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Standards for Facility Siting: Uncertain Utility in Decision-Making

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Uncertain Utility in Decision-Making

Gregory B. Baecher*

Abstract

One approach to regulating private siting decisions is by setting standards on the impacts of large constructed facilities. Theoretical structures of preferences for and among preferences, however, lead to implications which are sometimes overlooked in standard setting. Further, a central issue is that the objective function describing societal preferences is uncertain. Analytically including objective function uncertainty in standard setting allows information from several sources to be quantitatively coalesced, allows allocation decisions for investment in preference assessment to be quantitatively analyzed, and leads to speculations on the handling of temporal changes in preference.

I. Introduction

Suggestions have been made recently (Joskow, 1974) to regulate siting decisions for large facilities, in particular for nuclear power installations, through government imposed standards on non-financial impacts (external costs). These suggestions reflect a philosophy of government regulation of

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private decision-making which is not unique, but which differs from current regulatory policy of agencies such as the USAEC which monitor the decision-making process itself by means of project guidelines (USAEC, 1973), rather than monitoring the impacts of those decisions.

The proposal to use standards as a vehicle for regulating siting decisions is similar to the use of standards in health, transportation, and other areas of government regulation. This approach does not alleviate the problem of decision-making with multidimensional impacts of apparently non-compatible qualities, but rather transfers it to the standard setting body. The procedures for making these standards decisions and for assessing objective functions by which to evaluate possible alternatives are themselves open to criticism. In this paper, an attempt is made to look at standard setting decisions in light of theoretical structures of preference, and to assess the implications of approaches which balance beneficial against adverse impacts.

The points which will be concentrated on are that a balancing approach to standards leads to concepts of decision which are done injustice by much of current practice in siting, and that the central theme of standard setting for facility siting is perhaps more realistically decision-making with uncertain objective functions. Uncertainty in objective functions for a balancing approach to standards is inherent in the problem; if this position is accepted, then such uncertainty can be directly treated. This leads to a transference of the problem away from decision-theoretic aspects and toward assessment aspects; the more effort invested in assessing objective functions the less error in the inferences. However, this process suffers diminishing returns--some of which diminish precipitously due to blocks in our ability to infer certain preferences from behavior--

and the question becomes one of investment and allocation. The points this paper address are simple, but they are often neglected in practice. Pragmatically, in planning procedures for standard setting decisions, one should focus on degrees of uncertainty in objective functions rather than bemoaning ignorance of them.

To begin, we address the concept of impact balancing and its theoretical implications; then we turn attention to assessing objective functions and including preference uncertainty in standard setting. Finally, we look briefly at the administrative nature of standards and the impact of uncertainty on those facets of standards.

II. Balancing Approach

The logic of standard setting for impacts of large constructed facilities is clear: optimal levels of impacts, whether they be radioactive releases, landscape degradation, or air pollutant emissions are those levels at which the marginal rates of preferential substitution among impacts balance with marginal rates of technically feasible substitution. External costs of large facilities are "public goods," they are costs shared by society as a whole; internal costs and benefits are private, they accrue primarily to the private entity siting the facility. It is therefore in the interest of private decision-makers to exploit external costs beyond levels which are optimal for society. By setting standards on external costs, one attempts to constrain private decisions within regions of the impact space which are near the social optimum, that is, regions in conformity with the resources and preferences of society.

Structures of Preference

Large constructed facilities lead to sets of impacts against objectives which society holds to be important.

Abstractly, these might be divided into economic costs and benefits, environmental degradation, and social disruption, with subsequent subgroupings of each. Individuals, and thus society, have preferences for these consequences both for each alone and for groupings of them; these preferences are not necessarily linear over levels of any one consequence or are they necessarily independent. Thus, in assigning numbers to preferences for impacts, one must be careful about changes in the marginal rates of preference as impact levels change and about the properties of independence which prevail among impacts of different sorts (Keeney, 1969). These latter properties may not be constant over the entire range of impacts, and, therefore, it is marginal changes in levels of impacts which are of importance and not their absolute levels. Unit changes in impacts may lead to different amounts of preferential change for different base levels of each impact. This means that traditional methodologies for balancing impacts such as cost-benefit and benefit-risk analysis may not do justice to the true complexity of preference structures, and will lead to near-optimal balancings only if they approximate the true preference structure for the region in the impact space which is of interest. Of course, there is no way of knowing whether or not they are approximations unless more detailed analyses of preferences are considered.

The discussion of balancing approaches here will be couched in terms of measurable utility theory. Whether or not each parameter of this theory is operationally measurable, or even whether or not one accepts each axiom upon which the theory is based will be of little concern. The conclusions drawn derive from the balancing nature itself and not from this particular theory. Measurable utility merely provides a convenient vehicle for discussing the implications of balancing.

Let there be some set of objectives which are held important, and impacts against which will be considered the criteria for selecting among decision alternatives; assume that this set of objectives is complete in the sense of including all impacts of importance. Let there also be some set of scales or indices upon which to measure impacts against each objective; these will be called *attributes* and denoted $\underline{x} = \{x_1,...,x_n\}$. Associated with each objective is one or more attributes and outcomes scaled on the attributes are assumed to fully describe the importance of all impacts against the associated objective.

Technical predictions of impacts generated by any decision alternative (e.g., level of standard) are made on the attribute scales in the form of probability distributions. That is, while one may not predict impacts with certainty, one may predict probability distributions over the space of attributes, conditioned on each decision alternative. These predictive functions will be called the *technological relations* of a decision. Finally, the preferability of a set of impacts is measured by a utility function, $U(\underline{x})$, defined over the attribute space, and the optimal decision is taken to be that which maximizes the expectation of utility over uncertainty in the technological relations.

Technological Relations

Most of the siting literature concerns establishing technological relations (i.e., prediction models). These relations describe technically feasible combinations of impacts deriving from the set of decision alternatives; as such, they must include everything between the plant boundary and primary impacts. Implicitly, these relations describe three things: the marginal rate of technical substitution among impacts, uncertainty in impact predictions, and the relationship of secondary (surrogate) standards (e.g., radiation release at a facility boundary) to primary impacts (e.g., changes in morbidity and mortality).

Evaluating technological relations is conceptually straightforward, even if in practice it is often difficult. Nevertheless, establishing technological relations is a problem no matter how a decision is reached, and sophisticated decision methodologies do little to aid their evaluation. Assuming even that elements of the physical environment could be accurately predicted, determination of primary (as opposed to surrogate) impacts would remain a problem because of experimental difficulties and lack of experience with similar impacts. This gross uncertainty in mapping measurable impacts to primary consequences has been discussed by Häfele (1974) under the name "hypotheticality," and is an underlying theme of decision-making with respect to rapidly developing technology.

Individuals have preferences with respect to what might be called "basic" attributes, impacts which affect them at an individual or "quality-of-life" level. Individuals' preferences for surrogate impacts such as levels of air pollution, radiation exposure, or land degradation derive from how these surrogates map into basic impacts such as health and aesthetic qualities. Most of the assessment information we have on preferences, however, deals with surrogates, either in the form of economic data or opinion survey data. This information is unbiased only to the extent that individuals, when electing economic behavior or answering interviewers' questions, clearly perceive the true mapping onto basic attributes about which one must presume individuals do have well defined preferences. In fact, it is not clear that individuals do have a clear perception of the mapping from surrogate to basic attributes, and this accounts for part of the seemingly inconsistent preferences surrounding certain aspects of risk, for example, nuclear facilities.

To the greatest possible extent, one should attempt to assess preferences over basic attributes rather than over surrogates, even though in practice standards must for operational reasons be placed on the latter rather than the former. The reasons for this are straightforward. First, there is perhaps less error in the perceptions of individuals for their preferences concerning basic impacts than for surrogates; they have more intuitive feel for basic impacts, and thus assessment is easier. Second, perceptions of the mapping from surrogate to basic impact are often fuzzy and thus lead to errors not due to uncertainty in preference, but due to confusion over what impact one's preferences are being assessed for. Third, preferences over basic impacts have a greater temporal stability than those over surrogates.

Given that preferences can be assessed over basic attributes, the mapping from surrogates can be included as part of the technological relations. Thus, uncertainty in these mappings can be handled as are other predictive uncertainties.

Quantitative Requirement

Mappings from surrogate to basic attributes are normally continuous from very low levels and do not display thresholds which might otherwise be natural breaking points for standards. Evidence of this lack of thresholds can be seen in many impacts of large facilities (e.g., Bibbero and Young, 1974; Morgan and Struxness, 1971; Rice and Baptist, 1974). This means that comparisons of preferences among alternatives must be quantitative. Qualitative balancings, priority lists, and ordinal scalings cannot capture the problem of balancing under uncertainty. "Safety" and "benevolence" and phrases like "low as practicable" simply do not have meaning in this context.

To treat impacts in isolation and establish "safe" levels for each means possibly constraining impacts below the point of balancing (Section 4) and possibly foregoing beneficial changes in other impacts which might have been "bought" with the same resources, (either within the context of impacts generated by the one facility or that of investment in other facilities). Since investments in preventing adverse impacts generally follow diminishing returns, increments of investment above the balancing point could more efficiently (in a cost-effectiveness sense) be spent in reducing other hazards or undesirable impacts (e.g., Cohen, 1975).

Implications of a Balancing Approach

Given a balancing approach to standards, a few implications vis-à-vis current approaches become apparent.

1. Optimal Standards are Site Specific:

Levels of impacts which are technically feasible depend on the site; so do exogenous variables (population density, atmospheric conditions) which also affect the desirabilities of impacts. If the utility function for impacts is constant over geographic space, then the point in the impact space at which expected utility is maximized must also be site specific.

A facility or set of facilities generates emissions at points in space as shown schematically in Figure 1. Through natural processes of atmospheric dispersion and the like, these emissions lead to a spatial distribution of impacts (air pollution concentrations, say), which are

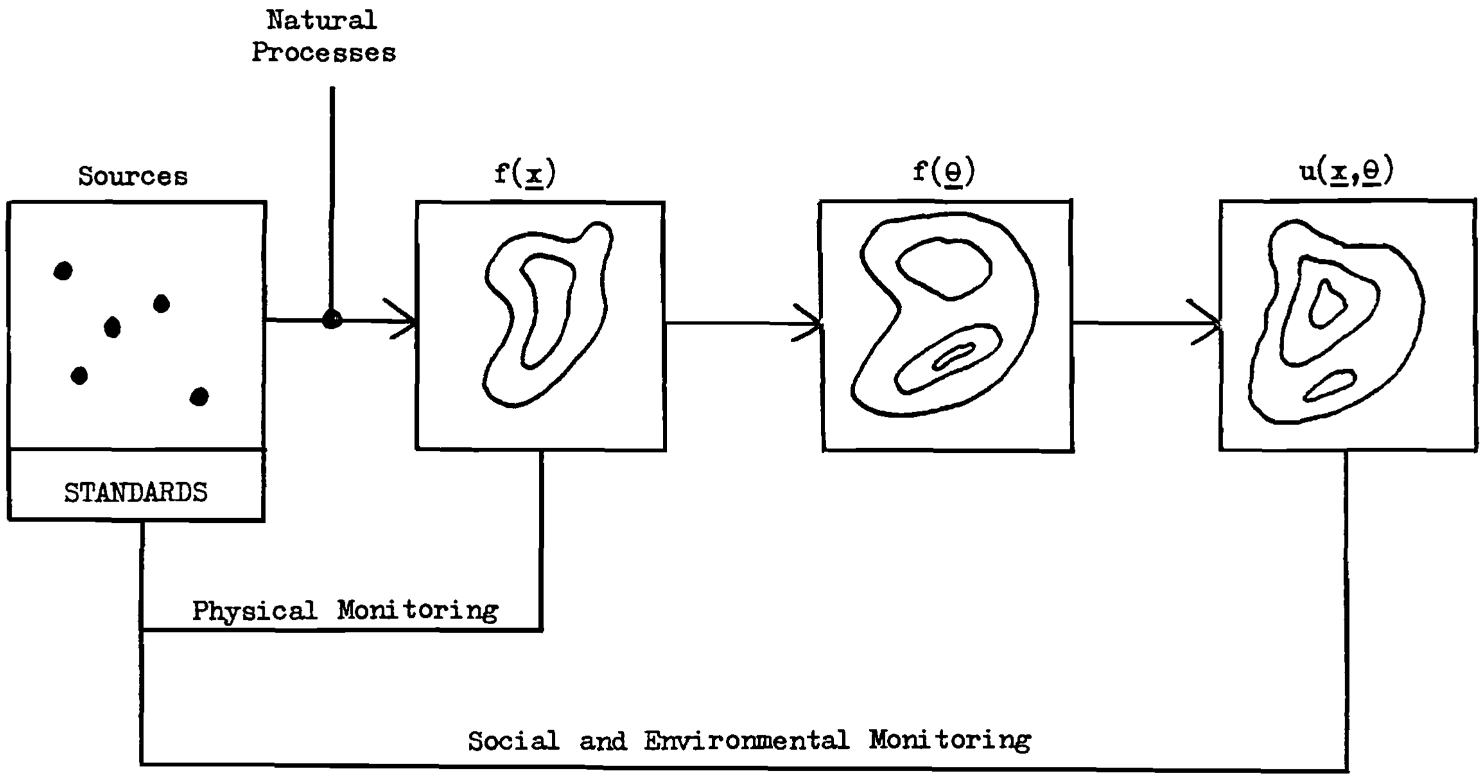
Natural Processes
Sources
STANDARDS
f(x)
f(θ)
u(x,θ)
Physical Monitoring
Social and Environmental Monitoring

Figure 1

predicted through a set of technological relations as $f_{y,z}(\underline{x})$, where (y,z) is spatial location. This function depends both on the dynamics of natural processes and on the source locations. Also distributed over space are certain exogenous variables, $\underline{\theta}$, like population, land-use, and natural eco-systems which are important in establishing preferences. Together the two sets of variables $\underline{x}$ and $\underline{\theta}$ are arguments of a utility function $U(\underline{x},\underline{\theta})$, which is defined societally and independent of spatial location. The objective function for standard setting is the integral of this spatial distribution of $U(\underline{x},\underline{\theta})$ with some allowance for its shape (i.e., spatial equity). Because this objective function is constant while the predictive relations describing $\underline{x}$ and $\underline{\theta}$ depend on site location, the level of any one impact x_i at the optimum depends on the site. Therefore, standards which are specified uniformly can, at best, only approximate the true optimum x_i for any particular site.

While there has been much discussion of spatial monitoring of pollutant concentrations (Darby, et al., 1974), as opposed to source monitoring, the only role this monitoring plays aside from record keeping is to refine the predictive models we use _a priori_ to make predictions on the spatial distribution of $f(\underline{x})$, and thus to predict expected changes in the integral of the preference function $U(\underline{x},\underline{\theta})$ as a result of different standards. Administratively it has no direct part to play in standard setting[1].

2. "Acceptable" Standards cannot be Transferred Directly from Other Activities:

Different technologies and different sites have different sets of technological relations and lead to differing values

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[1] This is not the case if standards are to be used as dynamic control variables which are continually updated (Baecher, 1975b), but this is not as they are used in siting.

of utility at the optimum. However, if the point at the optimum changes, the level of any one impact at the optimum may change as well. Thus, the level of any one impact associated with a current technology or siting may not be directly transferred for a new technology or site without running the risk of suboptimal standards.

As an example, consider the utility function shown in Figure 2, defined over the two-attribute space (x_1,x_2). Assume that technological relations A and B correspond to two technologies or sites or to any two activities. Let x_1 be a measure of health impact and x_2 some other impact, and assume that only these two impacts are important. In changing from A to B the optimum level of utility increases, but the level of impact against x_1 at the optimum decreases. Therefore, the old level of impact against x_1 (labeled x_1') is not optimal with respect to the new technology. The new optimum is x_1''. Only the structure of preference for impacts (e.g., the utility function) may be transferred, and if this structure is to be transferred it must account for impacts against all important objectives.

III. Measurement of Preference

Perhaps the central issue in standard setting decisions is uncertainty in the objective function (e.g., utility function) used to evaluate alternative levels for standards. This uncertainty can never be eliminated, or perhaps even reduced to low levels, so bemoaning ignorance simply sidesteps the central problem and shrugs the responsibility. Making "best estimates" of preferences or reverting to other criteria for decisions seem similarly unsatisfactory, while specifically including objective function uncertainty in decisions seems the most direct way of treating the problem.

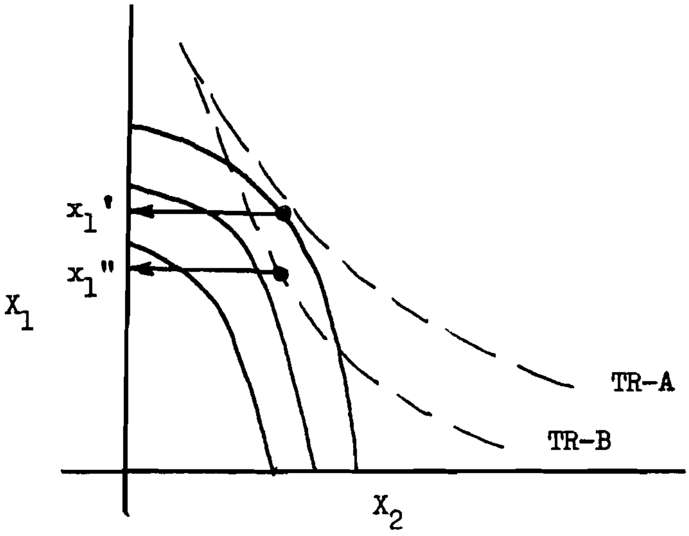

Figure 2

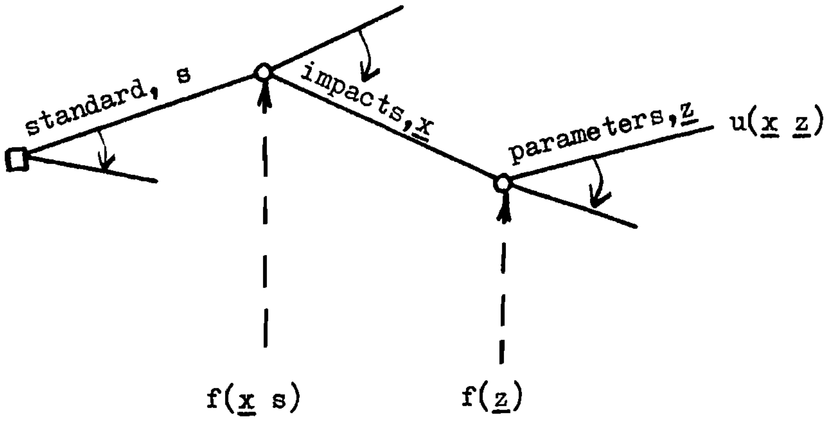

Figure 3

Structures of preference for impacts of large facilities are based on theoretical constructs of preference, whether these be utility theory, economic efficiency, or some other concept; thus we make a leap-of-faith in establishing these theoretical structures. However, once the structure is established, uncertainty may be expressed as uncertainties in the parameters of those mathematical functions.

If we let the societal utility function be $U(\underline{x}|\underline{z})$ in which $\underline{z}$ is the set of parameters on which the function depends (e.g., marginal rates of preference changes over single attributes and rates of interdependency among attributes), then in assessment we infer probability distributions over the $\underline{z}$. For example, using the economic efficiency model of preference, the societal utility function is of the form

$$U(\underline{x}|\underline{z}) = z_1x_1 + z_2x_2 + \ldots + z_nx_n \quad , \qquad [1]$$

and assessment (here from market data) consists of inferring the probability function $f(z_1,z_2,\ldots,z_n)$. With the efficiency model, these inferences usually take the form of point estimates of the $\underline{z}$. Using measurable utility theory the mathematical form of $U(\underline{x}|\underline{z})$ is different, but the idea is the same.

If we adopt a methodology which allows us to analytically treat uncertainty in the $\underline{z}$, then we are able to make investment and allocation decisions for the way effort is expended in assessing preferences. Also, if we adopt a methodology allowing us to treat uncertainty, we are able to analytically combine differing types of information (e.g., market information, direct questioning) through Bayesian analysis.

Given that we must make decisions with uncertainties in the objective function, the degree of uncertainty introduced by limited assessment information becomes like uncertainty in technological relations. Different parametric values for the utility functions lead to different values of utility for outcomes, and if an agency or individual wishes to make decisions using societal utilities, then this is simply one more component of total uncertainty about "states of nature." An optimal decision is that which leads to a maximization of expected utility over the probability distributions, both of the impacts and of the parameters (Figure 3). As these uncertainties are independent, the expectations over impacts and parameters may be analyzed in isolation.

Treating parametric uncertainty in utility functions as uncertainty in the state of nature allows us to approach assessment tasks (i.e., investment and allocation decisions) in precisely the same way as other information gathering activities--by determining the expected value of the information to be gained and allocating in such a way as to maximize the expected increase in utility due to sampling (Pratt, Raiffa, and Schlaifer, 1965). Given several techniques for gathering assessment information and their associated precisions, we can evaluate the probabilities of investments in each leading to decreasing uncertainty in the utility function and, consequently, to increases in expected societal utility resulting from the optimal standard level. This affords an analytical procedure for comparing differing methodologies of assessment and thus for allocating effort among them.

One must be careful here to distinguish between "unknowns" in impact and "unknowns" in utility. Most of the discussion concerning unknowns in siting and standard setting treats uncertainties in predictions of impacts, and, in particular, the uncertainties in mapping impact levels as measured on surrogate scales (e.g., man-rems of radiation) onto human or natural attributes (e.g., morbidity). This is not the same as uncertainty in the utility function, which is the degree to which natural impacts are or are not held to be desirable. The problem of gross uncertainty in impact predictions is a major one (e.g., Häfele, 1974), but it is not one addressed here.

Sources of Error in Utility Assessment

There are three sources of error in assessing utility functions of interest groups and, therefore, within the present context, in assessing utility functions upon which to base public decisions. The first is error in the responses an individual gives to preference questions; that is, discrepancies from his "true" preferences either known or unknown to himself; these include both random error and bias error. The second type of error is that induced by uncertainty in the "best" parameters of the analytical preference function which is assigned to his answers; that is, if his responses are as shown in Figure 4, what is the "best" preference curve to fit to his answers. The third type of error is sampling error generated by the fact that only a sample of all people within a group may be questioned; that is, problems of sampling inference.

Errors in the responses a subject gives either to an interviewer's questions or his behavioral responses to economic situations may either be random, in which the errors are distributed about the individuals' "true" preferences with an expectation of zero; or they may be systematic (i.e., bias errors), in which his answers or behavior deviate in consistent, although perhaps little known directions and magnitudes from his "true" preferences. The first are easily handled with statistical techniques and may be reduced by redundant and more detailed questioning. The second are not

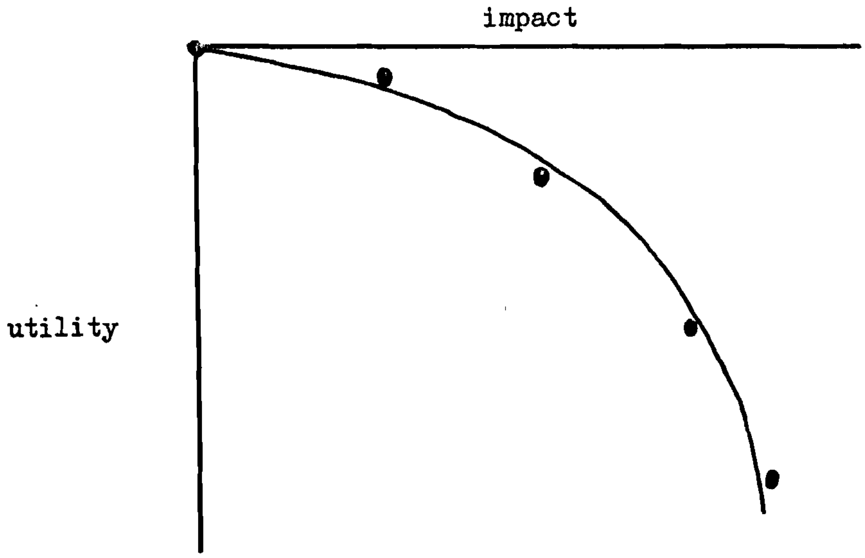

Figure 4

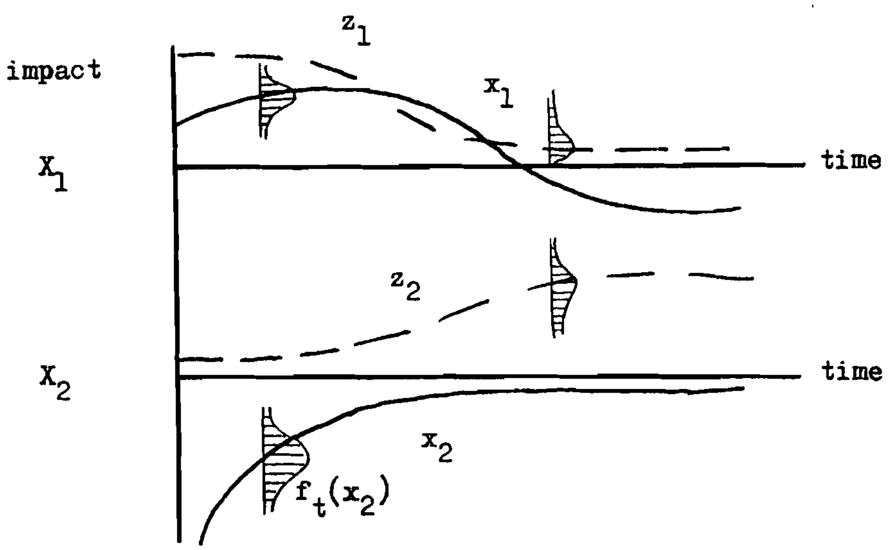

Figure 5

so easily handled. In fact, risk assessment work currently underway addresses precisely this question of levels and directions of bias errors (Otway, 1975).

Simplistically, we might divide bias errors into those which are caused by lack of information on the part of the individual or the differences between perceptions of reality and reality itself, and those of a deeper psychological nature involving emotional content of the impacts about which preferences are being assessed.

Slovic (1972), in addressing differences between perception and reality, has discussed systematic errors made by individuals in dealing with probabilistic outcomes of decisions. This work is based on laboratory experiments initially undertaken by Edwards (1954) and subsequently expanded by others. The conclusions one draws from this work is that people are very poor information processors and thus the answers they give to questions and the behavior which manifests in economic situations may reflect incorrect perceptions of reality; thus, one may not directly infer preferences from this data without correcting for perceptual biases. Yet Winkler and Murphy (1974) clearly illustrate that in actual situations individuals do not display nearly as much error as in laboratory situations. To conclude from the laboratory experiments that this error does exist and thus to make corrections on the basis of it has the potential of leading to grossly erroneous inferences about preference. Barring further work on human information processing in real decision situations, it would seem inadvisable not to accept subjects' direct answers and behavior as indicators of preferences assuming accurate perceptions of reality.

Bias errors resulting from more deeply held emotional or psychological factors are not so readily dismissed, given our limited knowledge of the psychology of choice. But as decisions must be made with current techniques of inferring preferences, a pragmatic solution is necessary. There seems little choice open except to accept what individuals say they prefer in simple choices involving trade-offs among impacts. Adopting the approach of "what they would have preferred, if only they knew what they wanted" transgresses the ethical basis of analysis, and heavily weighs inferred social preferences by values of the analyst. As this is a founding tenet of free-market philosophy, it is not a concept without historical support.

The most one can do, perhaps, is to reduce the questioning of subjects to impacts which are as basic as possible, and transfer mappings from surrogates to the set of technological relations. This removes much of the interpretive mapping to objectively described predictions, and so reduces questioning to more immediate (to the subject) consequences. Such an approach may partially overcome the empirical discrepancies one encounters, for example, in assessing the undesirability of equivalent levels of traffic and radiation risks.

One readily admits that speaking of very basic impacts (e.g., morbidity) and proposing to assess preferences over these impacts is itself presumptuous. But the whole problem of psychological biases is one which must be approached empirically. Just as Davidson, Suppes, and Siegel (1957) were forced to develop psychologically unbiased random events for laboratory experiments, so one must "see what works" practically by trying various strategies of questioning, reviewing their consistency, and subjects' willingness to deal with them. Work along this line is currently being attempted by Collins (1973; 1975).

Errors introduced by constraining individual preferences to conform with simple (or sometimes not so simple) mathematical relationships cannot be avoided because mathematical expressions of preference are needed to aggregate and to express uncertainties. However, this component of error can be straightforwardly analyzed through a regression procedure using uninformed prior distributions. If these errors exceed bounds which seem appropriate for compatibility (i.e., "goodness-of-fit" in a classical sense), then this simply reflects on the choice of preference structure and the analytical model must be modified until the errors become small.

The major component of uncertainty in inferring group preferences is probably sampling error, given that satisfactory ways develop for approaching individual biases. The reason is that random errors in individual preference assessments can be made exceedingly small if care is taken in assessment (Keeney, personal communication, 1975). Fortunately, sampling error can be directly estimated using Bayesian sampling theory (Baecher, 1975a). In essence, this process proceeds as follows: the desired result is a probability distribution describing uncertainty in the parameters of the group utility function $U(\underline{x}|\underline{z})$; that is, a probability density function $f(\underline{z})$. Given some sample of preferences from m individuals within the group, each of which might be described itself by a probability density function (pdf) accounting for measurement and fitting error, $f_i(\underline{z})$, $i = 1,\ldots,m$, the posterior distribution of uncertainty on the distribution of parametric values within the group is

$$f'(\underline{z}_o|\text{data}) \propto f^o(\underline{z}_o)\ L[f_1(\underline{z}),f_2(\underline{z}),\ldots,f_m(\underline{z})|\underline{z}_o] \qquad [2]$$

$$\propto f^o(\underline{z}_o) \prod_i L[f_i(\underline{z})|\underline{z}_o] \qquad [3]$$

in which $f^o(\underline{z}_o)$ is the prior distribution and $L[\cdot]$ is the likelihood function. A group utility function is constructed by aggregating the distribution of parametric values across the group by an appropriate aggregation rule (e.g., Keeney and Kirkwood, 1974).

An intriguing property of this procedure for inferring uncertainties in group preference is that information other than direct assessment data may be analytically included in the form of the prior distribution, $f^o(\underline{z}_o)$. For example, market data on the impact in question can be summarized as a prior distribution of possible parameter values for the preference function, and then updated by subsequent interview data to yield a composite uncertainty. This allows one to combine seemingly incompatible types of preference information into a single estimate of parametric values, with associated uncertainty. Likelihood functions for the subsequent directly assessed data might be determined using multidimensional scaling (Shepard, 1964), regression procedures (Slovic and Lichtenstein, 1971), or a variety of other methods (e.g., Wilcox, 1972). Non-parametric approaches to methodologically similar problems have been developed by Jewell (1975).

Sources of Information for Preference Assessment

The traditional approach to assessing societal preferences has been to infer from economic (i.e., market) data on marginal prices people are willing to pay either to enjoy some impact or to avoid it, sometimes called the inferred preferences method. This forms the assessment basis of cost-benefit analysis, for example, as well as Starr's (1970) benefit-risk analysis. The central deficiencies with this method are:

1) It treats historic data which may not reflect current preferences.
2) It deals only with impacts for which we have extensive experience.
3) It implicitly assumes simple determination of preference in terms of economic indices which may fail to grasp the multiply determined nature of individual choices, and which fail to distinguish between perception and objective impacts.
4) It assumes independence between impacts of different types and a linearity of preference (fixed at current marginal rates) over levels of any one impact. Thus, it implies structures of preference which do injustice to its true complexity.

The second traditional approach has been opinion surveys which directly approach individuals and ask their opinion in simple agree/disagree or choice among certain impact questions. The major deficiencies with this approach are that:

1) It treats and measures perceptions of impacts rather than preference for objective impacts (e.g., in measuring the preference for impacts measured on surrogate attributes the subject must supply the mapping to natural attributes--which may only, in tenuous ways, reflect the true mappings).
2) They measure intent of behavior in decision situations rather than behavior. There is no way of insuring that those things which individuals say they prefer are actually those they choose in real decisions. Although it is certainly not clear whether the pensive reflection attempted in direct assessment is not a better index than the active choices people make with unspecifiable motivations.

3) The results of opinion surveys are notoriously unstable (i.e., they change rapidly).
4) They generally lead to qualitative rather than quantitative relations among preferences for different types of impacts, and often allow little way of inferring trade-off rates of preference among different impacts (which is the most important information for decision-making).

At present too much emphasis is being placed on historic preference information (mostly market data) and too little on data from direct questioning (Otway and Cohen, 1975).

Two direct techniques for assessing preferences which might be applied more extensively are utility assessment (Schlaifer, 1959) and the decision inference methods of behavioral psychology (Slovic and Lichtenstein, 1971; Shepard, 1964). Both these sets of methods allow quantitative inferences about rates of trade-off among differing impacts and on marginal rates of preferential change with varying levels of individual impacts.

The most important parts of assessment techniques which these latter methodologies allow consideration of are: 1) the completeness of indices used in capturing trade-offs employed by individuals in reaching decisions, and 2) the sensitivity of the methods as expressed in error levels on the quantification of preference. Without the second, one is limited in the way one makes allocation decisions among assessment investments.

Three requirements of a satisfactory assessment methodology would be that it:

1) Separate perception of impacts from objectively specified levels;
2) Account for multiattribute determinacy and quantitatively handle preferential trade-offs among impacts;

3) Quantify uncertainty in inferred structures of preference.

Based on the preceding discussion, a proposed methodology for preference assessment for impacts of large facilities would be the following. It should use a limited number of attributes of impacts so that interdependencies among impacts may be adequately explored; it should use the most basic attributes possible to reduce emotion laden questioning; it should not correct either for subjective probability or for psychological bias (as the allocation of mappings from surrogate attributes to basic attributes would be contained in technological relations); it should use economic data as prior information which is subsequently updated by direct utility or other assessment data; and it should analytically express uncertainty in assessment through a scheme which includes both uncertainty in individual assessments and sampling inference.

Time Changes in Preference[2]

We have dealt so far with current uncertainty in objective functions. However, a taxing question is what do we do with societal preferences which change over time. Siting and associated standard setting does not, in general, deal with long-term impacts, but rather with design lives of intermediate length and small-scale decisions. Thus, our immediate concern is pragmatic and this is the temporal problem we address.

One takes a leap-of-faith in choosing a structure for the objective (preference) function. If one assumes that this structure (although perhaps not the actual values of

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[2] The impetus and inspiration for this approach has resulted from discussions with Harry Swain (personal communication, 1975).

its parameters) is constant over time, then one may express temporal uncertainty just as sampling uncertainty, by establishing probability distributions on the set of parameters. If the structure itself changes over time the problem is entirely different, and it is this latter problem which must be addressed by such things as long-term energy policy. Structural changes include qualitatively new ways of perceiving the importance of impacts (not simply changes in magnitude), as well as the recognition of previously ignored or unnoticed impacts. Here, however, we focus on the problem of time invariant structures of preference in which the parametric values have uncertain time streams.

Expanding our notation, let the societal utility function previously denoted $U(\underline{x}|\underline{z})$ refer now to some increment of time Δt_o; this will be represented as $U\left(\underline{x}_{t_o}|\underline{z}_{t_o}\right)$ where $\underline{x}_{t_o}$ and $\underline{z}_{t_o}$ are the values of impacts and parameters during the interval Δt_o. Both $\underline{x}_{t_o}$ and $\underline{z}_{t_o}$ are uncertain, but may be represented by some joint probability density function denoted $f_{t_o}(\underline{x}|\underline{z})$ (Figure 5). Estimating the function $f_{t_o}(\underline{x}|\underline{z})$ is a difficult task, but is being attempted in such undertakings as the Vancouver Urban Futures Study (Collins, 1973); clearly, the further into the future these predictions are made, the more variance there will be in the estimation. Here we will assume that such estimations can be made, and that imprecision in our ability to make this prediction can be included as increased variance.

The preference for impacts during the interval Δt_o is simply the utility function given $\underline{x}_{t_o}$ and $\underline{z}_{t_o}$; allowing for uncertainty and adopting expected utility as the criterion of optimality, the "best" decision alternative for the period Δt_o is that which maximizes

$$E\left[U\left(\underline{x}_{t_o} \mid \underline{z}_{t_o}\right)\right] = \int_{\underline{x}} \int_{\underline{z}} U\left(\underline{x}_{t_o} \mid \underline{z}_{t_o}\right) f_{t_o}(\underline{x},\underline{z})\ d\underline{z}\ d\underline{x} \quad . \qquad [4]$$

Assuming no time discounting of utility, the best current decision alternative is that which maximizes[3]

$$E_t[U(\underline{x} \mid \underline{z})] = \int_t \int_{\underline{x}} \int_{\underline{z}} U(\underline{x}_t \mid \underline{z}_t)\ f_t(\underline{x} \mid \underline{z})\ d\underline{z}\ d\underline{x}\ dt \quad . \qquad [5]$$

As long as the structure of preference over impacts remains stable, the nature of utility functions handles problems of risk aversion to future uncertainties of impacts and parameters, and thus the analysis is not merely an averaging of impacts over time. The problem for intermediate interval decisions thus reduces to parametric estimation, and our inability to accurately predict changing magnitudes of preferences among impacts is reflected in the dispersion of our probabilistic estimates of time streams of those parameters.

IV. Administrative Aspects of Standards for Siting

We have discussed the theory of standard setting as balancing impacts against a host of societal objectives to yield a social optimum. We have also pointed out that we consider the central issue in all of this to be the logic of decision-making with uncertain utility functions. However,

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[3] Complex theoretical structures of temporal utility aggregation could be applied to this sort of approach (e.g., Meyer, 1969) but the thrust of the argument would remain unchanged.

standards are fundamentally administrative entities which we adopt in order to better regulate private decision-making. Therefore, we now turn brief attention to ways of specifying standards which will, in theory at least, best accomplish this aim.

Legal and Administrative Nature of Standards

Elements within society have different structures of preference over impacts associated with large facilities and administratively we institute standards so that actual decisions will be brought closer to societal optima than individual preference structures would otherwise lead to. Since many of the impacts of large facilities are of a public good nature (air pollution, etc.), it is in the interest of individual decision-makers to exploit these costs to a greater degree than is in the societal interest. These points refer not only to industrial decision-makers, but also to interests such as environmental groups whose structures of preferences also do not necessarily coincide with societal structures. For example, air pollution standards which are too stringent are no more in the "public interest" than ones which are too relaxed. To err on the side of "safety" is to err on the side of increased costs--both social and environmental, as well as financial--of other impacts. One of the clearest examples of this is Majone's (1974) on air pollution standards. Increasingly strict air pollution standards in many cities have caused increasing loads on other facilities for removing wastes (e.g., water and solid waste); this means increased degradation of water and landscape quality, as these are the new depositories of what was air pollution waste. It may be in "society's" interest to have less stringent air standards and thus less water and land degradation, even though activist groups continue to push for more and more stringent air standards.

There are several ways in which private decisions may be encouraged to approach societal optima, and standards as they are now used is merely one of them. For example, one may set standards as (Keeney, 1974):

1) Minimum or maximum levels of impacts as now employed.
2) "Windows" which specify maximum <u>and</u> minimum levels of given impacts.
3) Multivariate limits on several impacts simultaneously.
4) Specifications of societal objective functions or marginal rates of trade-off between impacts of different types.

The first three monitor the results of decisions, the fourth monitors decision-making.

The advantage of monitoring standards rather than decisions is that the licensing process is speeded, the work load of administrative agencies is reduced, and the regulatory agencies, ostensibly, are better able to judge the preference structure of society and invest more resources in assessment and analysis than private decision-makers. Thus, ostensibly, there should be less error in the agency inferred utility function, and the level of standards selected by them may be more nearly optimal than are site specific optimal impact levels analyzed with fuzzier information.

The typical case of individual standards on the level of a single impact is illustrated in Figure 6. As both the technological relations (TR's) and the utility functions are uncertain, however, the societal optimum can only be described as some probability density function over the impact space. Given TR-A and a private utility function

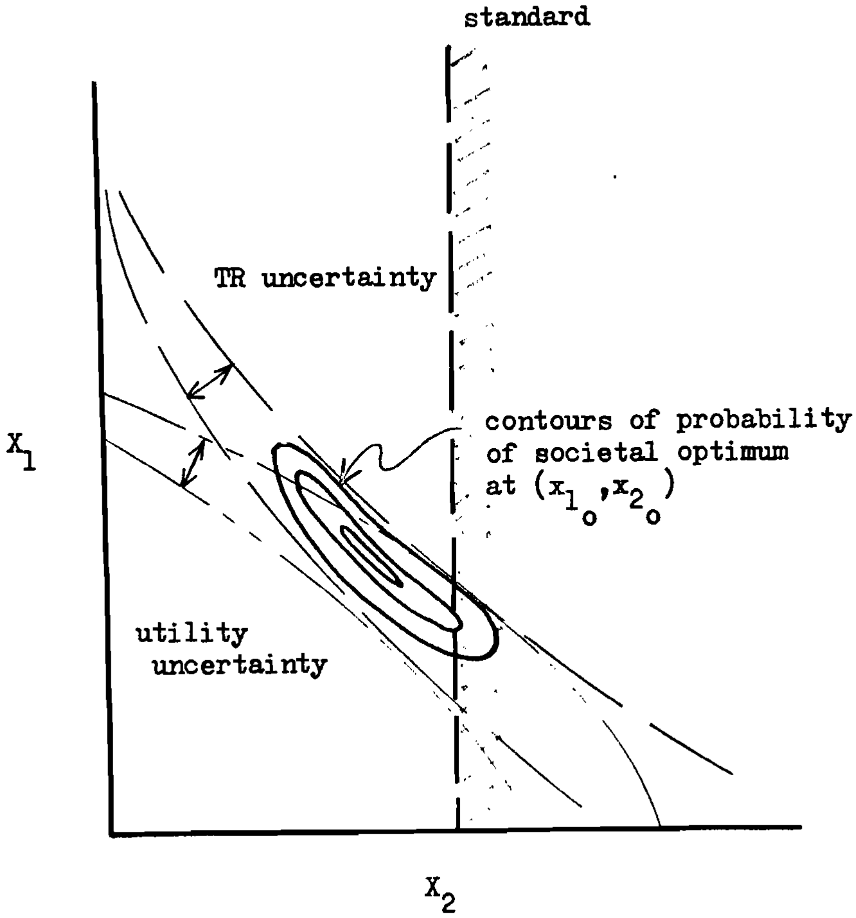
standard
TR uncertainty
contours of probability of societal optimum at (x_{1_0}, x_{2_0})
X_1
utility uncertainty
X_2

Figure 6

as shown, a standard can be set such that the private decision is constrained to lie near the probable societal optimum. However, if TR-B actually prevails, the standard is too strict and an unconstrained private decision might have led to a more nearly optimum balancing. Such a standard assumes a "target" group of decision-makers, and if another group, which placed more importance on the second impact, were influential in the decision, then again the private decision would diverge from the probable social optimum. Without a specified target group, window standards or joint standards on both impacts would be needed to insure a near optimal balancing. These are shown respectively in Figures 7 and 8.

Window standards suffer the disadvantage that they are politically unacceptable since they specify minimum levels of undesirable impacts and maximum levels of desirable ones. Thus, they are easy political prey for groups whose preference structures diverge from the societal structure, and are difficult to justify publicly. Joint standards are more easily justified as the trade-off relationship between impacts may be more directly indicated. If one is to adopt joint standards, however, there seems no reason not to go directly to sliding scales of joint levels which reflect marginal rates of trade-off among impacts. Again, this is illustrated for the two attribute cases in Figure 9.

Adopting a sliding scale implicitly grades into specifying societal preference trade-offs themselves, but perhaps avoids the political difficulty of being overly exact in stating a precise surrogate "welfare function." Specifying an expected societal preference function or a range for this function, expressed in marginal rates of trade-offs among impacts, certainly seems most likely to lead to near optimal decisions but requires careful monitoring of siting decisions

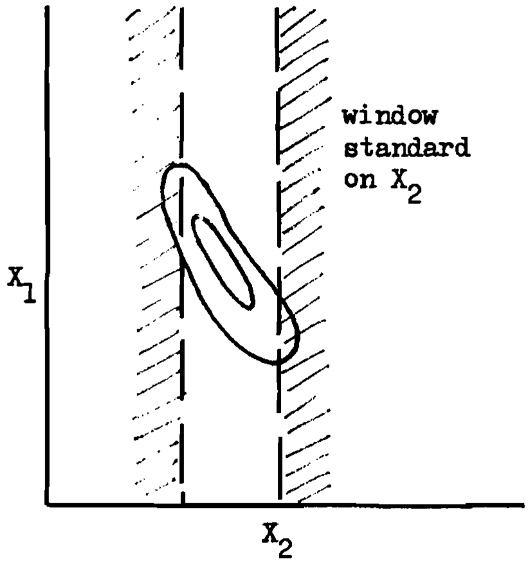

Figure 7

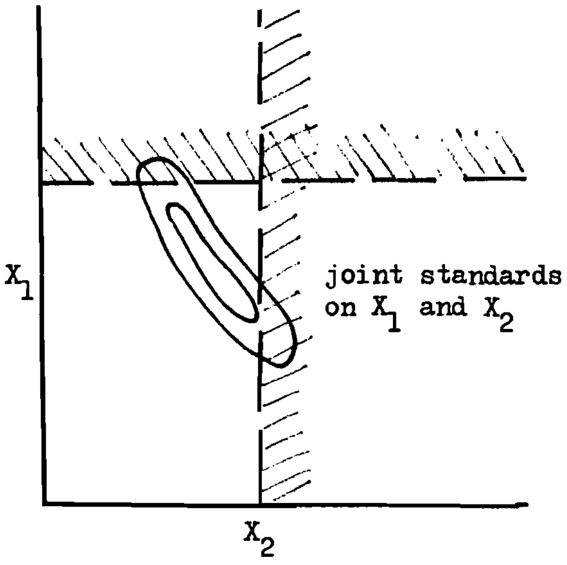

Figure 8

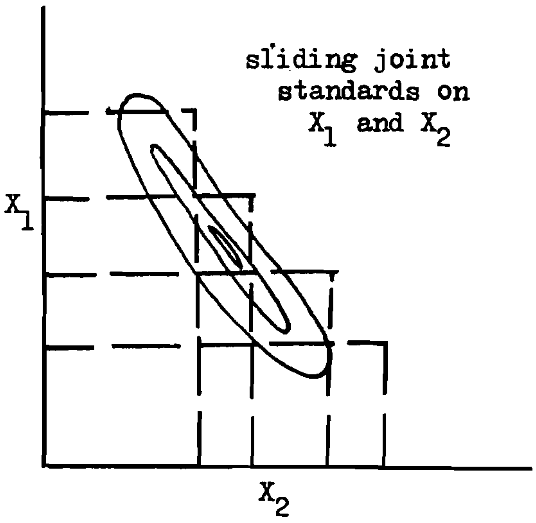

Figure 9

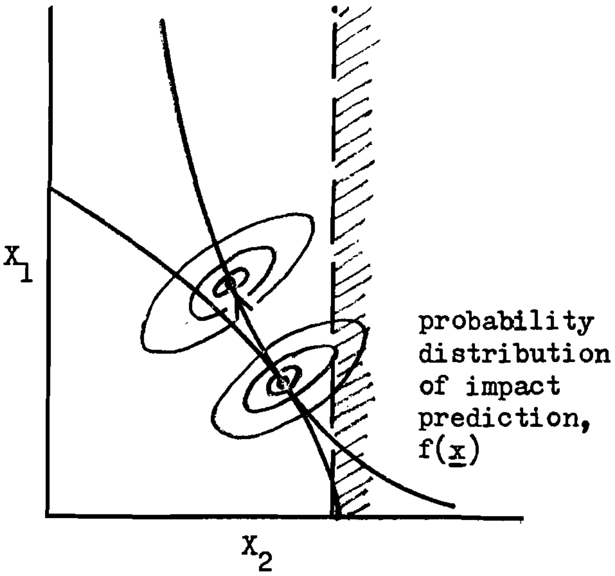

Figure 10

themselves and is thus more difficult to implement. At present, regulatory agencies, such as the USAEC, use precisely this procedure, except that they allow private decision-makers to assign the societal rates of trade-off from their own analysis and then monitor not only the decision analysis itself, but also the inferences of societal preferences (USAEC, 1973).

A last point is that any way one sets standards must account for uncertainty in impact predictions. Not doing so means that decisions must be made below societal optima in order to insure the required low probability of violation. Whereas a balancing of impacts at point 1 in Figure 10 may most closely approach the societal optimum, to insure a satisfactorily low probability of violating the standard, a private decision would have to be moved toward point 2--a balancing which has an expected societal utility more removed from the optimum. This philosophy of standards is gaining acceptance in some applications (e.g., in air pollution, Bibbero and Young, 1974), but should be more widely employed in siting.

Technological Change

If one adopts standards of either the level or window type, the best levels to choose depend on the set of technological relations. If this set of TR's changes, the best standards change. Therefore, the standard setting agency must constantly evaluate and update its standards to reflect technological change. As the TR's change, if the standards do not also change, then they force private decisions perhaps away from social optima. Given some technological advance which lowers the TR from 1 to 2 in Figure 11 (this might be, e.g., decrease in the marginal cost of lowering pollution emissions), the social utility at the optima increases from

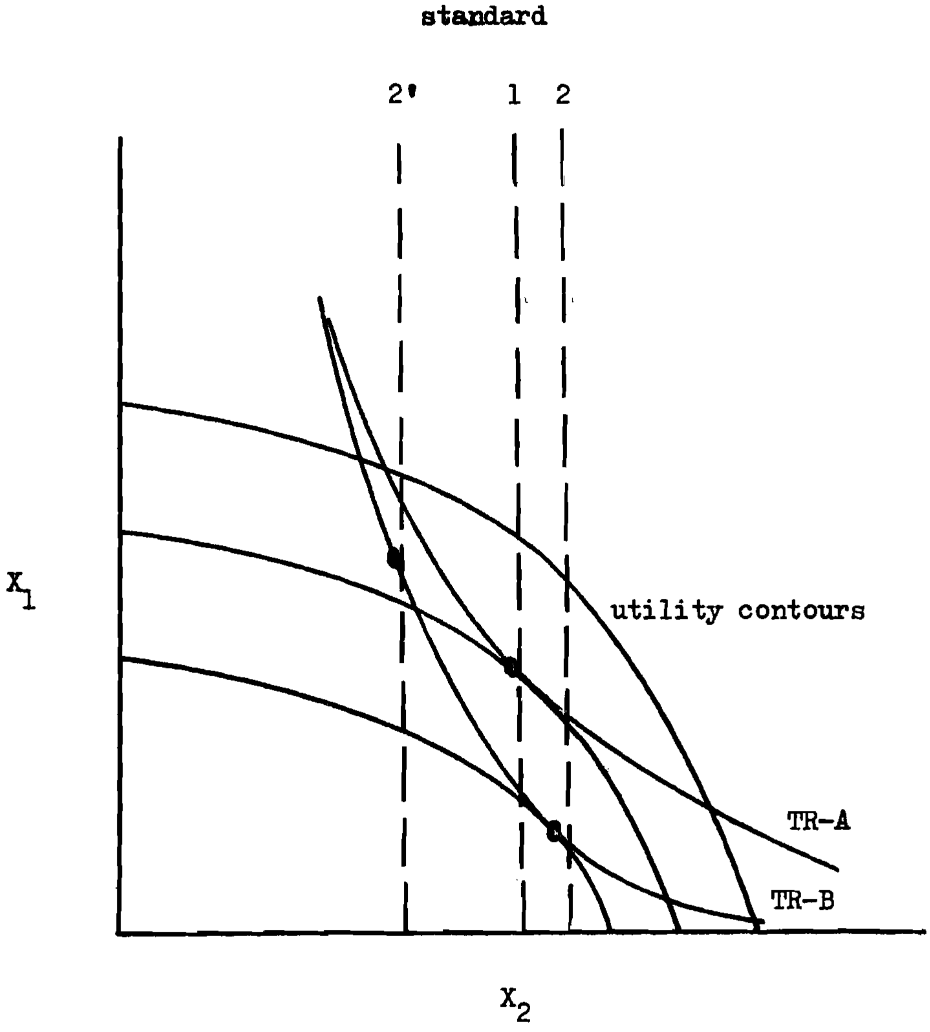

Figure 11

a to b, but the absolute level of adverse impact B also increases as the optimum changes. With the new technology, maximum increase in social utility can only be realized by making the standard on B less rather than more restrictive. Leaving it the same leads to some increase in utility, but not as much as might be attained. Making the standard more stringent leads to inconsequential increases or even decreases.

One of the major advantages of level and window standards is that they become targets or goals of administrative endeavor. Their success is strongly tied to their fixity and permanence. By changing standards too often they lose their advantage of providing an administrator with a constant yardstick (Majone, 1974).

This flaw does not so much mar the use of trade-off rates as their permanence depends on the preferences of society, which although changing, presumably do so at slower rates than technological advance.

V. Conclusions

Standards imposed on levels of impacts generated by large facilities are vehicles for regulating private siting decisions in such a way that levels of impacts against multi-attributed objectives of society may be balanced. Based on theoretical structures of preference for uncertain impacts, however, certain implications become clear which are sometimes overlooked in practice. First, optimal standards (i.e., optimal levels of impacts against any one objective) are site specific; they change with site and facility technology. Second, "acceptable" levels of impacts against any one objective for one site, technology, or activity may not be directly transferred to new sites or technologies and still be optimal.

The central issue in decision-making for standard setting is perhaps best described as decisions with uncertain utility (i.e., objective) functions. Adopting a quantified approach to objective function uncertainty allows one to compare different assessment methodologies, allocate effort among them, and quantitatively aggregate information from seemingly incompatible sources (e.g., market and direct assessment data). Also, given a quantified approach to objective function uncertainty allows speculation on quantified approaches to treating the problem of temporally changing preferences for and among impacts.

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