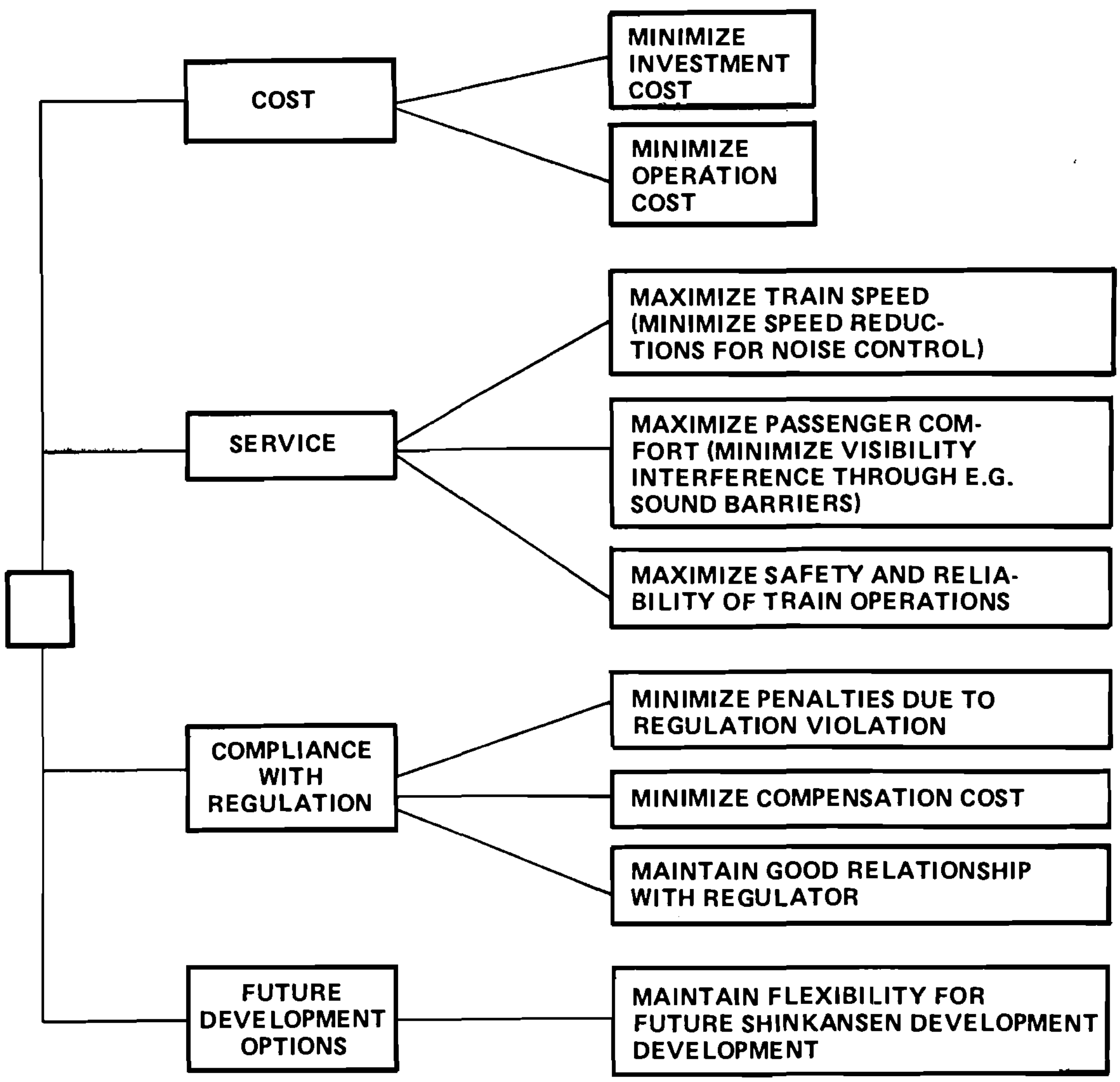


Figure 10. Potential objectives of JNR in decision making for noise pollution control.

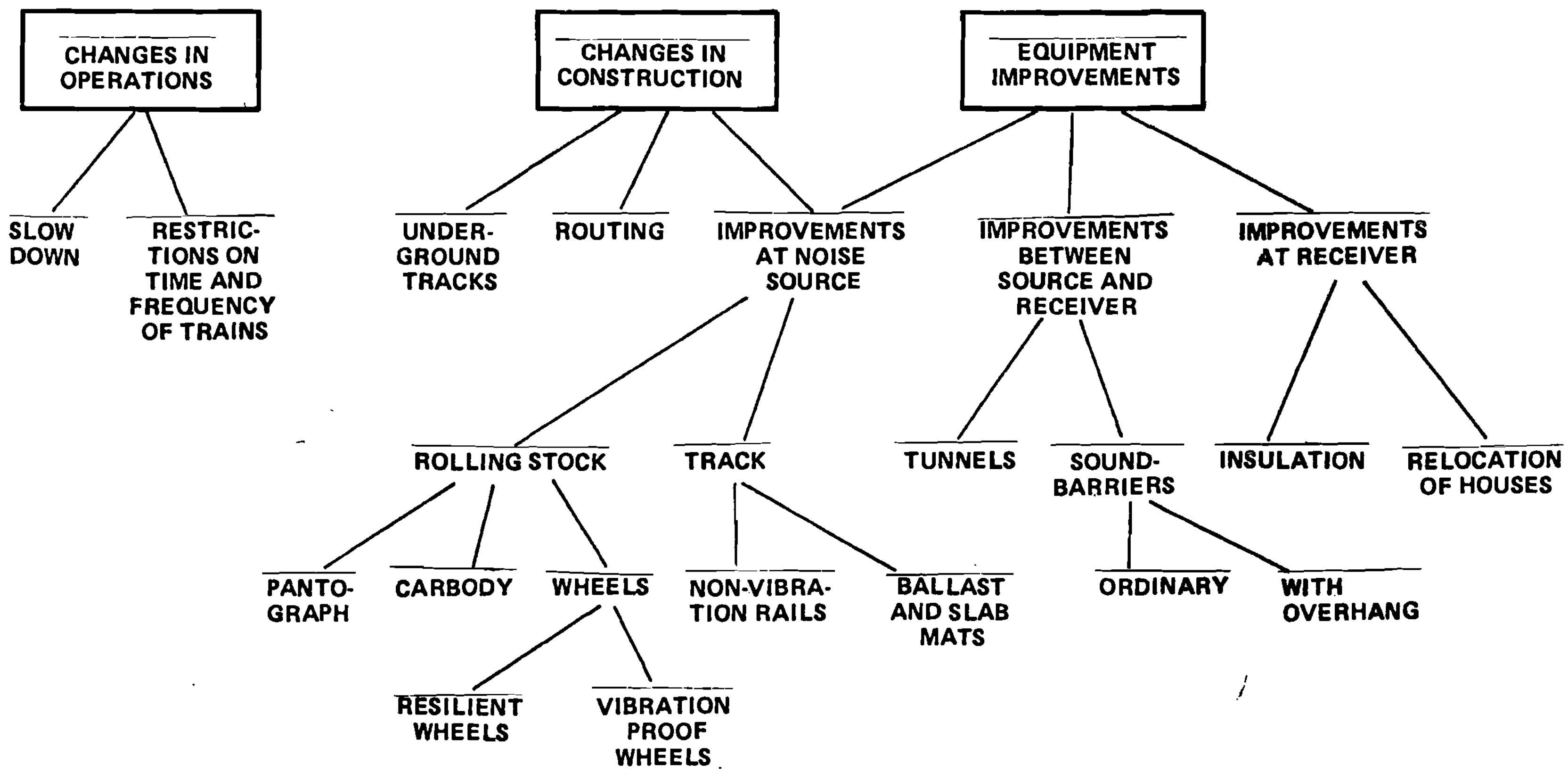


Figure 11. Alternatives for Shinkansen noise pollution abatement.

- legal litigation;
- extralegal actions.

In fact all these steps have been followed by the Nagoya Association except for the last.

The Environment Agency had the alternative of setting either environmental quality standards (targets, desirable states to be reached some time in the future) or enforcement standards (tools for forcing the JNR to begin noise protection measures). One of the main findings of the study was that the Environment Agency intended to set environmental quality standards, but in effect set standards which turned out to be enforcement standards with precise guidelines and deadlines for the JNR to comply (see Table 2). However, these standards were set almost exclusively on the basis of noise-complaint relationships which were established through research of the Environment Agency and independent research institutes. The standards were set such that approximately 30 percent of the people subjected to the standard level of noise would tend to complain. No other technical information (for example on noise-speed relationships, on the availability and performance of noise abatement technology) were explicitly considered. Neither had the costs of such noise abatement technology been taken into account.

This is a reversed picture of the chronic oil case where standards were set mainly on cost and performance considerations (within political constraints), neglecting environmental considerations because of a lack of data. In the noise case, cost and performance were neglected and noise standards were set mainly on environmental considerations. This would have been appropriate for environmental quality standards. However, for enforcement standard considerations of a technical nature, cost and performance should have been taken into account. Therefore, one of the conclusions of the study was that the Environment Agency of Japan did not use a sufficient data base for justifying the (enforcement) standards.

Other findings of this study include:

- Only limited alternatives for noise regulation were considered (no consideration of slowing down the trains in certain areas, zoning, etc.);
- Standards were set on an arbitrary complaint level;
- The JNR was only reactive in the process of standard setting;
- The JNR views the noise problem as purely technical;
- Slowdown effects on noise reduction were played down by the JNR.

Table 2 ENVIRONMENTAL QUALITY STANDARDS FOR SHINKANSEN (BULLET TRAIN) NOISE

Ministerial Order issued by Environment Agency on 29 July 1975, based on Article 9, Basic Law for Environmental Pollution Control Measures.

CATEGORY OF AREA	REGULATION LEVEL
Class I	70 dB(A) or less
Class II	75 dB(A) or less

ZONAL CATEGORY	TARGET FULFILMENT PERIOD		
	AREAS ALONG EXISTING SHINKANSEN LINES	AREAS ALONG LINES UNDER CONSTRUCTION	AREAS ALONG NEWLY BUILT LINES
A Areas with 80 db(A) or over	in 3 years	on start of service	on start of service
B Areas with 75-79 dB(A)	(a) in 7 years (b) in 10 years	in 3 years after start of service	on start of service
C Areas with 70-74 dB(A)	in 10 years	in 5 years after start of service	on start of service

Note: In any area, where it is failed to achieve the standards within above specified periods, in spite of best effort, performance should be completed as early as possible.

Having uncovered some shortcomings and problems in two real world standard setting cases, one asks the next question of possible methodological improvements in standard setting noise. For this purpose, decision and game theoretic models were developed which will be described in the following section.

DECISION AND GAME THEORETIC MODELS FOR STANDARD SETTING

Purpose and Structure of the Models

Decision and game theoretic models can be useful methodological tools for studying decision making of multiple groups under uncertainty and possible multiple conflicting objectives. The possibility of using such models for standard setting had been recognized by several researchers (see, for example, National Academy of Sciences, 1975). Therefore, the development and application of such models was one of the major tasks of the standard setting research at IIASA.

The purpose of the *decision theoretic model* was to provide a framework, structure, and a formal language along which a regulatory agency can organize its information processing and evaluation tasks when setting standards. The usual single decision maker model (see Raiffa, 1968; Howard, 1968) was adapted for these purposes by extending it to a three decision makers model which encompasses the decision making of a regulator, a developer (producer), and an impactee. The model is a one-stage hierarchical optimization model in which optimal responses of the developer to regulation and of the impactee to development actions can be determined. It was soon recognized for some applications that this model was too simple and needed more feedback loops and an extension into a dynamic process. Such an extension was then elaborated in a three-decision maker *dynamic game model* by which future actions could be simulated in standards setting and certain "optimal" solutions (for example equilibrium points or Pareto optimal solutions) can be determined.

Before going into the detailed discussion of the models, one has to point out the main similarities and differences between these models. The decision model is a static detailed model of trade-offs, information processing, and decision making of the three decision making units (regulator, developer, and impactee). Through the use of probabilistic submodules for the detection of regulation violation and for environmental impacts it allows a finely graded analysis of the regulation problem. In turn it gives up the dynamics and multiple interactions between the decision making groups over time.

The dynamic game model makes such extension possible but only at certain costs. Although it has the same *structure* (three decision makers, a hierarchical solution concept as one possibility), it operates on a much more aggregated level. It does not explicitly construct utility functions or probabilities of detection, but incorporates these aspects in an aggregated way in the transition probabilities between the stages of the game and in aggregate utility functions defined on the actions of the three decision makers. Although the game theoretic model does not allow a detailed analysis of trade-offs and probabilities, it can be very useful for parametric analysis of the crucial points in a dynamic standard setting process.

The Decision Theoretic Model

A detailed description of the model can be found in v. Winterfeldt (1978, TR-8,9). The rough structure of the model is shown in Figure 12. The model considers three decision making units, generically called the regulator, developer, and the impactee. For each decision unit a normative model (for more details on building decision models, see Raiffa, 1968; Keeney and Raiffa, 1976; Howard, 1968; Edwards, Lindman, and Phillips, 1965) is constructed which operationalizes qualitative objectives as numerical consequence measures, and specifies probability distributions over these consequence measures. These probability distributions depend on the action taken and on external actions or events (for example, detection of a violation of a regulation and the information available). Finally, an evaluation model is built by which trade-offs and possible risk attitudes of the decision maker are taken into account, and which allows to numerically evaluate alternative action.

If a regulator decides on a particular standard, here labeled r, the developer's decision making will be influenced by the possibility of detection of regulation violations and the resulting sanctions. Through the decision model an optimal response d(r) by the developer is determined, which may not be the decision he would have taken without regulation. Through pollution generating events and effects the environment and its users (impactees) are affected. Impactees may decide to leave polluted areas or to take legal action against the polluter. Again through the decision theoretic model an optimal response by the impactee a(d) can be determined. Thus the model can determine optimal responses d(r) and a[d(r)] as a function of r together with the associated numerical evaluations of these actions (utilities) U_R, U_D, U_A.

In order to make such a hierarchical optimization possible, several crucial independence assumptions had to be made:

- the consequences for the regulator depend only on his own action;
- the consequences for the developer depend only on the regulator's action and his own;

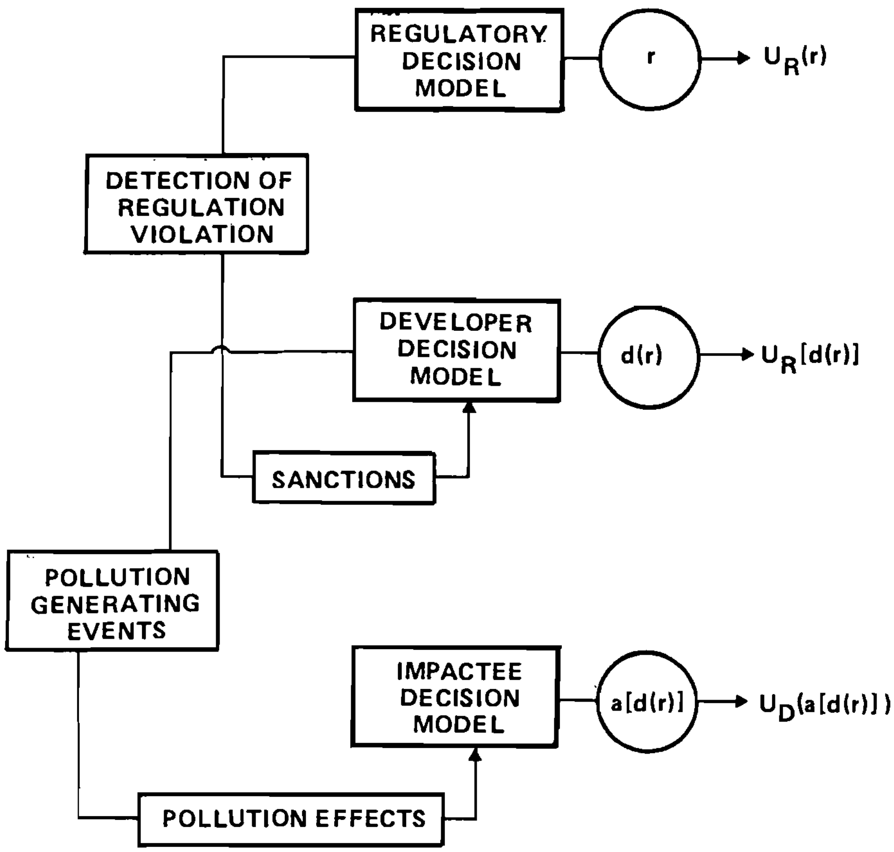


Figure 12. Schematic representation of the regulator-developer-impactee model.

- the consequences for the impactee depend only on the developer's action and his own.

The decision models for the three decision units are a combination of a hierarchical inference model (see Kelly and Barclay, 1973) and a multiattribute utility model (see v. Neumann and Morgenstern, 1948; Savage, 1954; Fishburn, 1970). The models have been adapted to standard setting such that all parameters can in principle be assessed through expert interrogation without a very difficult formal elicitation process.

In addition to these basic models two submodules labeled "Detection and Sanctions" and "Pollution Generating Events and Effects" were created which link the three decision units. The detection and sanction submodule for normal operating losses is built on performance distributions of the equipment which reflect the uncertainty about day-to-day performance, the uncertainty about the parameters of the equipment, and the uncertainty built in the monitoring and inspection procedures of the regulator. The pollution generating events and effects submodule is basically an event tree exemplified in Figure 13. The tree starts with operating conditions following the developer's decision on equipment. It then goes through random emission levels, and over ambient levels to ultimate pollution effects. At each stage conditional probability distributions are assessed on the basis of expert judgments or models.

The model has been constructed in this extensive form for both emission and safety standards. More limited applications have been done for emission standards. The possible uses of the models are:

- to structure the regulation problem;
- to enable regulators and experts to express uncertainties and intangibles quantitatively;
- to identify a set of good standard solutions;
- to allow a study of the sensitivities of the regulatory solution to conflicting values, opinions, and information.

The Multistage Game Theoretic Model

A great part of the pollution regulation problem can be adequately treated by the previous one-stage model including special long-term problems where the time points of necessary adaptation are far apart. Among these, however, are problems where either the physical or the economic conditions are changed substantially by the measures of the groups involved, or where later measures depend on previous measures. Furthermore, it

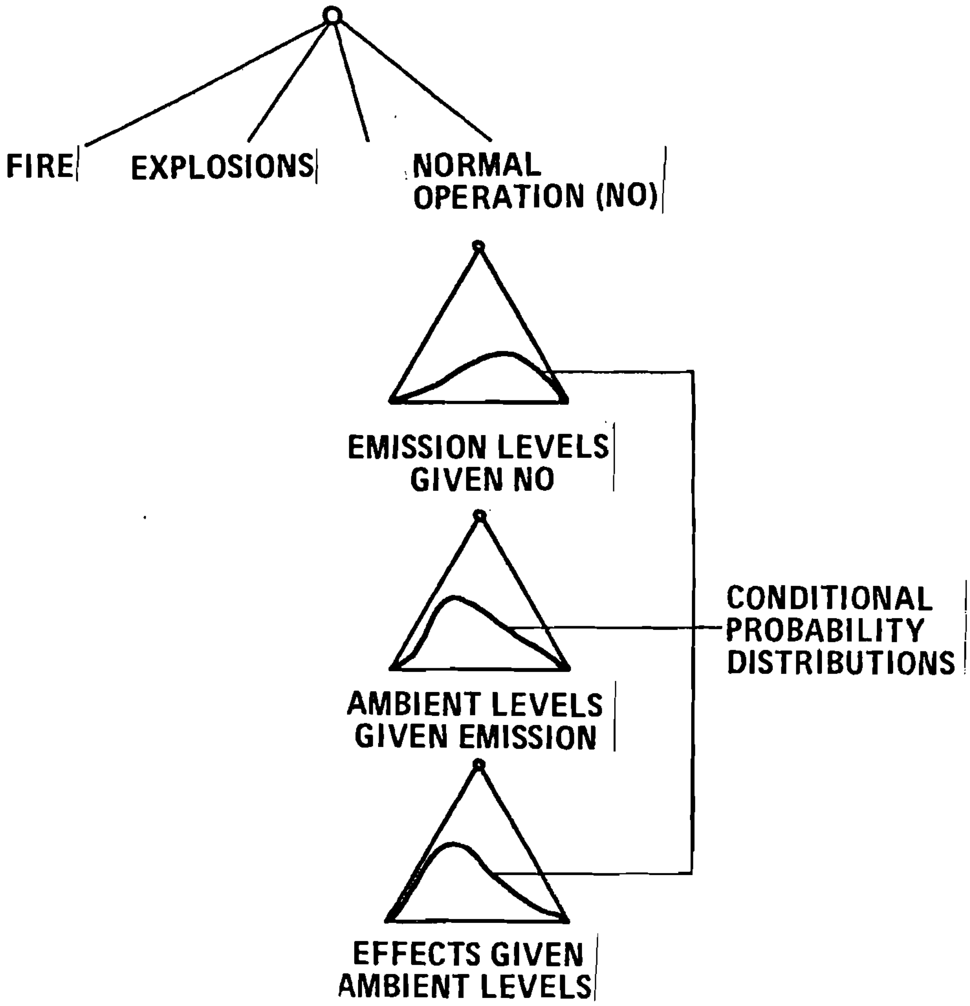


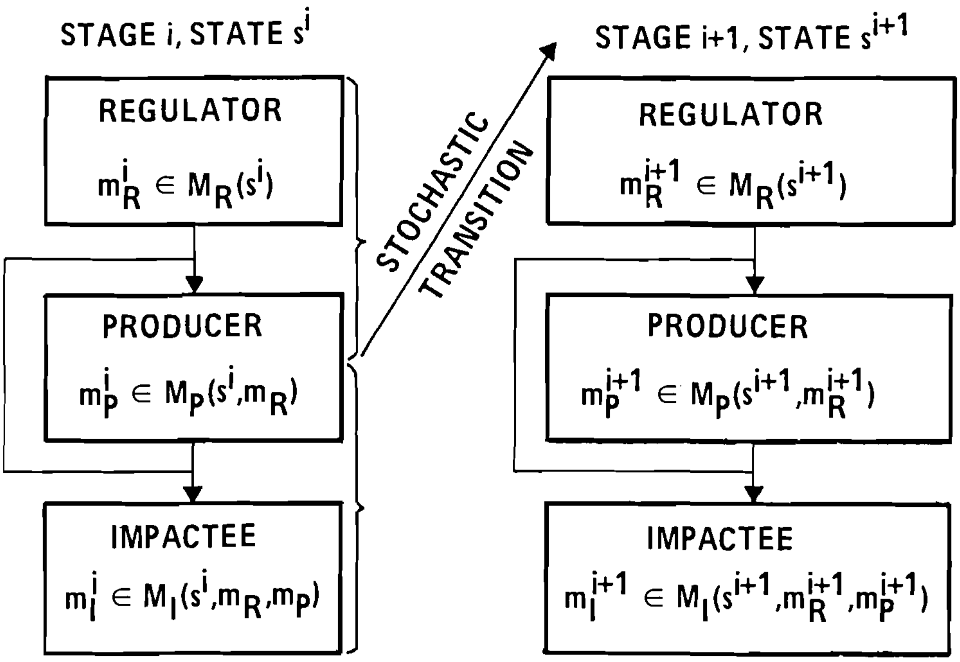
Figure 13. Segment of an event tree for pollution generating effects and events.

was our aim to include the conflict situation between the groups involved. Hence for an extension of the model we primarily have to choose among simulation, gaming, and game theory.

Simulation could be applied if we had a complete model of the consequences of actions and if we prescribed the behavior or the strategies of the groups. Then the consequences are determined usually by programming. There are two reasons why this approach is difficult to deal with. First, it takes a large computational effort to obtain an appropriate standard setting procedure. Second, the behavior of the groups involved would be completely hypothetical. The last problem could be avoided by gaming where players choose actions. The players can be experimental subjects and observers such that the development of the basic real life problem could be predicted and perhaps an "optimal" standard setting procedure extracted. The main objection against these approaches is that they consume substantial time and money.

Contrary to simulation and gaming, game theory yields goal-oriented decision making processes of all groups involved. It is based on the assumptions that each individual has a utility function which he strives to maximize, and that each individual is able to perceive the game situation. We established a dynamic game theoretic framework (see Höpfinger and Avenhaus, 1978, TR-8) for the conflict situation in environmental decisions. As in the decision theoretic model, three decision units are considered: the regulator, producer, and the impactee unit. The regulator may consist of various administrative units and experts that interact to fix a standard. This standard generally reduces the gain of the producer representing, for example, several energy producers emitting pollutants. By means of this standard the impactee representing the population affected by the pollution has to be protected. It is hoped that the model is general enough to treat some essential features of most problems of standard setting. Furthermore, it should permit parameter analysis such that crucial uncertainties about health effect and economic development can be identified.

The models developed are three person games in extensive form with a structure shown in Figure 14. Only time periods or stages are considered instead of a time continuum. Thus a game is played at each stage and the players' choices control not only the payoff but also the transition probability governing the game to be played at the next stage. Since the transition probabilities are often not exactly known we admit that for the players' subjective transition probabilities exist which may differ from one another. Contrary to the more usual games where players make simultaneous and independent choices, we have provided for perfect information for the component game by introducing the following structure. At each stage, first the regulator makes his choice, then the producer is informed about it and makes his choice, and finally the impactee makes his



$M_R(s^i)$: Set of regulator's choices at stage i

$M_P(s^i, m_R)$: Set of producer's choices at stage i, given $m_R^i \in M_R$

$M_I(s^i, m_R, m_P)$: Set of impactee's choices at stage i, given $m_R^i \in M_R$ and $m_P^i \in M_P$.

Figure 14. Structure of the dynamic game theoretic model.

decision, knowing the regulator's and the producer's choices. The utilities are assumed to be the discounted sums of the payoffs of the utilities of the component games. In order to keep the computational burden within limits, only stationary strategies have been admitted. No unique game theoretic solution was worked out, but several possible solutions were considered in the applications.

The range of applications has been indicated by the cases of North Sea oil, sulphur dioxide, carbon dioxide, and noise (see Höpfinger and Avenhaus, 1978, TR-8). Only the cases of carbon dioxide and noise could be treated as multistage games due to shortage of time. In the first case, essentially all solution concepts were used.

A final judgment of the value of this game theoretic framework for dynamic standard setting procedures would require the treatment of a variety of problems. But some conclusions can already be drawn. First, the game theoretic model allows the derivation of "optimal" standard setting procedures where optimal relates to a special solution concept. Which solution concept is to be used depends on whether the regulator wants to exert his power of announcement or whether he agrees to "fair" comparison of utilities, which in the case of carbon dioxide results in strategies based on the most cautious estimate of the critical level, otherwise the regulator's estimate dominates. Furthermore, the critical parameters can be identified. As demonstrated for the noise case, juridical procedures can be formalized within this framework at least in such a way that a court sentence is represented by a transition from one state to another. Since the representation of the population as a rational player is not self-evident, one could alternatively want to represent it as a response function based on the population's perception of pollution and perhaps of the regulator's choices. Indeed, the impactee's strategy relating to a solution can be taken as such a response function.

Although in some cases, for example, if multilateral problems are treated, extensions of the model can be appropriate, it seems that there are basic features of the pollution problem, the structuring of which would specialize the framework much more and thus render it much more powerful. For example, one could specify the monitoring and surveillance aspect to determine whether the producer operates within the standard.

MODEL APPLICATIONS

Application of the Decision Model to Chronic Oil Discharge Standards

The decision theoretic model summarized in the section, "Purpose and Structure of Models" and developed in detail in v. Winterfeldt (1978, TR-9) was applied to the problem of chronic oil discharge standards in the North Sea. The purpose of this application was mainly a feasibility test of the model itself. As it turned out, however, some major lessons could already be learned from the model, which may have impacts on the decision making of the regulatory agencies in Norway and the United Kingdom. The model reflects the real standard setting situation in the United Kingdom. The decision unit which the model was to relate to for decision aiding purposes was the Petroleum Production Division in the Department of Energy which has the regulation responsibility for chronic oil discharges.

Table 3 presents the major model inputs from the policy analysis described in the section, "The Chronic Oil Discharge Study".

The regulatory alternatives were first formalized by the set of possible standard levels of oil concentration in the effluent, labeled SL:

$$SL = \{s\ell \mid 0 \leqslant s\ell \leqslant \infty\}$$

Standard sanctions were thought to have the following form:

$$SS = \begin{cases} 0 & \text{if no detection occurs;} \\ K_0 + C(d_{j+1}) - C(d_j) & \text{if detection occurs;} \end{cases}$$

where K_0 is a fixed penalty, $C(d_j)$ is the cost of treatment j, and $C(d_{j+1})$ is the cost of the next best treatment. The total penalty was then defined as a fixed amount plus the cost of improving treatment from d_j to d_{j+1}, which was assumed to be just the difference in cost between the two treatments. The following monitoring, inspection, and sampling definitions SM were analyzed:

<u>The United Kingdom's definition of a maximum standard (UK-MAX)</u>

Two samples are taken on every day. During any one month not more than two samples (no averaging) may exceed the standard sl.

<u>EPA's definition of an average standard (EPA-AV)</u>

The daily average of four samples may not exceed the standard sl more often than twice during any one month.

Table 3 QUALITATIVE MODEL INPUTS

	DECISION UNIT	ALTERNATIVES	OBJECTIVES	EXTERNAL EVENTS
REGULATOR	Petroleum Production Division, UK	1. Standard Level 2. Sanctions 3. Sample size, exemptions, inspection procedure	1. Agree with standards of other nations 2. Satisfy international demands for a clean North Sea 3. Agree with national energy policy 4. Agree with national environment policy	None considered
DEVELOPER	Offshore Oil Operators	1. No treatment 2. Simple Gravity Tank 3. Corrugated Plate Interceptor (CPI) 4. CPI and Gas Flotation 5. CPI, GF, and Filters 6. CPI, GF, F, and Biological treatment 7. Reinjection of oily water into empty reservoir	1. Minimise investment cost for treatment 2. Minimise operation cost for treatment 3. Minimise penalties due to regulation violation	Detection vs. Non-detection of standards violation
IMPACTEE	Fishermen Ecologists Public	No actions considered, viewed as "sufferers"	1. Minimise mortality of commercial marine organisms 2. Minimise tainting and chronic toxicity of fish and other marine organisms 3. Minimise ecological disturbances	Random Pollution Levels

The Norwegian definition of an average standard (NWY-AV)

The daily average of continuous monitoring may not exceed the standard sl more often than once during any one month.

United Kingdom's definition of an average standard (UK-AV)

The monthly average of two daily samples may not exceed the standard sl more often than once during the lifetime of the plant.

A standard r is therefore described as the triple (sl, sm, ss). The utility function U_R was defined as an aggregate of four utility functions v_{Ri} which expressed the degree to which the four regulatory objectives in Table 6 are met as a function of sl. The aggregate is a simple weighted additive function of the form:

$$U_R(sl) = w_{R1} \cdot 100 \cdot e^{-\frac{(sl-30)^2}{144}} + w_{R2} - 100 \cdot e^{-.014 \cdot sl} +$$

$$+ w_{R3} \cdot (100 - 100\, e^{-.014 \cdot sl}) + w_{R4} \cdot 100 \cdot e^{-\frac{(sl-40)^2}{577}} .$$

Figure 15 shows the shape of the regulator's utility function $U_R(sl)$ for two different weighting schemes: a unit weighting scheme in which all $w_{Ri} = .25$, and a differential weighting scheme which seems to reflect the United Kingdom's priorities among the three objectives.

The developer's alternatives are listed in Table 4 together with approximate investment and operations cost. Total costs were calculated on the basis of a 15 year lifetime of the production platform and undiscounted operations costs. The alternatives d_j are ranked in increasing order of cost and effectiveness. The developer's decision depends crucially on whether his treatment may lead to a detection of a violation or not. Table 5 presents the developer's decision problem in the form of a payoff matrix. In case of no detection the developer just pays the cost of treatment. In the case of detection he pays the cost of treatment, plus a penalty K_0, plus an incremental cost to improve treatment to the next best level, which just adds to the cost of the next best treatment.

The probability of detection (labeled Q_1) depends on the choice of treatment d_j, the standard level sl, and the definition of the inspection and monitoring procedure sm (UK-MAX, EPA-AV, UK-AV, NWY-AV). The utility function of the developer

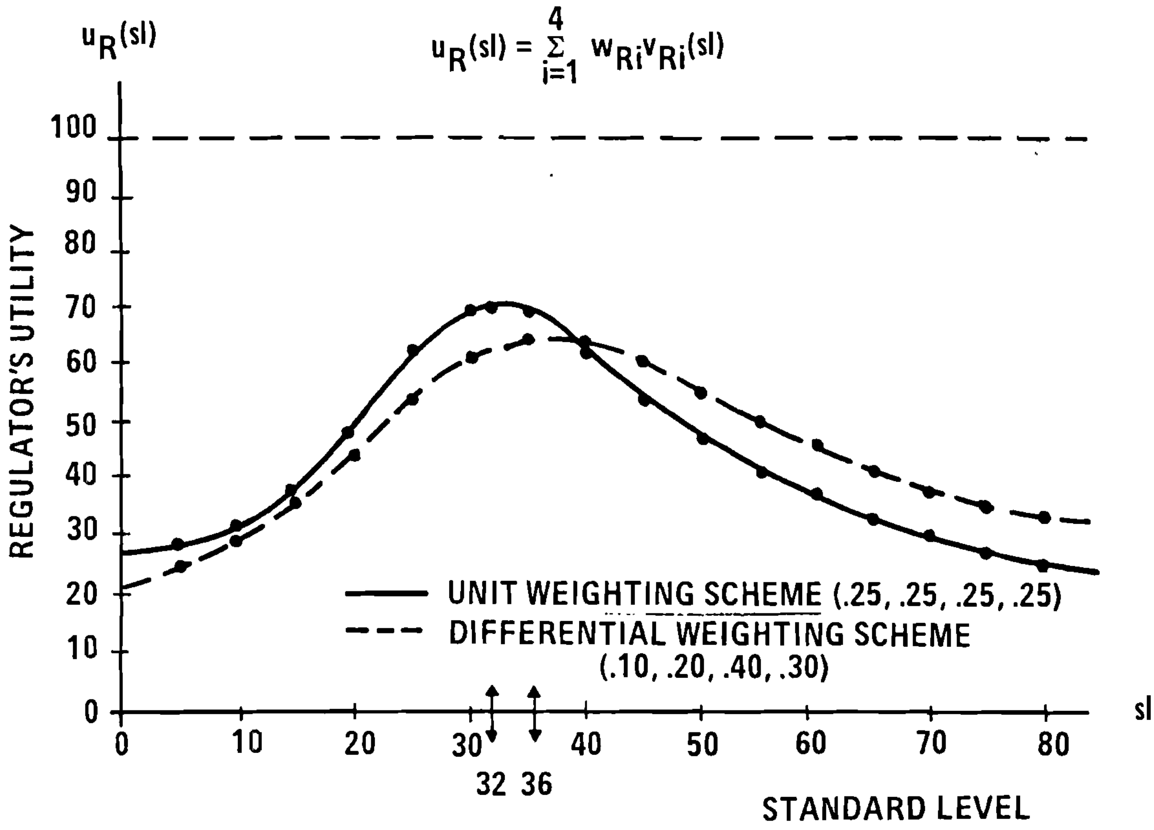


Figure 15. Overall value function of the regulator for two weighting schemes.

Table 4

ILLUSTRATIVE COST ESTIMATES FOR DEVELOPER'S TREATMENT OPTIONS

(10^3 Pound Sterling); 1978

	Installation	Operation/ year	C_{D1} Total (no disc.)
d_1 (no treatment)	0	0	0
d_2 (gravity tank)	0	3	45
d_3 (corr. plate int.)	70*	5	145
d_4 (CPI + Gas Flotation)	140**	10**	290
d_5 (CPI + GF + Filtering)	200	15	425
d_6 (CPI + GF + F + Bio)	500	50	1250
d_7 (reinjection)	2100***	115***	3825

* Source: CUEP[9]

** Source: Manufacturer's data

***Source: NAS[10]

All other data are rough estimates.

Table 5

PAYOFF MATRIX FOR THE DEVELOPER

(entries in 10^3 Pounds)

	DETECTION STATES	
	NO DETECTION (Q_0)	DETECTION (Q_1)
d_1	0	45 + K_0
d_2	45	145 + K_0
d_3	145	290 + K_0
d_4	290	425 + K_0
d_5	425	1250 + K_0
d_6	1250	3825 + K_0
d_7	3825	-*

* No detection is possible for d_7.

is defined as the negative expected cost:

$$U_D(d_j,r) = -p_D(Q_0|d_j,sl,sm)\cdot C(d_j) -$$

$$-p_D(Q_1|d_j,sl,sm)\cdot[C(d_{j+1}) + K_0],$$

where $p_D(Q_0)$ and $p_D(Q_1)$ are the probabilities of detection and non-detection, respectively. The objective of the developer is to maximize $U_D(d_j,r)$ with respect to $j = 1,2,...7$, given $r = (sl, sm, ss)$.

Probabilities of detection versus non-detection were modeled using treatment performance estimates, rough estimates of the probability distributions over the average treatment performance, and the respective monitoring and inspection procedures defined above. All distributions involved were assumed to be normal. Given costs and probabilities, optimal decisions of the developer could be determined together with their associated expected costs. Figure 16 gives a typical result of this analysis. It shows that the developer selects constant treatment decisions within certain ranges of the possible standard value. The cutoff points are those at which the cost of the next best treatment is just equal to the expected cost of detection.

Table 6 demonstrates the most important result of the analysis: the sensitivity of the cutoff points to different monitoring and inspection definitions. As can clearly be seen, the cutoff points at which the developer would change from d_j to d_{j+1} depend critically on the definition of detection. The UK-MAX definition forces the developer to respond most conservatively to a given standard, while the UK-AV definition leaves him the greatest freedom. For example, for the UK-AV definition, the developer would switch from CPI to gas flotation only if the standard is lower than 62 ppm. For the UK-MAX definition, this switch would already occur at 78 ppm. One would expect K_0 to also have a strong influence on the cutoff level. However, varying K_0 between 10,000, 100,000, and 1,000,000 Pounds did not have nearly the effect as varying the monitoring and inspection procedure. Also, using nonlinear utility functions for money did not have a substantial impact on the cutoff points.

The impactee model is very simple. The random emission level is assumed to be a proxy measure for the degree to which the impactees objectives are met. The value function is defined simply as the negative emission level. Since the impactees themselves have no action alternatives, the expected value can be calculated from the performance characteristics of the equipments as follows:

$$U_A(d_j) = -\bar{\ell}_j .$$

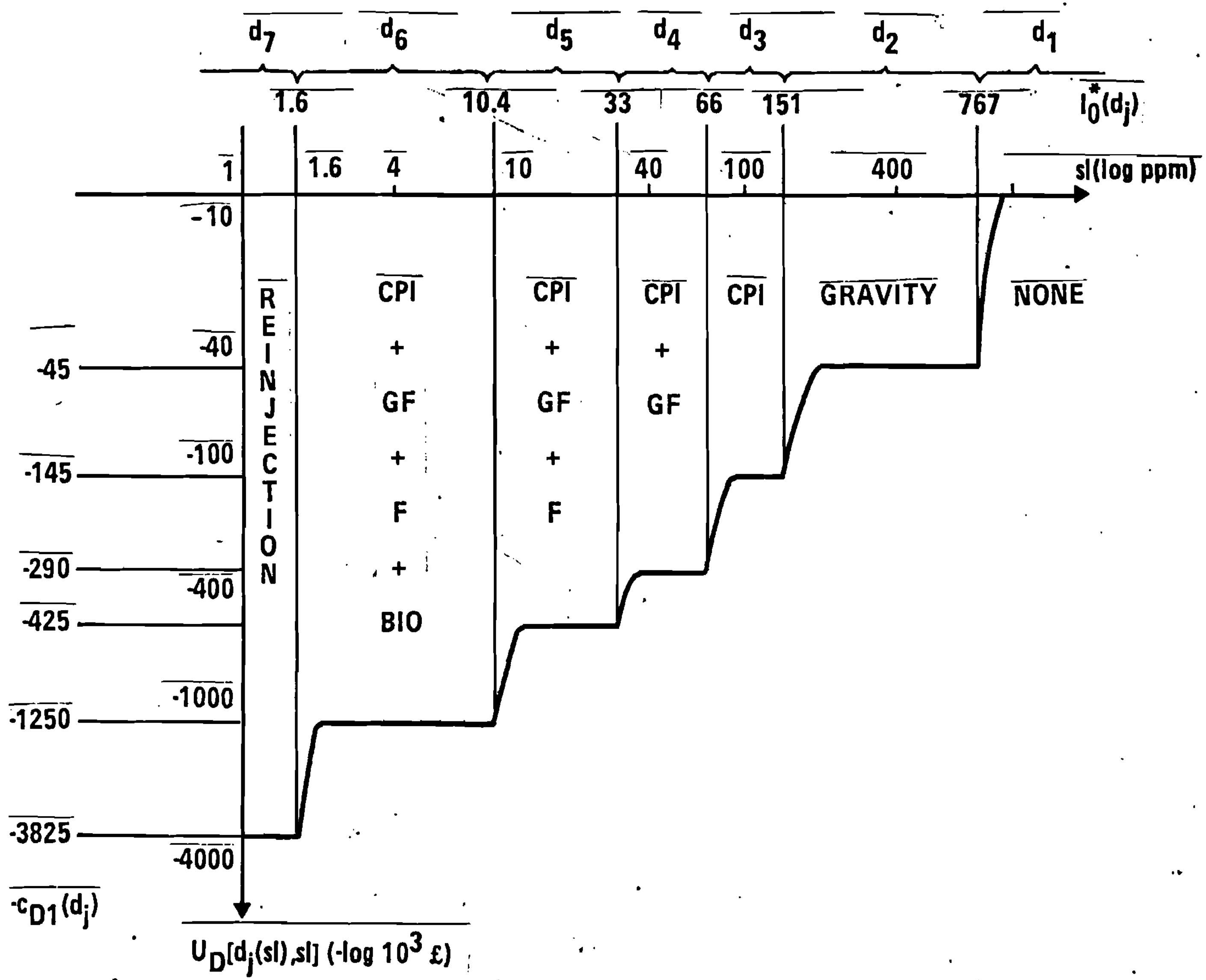


Figure 16. Optimal decisions $d_j(sl)$ and expected value U_D as a function of the standard sl (K_0 = 100 000, EPA-AV).

Table 6

CUTOFF LEVELS $l_0^*(d_j)$ AT WHICH THE DEVELOPER WOULD SWITCH FROM TREATMENT d_j TO TREATMENT d_{j+1} (FOR K_0 = 100 000)

	MONITORING AND INSPECTION PROCEDURE			
	UK-MAX	EPA-AV	NWY-AV	UK-AV
d_1 (none)	872	767	785	754
d_2 (gravity)	172	151	155	147
d_3 (CPI)	78	66	64	62
d_4 (CPI,GF)	38	34	34	32
d_5 (CPI,GF,F)	13.7	10.4	10.1	9.1
d_6 (CPI,GF,F,B)	2.1	1.6	1.5	1.4
d_7 (reinject)	-	-	-	-

Table 7 is an example of the final results of the analysis. For the purpose of constructing this table the utility functions of the three decision making units were standardized to cover similar ranges. The most interesting result is that there are several dominated standards, i.e., standards that are not better than others for any decision maker and worse for at least one. For example, the 50 ppm standard leads to utilities of 48 for the regulator, 28 for the developer, and 80 for the impactees. However, the 40 ppm standard results in the same decision of the developer, and thus the same utilities for the developer and impactees, while the regulator's utility increases to 62. In this case the 50 ppm standard would be considered dominated by that of 40 ppm. The model would suggest to eliminate it from further consideration.

The reason for this dominance effect lies in the fact that the developer responds to a continuous decision of the regulator by a discrete response, and that the impactees' utilities depend only on this discrete response. Within most of the range between two cutoff points (see Figure 13) the utility of the developer does not change* and begins to decrease only when the next cutoff point is approached.

The most important results of this illustrative model run can be summarized as follows:

- As long as the developer's response to standards is discrete and the impactees are considered sufferers, there will be many dominated standards, where dominance is dictated largely by the regulator's utility function.

- The nondominated standards tend to cluster around cutoff points at which the expected cost of treatment plus penalty is just equal to the expected cost of the next treatment. Thus the regulator's attention should be on the location of such cutoff points.

- The location of these cutoff points is controlled largely by the uncertainty about equipment performance, and the definition of the monitoring and inspection procedures (sample size, exemptions from detection, etc.).

- Penalty variations and nonlinear utility function do not have a strong effect on cutoff points.

---

*Strictly speaking this is not true, since there are, of course, small changes in the utility function even at values slightly below a cutoff point. However, for all practical purposes these decreases can be neglected. The actual dominance analysis neglected decreases of less than 100 pound sterling.

Table 7

UTILITIES OF REGULATOR, DEVELOPER, AND IMPACTEES AS A FUNCTION OF THE STANDARD sl

(K_0 = 100 000 , EPA-AV scheme, unit weights w_{Ri})

sl	d_j(sl)	U_R(sl)	$U_D[d_j$(sl)]	$U_A(d_j)$
0	d_7	26	-856	100
1	d_7	26.5	-856	100
2	d_6	27	-213	99
5	d_6	29	-213	99
10	d_6	30	-213	99
15	d_5	38	- 6	95
20	d_5	48	- 6	95
35	d_4	65	28	80
40	d_4	62	28	80
50	d_4	48	28	80
100	d_3	28	64	50
150	d_3	26	64	50
500	d_2	25	89	0
1000	d_1	25	100	-400

- Because of the influence of the monitoring and inspection procedure a standard is not equal to a standard. Standards with the same numerical value but with different monitoring and inspection procedures will be either stricter or less strict. For example, everything else being equal, a standard based on an average of four samples will be stricter than a standard based on an average of 100 samples or on continuous monitoring.

Based on this illustrative model analysis it is not possible to make a firm recommendation about standards. In particular, no attempt has been made to tackle the important question of modeling the ecological consequences of chronic oil pollution. Also, the regulator model is still rather crude. However, the model did demonstrate the importance of equipment uncertainty on the developer's decision making, thus confirming the qualitative concern the oil industry has about such uncertainties. Since standards are inherently statistical definitions, it may be important to pursue more a refined statistical analysis of the consequences of standard setting decisions.

Application of the Game Theoretic Model to Noise and CO_2 Standards

Application to Shinkansen Noise

The problem of Shinkansen noise pollution was described in the section, "The Shinkansen Noise Standard Study". In this section we will briefly outline the game theoretic application to the noise standard setting problem. We consider the following players from the policy analysis:

- regulator: Environment Agency;
- developer: Japanese National Railway Corporation;
- impactee: residents along the line.

Component states considered are:

- maximum quantity of noise near the railway line;
- location of population near the line;
- layout of soundwalls and other noise protection measures;
- upper bound of train speed.

The following choices of the three players are considered:

- The regulator sets a maximum level of speed or noise;
- The developer builds sound walls, reduces speed, dislocates or compensates residents;
- The impactees file complaints or petitions, organize themselves, or take legal action.

Consequences or costs and benefits are specified as:

- increased or decreased GNP;
- dislocation of neighbors;
- psychological, or health effects.

The states of the game are a subset of

$$\{(L,i) \mid \underline{n} \leq L \leq \bar{n}, i=1,2,\ldots 7)\}$$

where L denotes an upper bound for an admitted noise level, $\bar{n}$ the maximum level of noise produced by the train operated under economic conditions, $\underline{n}$ the minimum value of noise under which the train can run under economic conditions. (L,1) is the first state after construction of the railway line. Hence $(L,1) = (\bar{n},1)$. State (L,2) indicates that a petition has taken place. (L,3) states that the population affected by noise has built up an organization for negotiations with the government in order to arrive at a low noise standard. If negotiations fail, the impactee can start a law suit. This is indicated by (L,4). (L,4) can be followed by states of type (L,5), (L,6), or (L,7). (L,5) means that a permanent compromise is reached with the upper noise bound L. (L,6) means that the law suit is decided in a neutral or positive way for JNR and government. (L,7) means that the law suit is decided in favor of the impactee. (L,5), (L,6), and (L,7) are the final absorbing states. The relationships between these states and the transition probabilities are represented in Figure 17.

Transition probabilities are considered parameters in the game. They depend on the noise level n_I which the impactees consider acceptable in relation to the actual noise level n, and the possible standards l. Utility functions of the regulator and the producer are defined as follows:

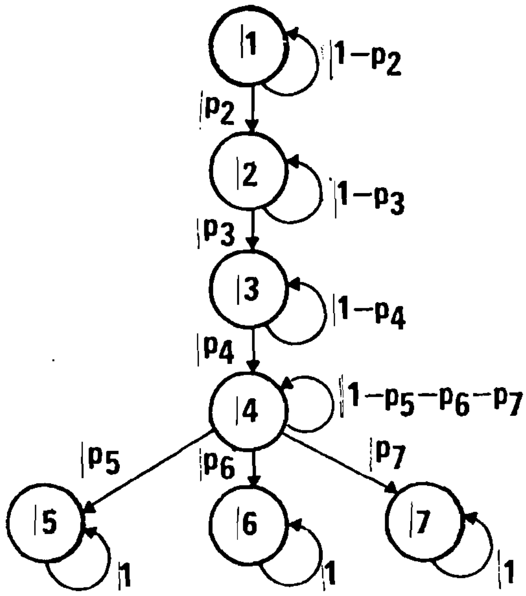


Figure 17. Schematic representation of stages and transition probabilities in the noise model.

$U_R: \; [\underline{n}, \bar{n}] \to \mathbb{R}$

$U_D: \; [\underline{n}, \bar{n}] \to \mathbb{R}$

where U_R is assumed to be unimodel with a peak at $\underline{n} \leq L^+ \leq \bar{n}$, and U_D is assumed to be strictly increasing in the noise level n. Since reductions of the noise level are costly, this form of the utility functions of the producer seems reasonable in many cases where continuous alternatives for noise pollution abatement exist. The single-peaked nature of the regulator utility function was motivated by the assumption that the regulator attempts to balance conflicting environmental, economic, and political objectives. The impactee was modeled as a response function, thus no utility function is considered.

For state i=7, i.e. the state in which impactees win the law suit (the noise level has to be reduced to $n=n_I$), the regulator's and the producer's utility functions become:

$$U_j(n_I, 7, \ell, n) = u_j(n) + c_j \qquad j=R,P \quad ,$$

where c_j reflects the additional costs the regulator and the producer incur as a result of the lost law suit. Given discounting factors $p_j \leq 1$, j=R,P, solutions for this game can be obtained through dynamic programing. Höpfinger and v. Winterfeldt (1978, TR-11) provided some such results for the hierarchical solution concepts assuming special forms of c_j, the costs of losing a law suit. Results include that the actions of the regulator depend crucially on the location of the preferred noise levels n_I and L^+ of the regulator and the impactee, respectively. Also the solutions of the game for the regulator depend heavily on the probability p_7 of losing a law suit.

Applications to CO_2

The dynamic game theoretic model for CO_2 standard setting is based on the assumption that a continuous increase of CO_2 in the atmosphere, caused by fossil fuel burning, will lead to irreversible and large changes of the climate of the earth if an *unknown* critical level of CO_2 is exceeded. The regulator is assumed to be an international agency, and the producer the group of CO_2 emittors. The states of the game are characterized by:

$$\{(C,L) \mid C_p \geq C \geq 0, \quad L \geq 0\} \cup \{k \geq 0\} \quad ,$$

where

> C is the amount of carbon dioxide in the atmosphere;
>
> L is the upper bound of emissions of CO_2 during a period;
>
> C_p is the maximal amount of all fossil fuel burnt;
>
> k is the critical value for the catastrophe.

k is considered a parameter since its precise value is not known. Let (C^1,L^1) denote the first state. C^1 can be assigned the present amount of atmospheric carbon dioxide, and L^1 the present maximal emission of CO_2. At each of the following stages, a component game of perfect information is played which is completely specified by a state. The player's choices control not only the payoffs, but also the transition probabilities governing the game to be played at the next stage. Each player has his own subjective estimate of the transition probability due to his subjective probability of the true critical value.

The perfect information of the component game is specified as follows: For state (C,L) the regulator's set of choices is

$$M_R(C,L)=\{\ell \mid 0\leqslant\ell\leqslant L\}$$

where ℓ denotes the upper bound (standard) for the emission of carbon dioxide by the producer. Then the producer chooses the amount a of carbon dioxide to be emitted. His set of choices is specified as

$$M(C,L,\ell)=\{a \mid 0\leqslant a\leqslant \ell\}$$

The impactee's set of measures is

$$M_I(C,L,\ell,a) = \{p \mid 0\leqslant p\leqslant 1\}$$

where p is an index of the pressure the impactee can exert on the regulator knowing the choices a and ℓ. p can denote the probability of a vote against the government or some other action against governmental institutions.

The set of measures in the case of a catastrophe, i.e. if the amount of carbon dioxide exceeds k, is defined by zero standard, no production, and no pressure:

$M_R(k) = \{0\}$

$M_P(k,o) = \{0\}$

$M_I(k,0,0) = \{0\}$

A physical transition model links the changes in carbon dioxide amounts in the atmosphere between stages to the actions of the regulator, the producer, and the impactee. Given state (C,L) and the choices (ℓ,a,p), the following states are possible:

$$(C+\beta a, L),\ (C+\beta a, \frac{L}{2}),\ \{k \geqslant C\}\ ;\ 0 \leqslant \beta \leqslant 1$$

The first component of the first and second states indicates that a constant share a of emitted carbon dioxide is added to the amount of atmospheric carbon dioxide. This is consistent with results of box models for the CO_2 cycle of the earth (see Avenhaus, et al., 1978), if a is emitted during the period at a constant rate. The estimates for β range from between 0.01 and 0.5. The amount $(1-\beta)a$ is assumed to disappear into the biosphere, upper mixed layers of the sea, and the deep sea. The second components express that either the old upper bound remains or is reduced by a factor of two. It is assumed that there is a probability pv that L is replaced by $\frac{L}{2}$, where $o \leqslant v \leqslant 1$ is a parameter, provided that the catastrophe will not occur. $k \leqslant C$ denotes the amount of carbon dioxide for which the catastrophe occurs.

All three players are assumed to have subjective probabilities about the critical amount k of carbon dioxide. They characterize the transition probabilities. To simplify the model the assumption is made that the subjective probabilities concentrate at points denoted C_R, C_P, and C_I for the regulator, producer, and impactee respectively. The model assumes that $C_R \leqslant C_P$ and $C_I \leqslant C_P$, thus allowing the producer to neglect a possible catastrophe. By making a series of assumptions about the form of the transition probabilities and the utility functions of the three players, and by assuming that the total utility accruing to each player is the undiscounted sum of the component state utilities, several solutions for the game could be derived.

The game has a large number of equilibrium points, three of which are specified as follows:

Let σ_R, σ_P, σ_I belong to the respective sets of choices M_R, M_P, M_I. Then the following three solutions are equilibrium points:

Solution 1: $\sigma_R^1(C,L) := \min[L, \max(0, \frac{C_R - C}{\beta})]$

$\sigma_P^1(C,L,\ell) := \ell$

$\sigma_I^1(C,L,\ell,a) := 0$

Solution 2: $\sigma_R^2(C,L) := \min[L, \max(0, \frac{C_I - C}{\beta})]$

$\sigma_P^2(C,L,\ell) := \ell$

$$\sigma_I^2(C,L,\ell,a) := \begin{cases} 0 \text{ if } \ell = \min(L, \frac{C_I - C}{\beta}) \text{ and } C \leq C_I \\ 1 \text{ if } \ell \neq \min(L, \frac{C_I - C}{\beta}) \text{ or } C > C_I \end{cases}$$

Solution 3: $\sigma_R^3(C,L) = 0$

$\sigma_P^3(C,L,\ell) = 0$

$$\sigma_I^3(C,L,\ell,a) = \begin{cases} 0 \text{ if } \ell = 0 \text{ and } C = C^1 \\ 1 \text{ if } \ell > 0 \text{ or } C > C^1 \end{cases}$$

Furthermore, it can be shown that only the first and the second solutions are Pareto optimal. Figures 18 and 19 illustrate these results in the regulator-impactee payoff plane. Final choices of the regulator may thus depend on the relationship between C_I and C_R or, respectively, on the relative distance of the Pareto optimal equilibrium points from the point of maximal payoff (which itself cannot be achieved). For example, in Figure 18, the regulator may wish to choose a strategy leading to equilibrium point 1, in the case of Figure 19 he may choose equilibrium point 2. These solutions would correspond to bliss optimal and Nash solutions. The hierarchical solution (in concept similar to the one of the decision theoretic model) would in contrast always lead to the first equilibrium point which is based on the estimate C_R as the critical value.

CONCLUSIONS

The intentions of the research on Procedures for the Establishment of Standards described above were:

- to analyze existing procedures for standard setting;
- to develop new formal tools to aid regulatory agencies in standard setting tasks.

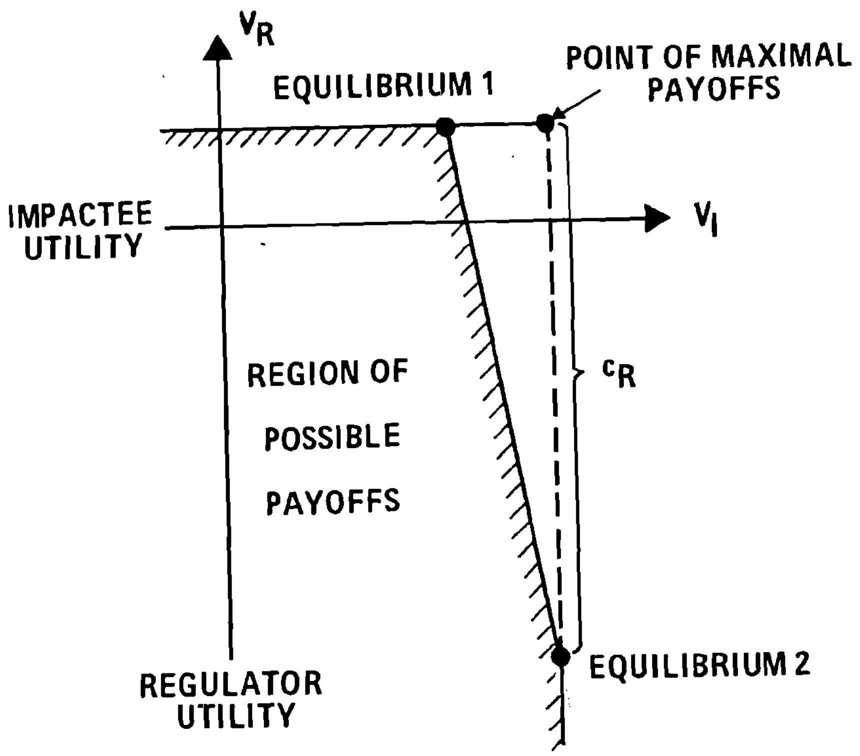


Figure 18. Payoff diagram for regulator and impacter ($C_R < C_I$).

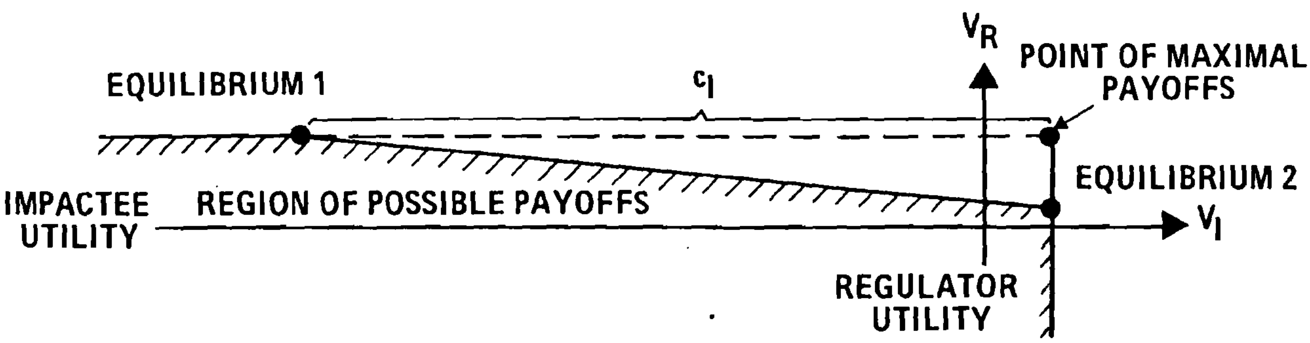


Figure 19. Payoff diagram for regulator and impactee ($C_R > C_I$).

Clearly two years of research in a more or less unexplored field with a mixed multidisciplinary and international team could not be expected to provide ultimate answers to the most pressing question of regulatory agencies: What should be done to improve regulatory standard setting procedures? But although we cannot yet provide a catalog of principles and procedures to improve standard setting, our research did identify problem areas that have priority, it showed the feasibility and limits of some new formal approaches, and it pointed out where improvement in standard setting is needed and how this could be achieved through formal analysis.

In this concluding section, we will first discuss what we consider the most urgent problems of environmental standard setting. Secondly, we will discuss the feasibility of analytical approaches such as policy analysis, decision theory, and game theory to overcome some of these problems. Finally, we will present some recommendations to regulatory agencies and researchers in the environmental field for improving standard setting procedures. Most of these conclusions were elaborated and consolidated in a review workshop on environmental standard setting held at IIASA in which representatives from regulatory agencies, industry, and environmental research institutes discussed the work presented in the previous sections (see also Appendix 3).

The literature review, the policy analyses, the discussions with regulators and environmental researchers provided us with a good understanding of how standard setting is done at the present time, and where the main problem areas lie. *Uncertainty* emerged as the main obstacle to regulatory decision making. Regulatory agencies and standard setters have to make decisions based on the information available, and this information is always limited, often conflicting in terms of data or interpretation, sometimes of relatively poor quality, and seldom presented in a format suitable for the practical tasks of standard setting. The piles of background research material usually collected to backup standard setting decisions, give an idea of how difficult it is for a regulatory decision maker to aggregate and evaluate the information pertinent to the decision problem.

Regulators find the problem of evaluating research most pressing. The questions they continually have to ask themselves in guiding, collecting, and evaluating research for a particular standard setting problem are: Which uncertainties are we willing to live with when making a decision? Which information should be collected to reduce unacceptable uncertainties? Who should carry out the work? How should the outcome of such research be evaluated? Another problem area is that of summarizing information of expert reports in a format amenable to the decision problem at hand. Summaries such as "...on the basis of available scientific data, no firm conclusions about the potential health effects of pollutant XY..." are not uncommon but rarely useful. Rather than drawing attention to potential risks and hazards and presenting at least ranges and best estimates which could enter the standard setting decision, such vague statements tend to draw the attention of the regulator to the more tangible (engineering and cost) considerations of the decision problem, thus changing the balance of the arguments. Part of this problem of summarizing information into a decision relevant format is the problem of quantifying uncertainties and effects. Although it has to be acknowledged that not every effect or not every uncertainty is quantifiable, there appears to be by far too little quantification in standard setting. Much could be improved by procedures for expert probability assessment and relative scaling methods used in decision and measurement theories. In the area of risk and safety standards, which this study only touched upon, the problem of assessing low probabilities and weighing them against disastrous consequences poses many additional problems as the nuclear or carbon dioxide cases demonstrate. Here the problem arises what to do if information can not be gathered in an incremental or experimental way. In such decisions new procedures for collecting and processing expert judgments have to be developed.

There are many more specific practical problems in the area of uncertainty in environmental standard setting, some of which have been discussed earlier:

- the problem of conflicting assumptions, data, and interpretations;

- the problems of uncertainties in the chain of emissions, ambient pollution levels, and ultimate pollution effects;

- the problem of uncertainties about synergistic effects of pollutants;

- the problem of uncertain responses of industry, impactees, and courts to regulations.

The second important problem area is that of *conflicting objectives, values, and interests* of the groups involved and affected by pollution and regulation. Some of the problems of conflict mentioned by regulators and environmental researchers relate to the methodology of coping with conflict situations and the possible institutional and formal approaches to conflict resolution, for example:

- how to express uncertainties and intangibles in a form that allows communication between conflicting decision groups;

- how to trade-off cost, performance, and effectiveness of pollution abatement technology and regulation alternatives;

- how to take into account political objectives in environmental decision making;
- how to achieve equity among the different groups affected by regulation.

While these problems can to some degree be attacked by formal tools (for example, cost-benefit analysis, decision theory and game theory), most regulators seem to place the real problem of conflict into the institutional mechanisms, which are often badly equipped to solve societal conflicts in standard setting.

The statutory framework, international regulations, and pressure group actions appear to be major constraints on regulatory decision making. Regulators have to rely nearly as much on their legal staff in drawing up regulations as they do on scientific experts. This seems to be true at least in the United States, and probably is for most Western societies. The courts are considered by some a proving ground for regulation, by others they are perceived as shadow regulators. But if it is the regulator's task to solve environment-development conflicts, the additional function of the courts becomes questionable. Or should it be the court's role to mediate between environment-development conflicts directly? In this case regulatory agencies would be reduced to merely provide the groundwork for the court's decision. Who, however, is better equipped to achieve the task of conflict resolution? Some researchers (for example, National Academy of Sciences, 1975) clearly place the main decision responsibility into the regulator's hand and ask for a revision of the statutory framework. Others ask for special courts, for example, science courts. Still others ask for improved conflict resolution mechanisms within the regulatory decision making process, for instance through public participation. In any case, as of now regulatory representatives regard themselves still far away from any satisfactory institutional solution to the conflict problem in regulatory decision making.

The methodological contribution of our research on standard setting procedures was mainly the development of a policy analysis approach, and decision and game theoretic models. Each of these approaches proved valuable in the analysis of the specific standard setting cases. Each of them also had its specific limitations. The strength of the policy analysis approach included:

- It takes a broadly oriented view of the standard setting problem and thus avoids an early restriction to specific solution;
- It forces the analyst (and the regulator) to span a wide range of actors, alternatives, and objectives for achieving regulatory goals;

- It provides a structure to the environmental standard setting problem;

- It can point to possible gaps, oversights, and weaknesses in the information collection and evaluation task performed by the regulator.

On the other hand, we have to acknowledge certain limits and weaknesses of the policy analysis approach:

- The analysis provides a purely qualitative picture of the standard setting problem;

- The data base and the evaluation principles are "soft", and are open to possible biases and misconceptions of the analyst;

- It is a methodology for problem identification rather than for problem solving.

However, if one keeps in mind these weaknesses, the policy analysis approach may provide a good tool for a pre-analysis of the standard setting problem. It could be used to review the status quo of the regulation situation, before the actual "hard" research part begins. It can help the regulator to structure the problem in a common language, to identify information needs, and to increase his awareness of groups, actions, and objectives he should consider in standard setting. Although the applications of the policy analysis approach presented in this paper were largely concerned with describing ongoing or past standard setting cases, the methodology easily transfers to new cases as a starting point for standard setting procedures.

While policy analysis can provide a broad picture of the standard setting problem, the decision and game theoretic models developed are meant to aid regulators in finding good solutions once a specific subproblem for standard setting is identified. Specific here means that pre-decisions have been made about regulation alternatives, objectives, and possibly information sources to be used in the standard setting task similarly as shown for the chronic oil discharge problem in the section, "Application of the Decision Model to Chronic Oil Discharge Standards". The decision theoretic model was designed to aid regulatory agencies in standard setting tasks by:

- structuring the regulation problem;

- enabling regulators and experts to quantitatively express uncertainties and intangibles;

- making trade-offs explicit in form of value and utility functions;

- identifying a set of "good" standard solutions through a hierarchical optimization algorithm;

- allowing a study of the sensitivity of regulatory solutions to conflicting values, opinions, and the degree of information used.

There are many substantive and formal criticisms against such a modeling approach. The most persuasive is that such a model is an overformalization of a highly complex and political process, and that the degree of quantification required by the model could not be achieved in a real-world standard setting process. Another substantive criticism is that the model is silent about the real interactions between the decision makers, about their institutional embedding, and constraints, and instead models an idealistic and rational way of thinking about the standard setting problem which in actual practice has no chance of being implemented. But even those sympathetic with the formalization and the decision theoretic approach can find some major model limitations. The first criticism here is that the model is static. Although the model is in its probabilistic part a Bayesian model thus allowing updating based on incoming information, and although it allows considering streams of outcomes over time, it does not consider an optimal decision path over time. In addition the model says little about possible feedbacks between the three decision makers involved as time elapses. The intentions of the model made such simplications necessary, at least for a first round of modeling. It is impossible to model uncertainties and trade-offs in detail and at the same time consider a highly dynamic and interactive decision process.

The ultimate evaluation of the decision model must therefore be made setting out from its success or failure in applications. So far there has been only one illustrative application to chronic oil discharges. This application has provided some practical insights into the usefulness and the limits of the decision modeling, most of which were established in our discussions with the regulators involved in chronic oil discharges who provided us with valuable feedback about the use of such models:

- In principle the model appears applicable to relatively routine standard setting cases such as oil discharges;

- The value of modeling political objectives and evaluations is questionable. The regulator may prefer to omit this part of the model and use his own judgment;

- The developer model together with the detection submodule emerged as the heart of the model; the insights derived from them provided useful inputs into the regulatory decision making;

- the submodule of pollution generating events and effects was considered an interesting approach, but has not yet been effectively applied.

The game theoretic model applications of the noise standards problem and the global CO_2 problem do provide means for extending and elaborating the dynamic and feedback aspects of the decision theoretic model. In turn it removes itself from the practical assessment problems a regulator faces (information and value assessments) which it incorporates in aggregate form in utility functions and in transition probabilities. Still, the model applications have shown that through parametric analysis much is to be learned about the possible solutions of standard setting problems and the sensitive points regulatory action may want to approach or avoid. The mathematical abstraction may make the game theoretic model appear less of a practical tool than, say, policy analysis or cost-benefit analysis. But in combination with more traditional modeling approaches it could be a useful aid to regulatory decision making. The greatest problem one can foresee with the game theoretic model is the relative arbitrariness of utility functions and transition probabilities. But perhaps further refinement will make it possible to bridge the gap between the detailed but nondynamic decision model and the dynamic but highly aggregated game models.

It is perhaps too bold to make recommendations to regulators about ways to improve standard setting procedures on the basis of what has been said so far. But regulators, as they often told us during our research, have to make decisions on the basis of what is available, even if the tools available are still poor. Thus, rather than withdrawing into the comfortable and cautious attitude of saying that "no recommendations" can yet be made, we will try to extrapolate from our research and state some of the principles that in our opinion would be of value in standard setting procedures. What is ultimately aimed at is a set of formal methods and tools for standard setting embedded in the institutional regulatory decision making process. Several steps in that direction are possible.

First of all, in the pre-analysis phase of a standard setting problem, i.e. when a problem has been recognized or a task has been given to a regulator, an array of qualitative methodological tools should be used to span the problem in its widest perspective. In this pre-analysis phase approaches like the policy analysis in connection with an analysis of the legal requirements and constraints, and the political and institutional context bounding the standard setting problem could be helpful. Although a picture portrayed with such analysis is necessarily qualitative, it may help to focus in on a more precise problem formulation, and thus set the stage for a more detailed analysis of a reduced standard setting problem in which some pre-decisions about the nature of the regulation alternatives have been made.

In the task of information collection and evaluation, regulatory agencies should be aware of their objectives and force the researchers to collect data pertinent to the value relevant consequences which are considered crucial for further decision making. The regulator could impose format requirements for the presentation of research results to insure that his information needs are better met. For example, requirements could be made to express ranges of uncertainty, best guesses, and perhaps expert probability distributions as outputs of an analysis. This would also simplify the task of research evaluation, although it would by no means solve it. Research evaluation is still a major difficulty for which no appropriate tools have been developed, and to which none of the tools and models developed here address themselves directly. However, evaluation technologies such as multiattribute utility theory may be useful tools for the regulator to perform this task.

To study the implications of the research results on standard setting, a variety of approaches should be explored simultaneously. Cost-benefit analysis, simulation gaming, decision models, and game models are all possible candidates, each of them having their own virtues and limits. They have one thing in common, however: They attempt to organize the information and evaluation task in a way which otherwise would have to be done through intuitive decision making. By thus externalizing different ways of information processing and evaluation in standard setting tasks, the regulator may receive new insights into the sensitive points of the standard setting problem, bottlenecks, and, perhaps, additional information needs. Such models can never substitute for good judgment and decision making, but they can clarify and provide a basis for communication. This may be particularly important if the regulator wants to explore the effects of standards on different interest groups. A possible procedural way to connect these models in a practical way to regulatory decision making is by "standard setting laboratories", in which representatives of the various interest groups can interact through models.

Not much has been said in this report about the actual implementation of procedures, models, and ultimately standards within the institutional and organizational framework of regulation. It is clear that new methodological approaches would require new institutional mechanisms. Other approaches could perhaps make use of science courts or of public participation in regulatory decision making. We do not yet know how to achieve the crucial match between the institutional and methodological aspects of standard setting procedures. But the search for such a match may become a major future research task in the further development of procedures for the establishment of standards.

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APPENDIX I

LIST OF RESEARCHERS WHO PARTICIPATED IN THE VOLKSWAGENWERK FOUNDATION PROJECT, "PROCEDURES FOR THE ESTABLISHMENT OF STANDARDS"

A. Afifi,	IIASA and University of California at Los Angeles, USA
R. Avenhaus,	Kernforschungszentrum Karlsruhe and University of Mannheim, FRG Co-Principal Investigator
W. Edwards,	University of Southern California, Los Angeles, USA
D. Fischer,	IIASA and University of Waterloo, Canada
W. Häfele,	IIASA Co-Principal Investigator
E. Höpfinger,	IIASA and University of Karlsruhe, FRG Co-Principal Investigator
S. Ikeda,	Kyoto University, Japan
G. Majone,	IIASA and Russell Sage Foundation, New York, USA
L. Sagan,	IIASA and University of California at Los Angeles, USA
R.E. Schäfer	IIASA and International Atomic Energy Agency, Vienna, Austria
H. Sturhan	University of Mannheim, FRG
D. v. Winterfeldt	IIASA Project Manager

APPENDIX II

REPORTS WRITTEN FOR THE VOLKSWAGENWERK FOUNDATION PROJECT, "PROCEDURES FOR THE ESTABLISHMENT OF STANDARDS" (SEE VOLUME II)

Policy Analyses and Standard Setting Problems

STANDARD SETTING: EFFICIENCY, EQUITY, AND PROCEDURAL PROBLEMS by G. Majone, (TR-1)

A POLICY ANALYSIS FRAMEWORK FOR THE STANDARD SETTING PROCESS by D.W. Fischer, (TR-2)

SETTING STANDARDS FOR CHRONIC OIL DISCHARGES IN THE NORTH SEA by D.W. Fischer and D. v. Winterfeldt, (TR-3)

STANDARDS AGAINST NOISE POLLUTION: THE CASE OF SHINKANSEN TRAINS IN JAPAN by D. v. Winterfeldt, (TR-4)

Decision and Game Theoretic Models for Standard Setting

A DECISION AIDING SYSTEM FOR IMPROVING THE ENVIRONMENTAL STANDARD SETTING PROCESS by D. v. Winterfeldt, (TR-5)

A DECISION THEORETIC MODEL FOR STANDARD SETTING AND REGULATION by D. v. Winterfeldt, (TR-6)

A GAME THEORETIC FRAMEWORK FOR DYNAMIC STANDARD SETTING PROCEDURES by E. Höpfinger and R. Avenhaus, (TR-7)

Applications of Decision and Game Theoretic Models

MODELING STANDARD SETTING DECISIONS: AN ILLUSTRATIVE APPLICATION TO CHRONIC OIL DISCHARGES by D. v. Winterfeldt, (TR-8)

DYNAMIC STANDARD SETTING FOR CARBON DIOXIDE by E. Höpfinger, (TR-9)

A DYNAMIC MODEL FOR SETTING RAILWAY NOISE STANDARDS by E. Höpfinger and D. v. Winterfeldt, (TR-10)

Other

THE BIOLOGICAL BASIS FOR STANDARD SETTING FOR ENVIRONMENTAL POLLUTION: A CRITIQUE by L.A. Sagan and A.A. Afifi, (TR-11)

APPENDIX III

OUTLINE OF THE WORKSHOP ON ENVIRONMENTAL STANDARD SETTING

May 2nd and 3rd, 1978; Seminar Room, IIASA

Tuesday, 2nd May

9.00 - 12.00	Analytical Approaches to Standard Setting	
	Introduction	W. Häfele, IIASA
	Standard Setting: Efficiency, Equity and Institutional Problems	G. Majone, Russell Sage Foundation, USA
	Discussion	J. Thompson, Environmental Protection Agency, USA
		P. Knöpfl, Institut für Umwelt und Gesellschaft, FRG
	Decision Theoretic Models for Standard Setting	D. von Winterfeldt, IIASA
	A Game Theoretic Framework for Dynamic Standard Setting Proceudres	E. Höpfinger, Technische Hochschule Karlsruhe, FRG
		R. Avenhaus, Kernforschungszentrum Karlsruhe, FRG
	Discussion	J. Lathrop, Lawrence Livermore Laboratories, USA
14.00 - 17.00	Case Studies: Oil Pollution	
	A Policy Analysis of Chronic Oil Discharge Standard Setting in the North Sea	D. Fischer, IIASA
	A Regulator's View of the Standard Setting Problem for Chronic Oil Discharges	T. Read, Petroleum Engineering Division, UK
	A Decision Theoretic Model for Setting Chronic Oil Discharge Standards	D. von Winterfeldt, IIASA
	Discussion	T. Wilkinson, Shell Research Centre, UK
	Safety Aspects of Oil Blowouts	D. Fischer, IIASA
		R. Schäfer, IIASA
		B. Vedeler, Det Norske Veritas, Norway
		C. Bøe, NTNF, Norway
	Discussion	

Wednesday, 3rd May

9.00 - 12.00	Case Studies Continued	
	Environmental Problems of High Speed Transportation Systems in Japan	S. Ikeda, Kyoto University, Japan
	A Policy Analysis of Noise Standard Setting for Shinkansen Trains	D. von Winterfeldt, IIASA
	A Multistage Model for Noise and CO_2 Standard Setting	E. Höpfinger, Technische Hochschule Karlsruhe, FRG
	Discussion	
	Defining Acceptable Levels of Risk	J. Lathrop, Lawrence Livermore Laboratories, USA
	Discussion	
14.00 - 16.00	Future Directions (Round Table Discussion)	
	Social and Institutional Aspects of Standard Setting	All participants
	Methodological Improvements of Standard Setting Procedures	All participants
	How to Deal with Uncertainties and Conflicts in Standard Setting	All participants