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Comments on Decision Objectives and Attributes for the Nuclear Siting Study

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1. Introduction

The object of this paper is to summarize discussions at IIASA on attributes or indices for siting decision making. While I have attempted to include differing views on most attributes, I make no pretense of this being an unbiased review.

In addressing decisions of any type and public policy decisions in particular, the choices which one makes of goals, attributes, and normative models fairly well determines a priori what the conclusions will be. It is here that decisions are actually made. Therefore it is absolutely necessary that we be judicious in our selections. In some sense, all that follows these choices is a technical follow through, although this somewhat overstates the point.

The present paper may be summarized as follows. First, a short discussion of goals and attributes is presented; then a set of attributes is listed according to inferred objectives; and finally, each objective and attribute is reviewed and recommendations are made.

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2. Objectives and Attributes

General

This section discusses what is meant by objectives and attributes, and summarizes various classes of the latter.

Objectives are criteria of evaluation or dimensions along which outcomes of decision may be judged. They exist in hierarchies of importance, and clearly some objectives are encompassed by others. The closer to the top of this hierarchy an objective lies, the more "basic" it will be said to be. The most basic of all objectives deal with fundamental human values.

Attributes are measurable indices associated with objectives, or measures of effectiveness to assess the degree to which objectives are attained. We say that an attribute is "natural" if it follows immediately from the objective. For instance, the objective "minimize waste heat dispersed into receiving waters" has the natural attribute "amount of heat dispersed." Sometimes, however, two or more seemingly natural attributes can be associated with an objective but lead to different measures. With respect to minimizing health hazards, the two seemingly natural attributes, "number of statistical deaths" and "future life expectance" yield non-equivalent scales (Ralph Keeney, personal communication).

When no natural attribute can be identified, or when for some other reason a natural attribute cannot be used (e.g., measurability difficulties), a "proxy" attribute is usually chosen. A proxy attribute is one which is correlated with performance on the objective, but is not a natural measure of it. For example, in pollution studies the proxy attribute "pollutant concentration" is often used in lieu of the attribute "morbidity rate" in measuring performance against the "Maximize Public Health" objective, even though it does not directly measure health. It simply is a correlate which is easily measurable.

If neither a natural nor proxy attribute can be identified, one is forced to rely on purely subjective indices assessed directly over outcome scenarios. For example, given several different schemes of development one might scale a subjective index over the degree of flexibility in future options by assigning 0 to the least flexible, 1 to the most, and intermediate values to the others.

Basic Objectives: Basic Attributes

"Basic attributes" will be used here in referring to natural attributes of basic objectives. The use of basic attributes offers several advantages which are worth noting.

1. They reflect on goals of primary importance to individuals whose utility functions are being assessed.

2. Because of #1, they are comparatively easy to assess preferences over. Individuals have stronger feelings generally on basic values than on derived ones and thus may have an easier time verbalizing them.

3. Preference over basic attributes is less time sensitive than over non-basic attributes.

4. Preference over basic attributes is less dependent on "education" (i.e., familiarization with an issue) than non-basic attributes.

Clusters of Impacts

One last point will be made before starting on specific objectives and attributes. This is a point that Prof. Perloff (personal communication) thought should be stressed, and I include it here for that reason.

Decision-makers, particularly those in the public arena, tend to think of impacts of decisions in clusters (which may contain many interacting impacts). This reduces consideration to a small set of trade-offs which can be grasped intuitively. In the language of decision analysis, there are subsets of the total set of attributes which are "quasi" utility independent of their compliments.

It was Prof. Perloff's suggestion that we be explicit in treating clustering, particularly when dealing with decision-makers or "non-initiates," as this greatly increases a decision-maker's understanding of the dynamics of the decision analysis. Clearly, without such understanding it will be harder to convince him of the value of decision modelling.

3. Selected Objectives

Very briefly, the objectives which have resulted from discussions are the following:

1. Minimize individual exposure to radiation;
2. Minimize population exposure to radiation;
3. Minimize opposition density;
4. Maximize beneficial regional development;
5. Minimize clean-up "discomfort" of transportation accident;
6. Minimize ecosystem disruption and adverse aesthetic impact;
7. Maximize flexibility in facilitating evolving options;
8. Minimize cost.

In the following pages, each objective is discussed in turn according to the organization of Figure 1.

Figure 1

Goals, Objectives and Attributes

Goal	Objective	Attribute
Maximize Health and Safety	Minimize Individual Burden Minimize Societal Burden	Morbidity/Mortality Morbidity/Mortality
Maximize Beneficial Economic Impact	Minimize Capital and Operational Cost (Transport accident risk included in Operational Cost)	Monetary Units
Minimize Adverse Environmental Impact	Minimize Ecosystem Disruption	[Subjective value] [Impact index]
	Maximize Desired Regional Development	Subjective (Degree to which impacts conform to national settlement policy.)
	Minimize Adverse Aesthetic Impact	Subjective
Maximize Flexibility in Future Options	Minimize Blocking Future Facility Development	Subjective
Minimize Risk of Politically Disastrous Situation	Minimize Risk of Strong Political Reaction	Subjective (on opposition scenarios)

Maximize Health and Safety

Implicit in our choice of objectives relating to health safety is the assumption that only radiation exposure is an important consequence; other forms of impact on health and safety, such as increased air pollution, are dismissed. In the present discussion, I try to draw two distinctions, that between individual and societal exposure to radiation, and that between morbidity and mortality.

Individual exposure is that highest exposure to which any single individual in a population is subject. Implicit in the present usage is exclusion of process workers (in other words, only individuals "involuntarily" subject to radiation are considered). Societal exposure is the integral of radiation exposure over human population. These two reflect on different values. Individual exposure reflects on "equity," the distribution of benefits and costs over space, time, and societal groups; societal exposure reflects on "efficiency," the net benefits and costs to all of society.

Morbidity and mortality differ in that the former refers to life-length and statistical death, while the latter refers to death directly. These are not necessarily the same preferentially, although they are often treated as such. One statistical death due to continuous radiation release and one actual death due to an accident may be very different attributes to a particular decision-maker or individual; however, the conclusion can only be drawn from assessments in the particular situation.

However, this distinction between morbidity and mortality should concern us because we are forced to deal with both types of impact.

Assessment of Utilities

From the preceding discussion and some basic properties of utility functions, a few comments are in order on assessment over individual and societal exposure.

First, exposure dose as used for the attributes "individual" and "societal burden" (as defined in Avenhaus, Häfele and McGrath, 1975) is not a basic attribute, it is a proxy for increasing morbidity and mortality. As such, an individual must be "trained" in the relationship between dosage and more understandable concepts (in human terms at least). Also, we have seen that preference over exposure dose, like over other proxy attributes, is time sensitive. As more and more has been learned of the effects of radiation exposure in terms of increases in morbidity and mortality, societal preference as reflected in national standards have changed. I doubt that preference over increases in morbidity and mortality have changed so much in the same time. Therefore, were it possible to use increasing morbidity and mortality as attributes and relate them to radiation exposure through probabilistic relations, we would be a step ahead. Of course, there are difficulties in using the basic attribute approach, but also advantages.

Assuming that utility functions over the effects of continual and accidental release are, at least conceptually, expressible in terms of increasing morbidity and mortality, one might look at a decision rule based on maximizing expected utility and see what it leads us to.

Let, r = radiation burden (m rem/yr) due to continual release,

c = radiation exposure dose due to accidental release,

$b(r)$, $b(c)$ = the function relating increases in morbidity to radiation exposure rate or dose c (probability functions could easily be used),

$t(r)$, $t(c)$ = functions relating r and c to increases in mortality,

$f_x(x)$ = a probability density function on the random variable,

$*$ = some theoretically proper operator.

If we consider r to be a fixed variable, and c to be a random variable described by $f_c(c)$, then

$$u(r,c_o) = u[b(r),t(r)] * u[b(c_o),t(c_o)] \qquad [1]$$

where c_o is a specific value of c. The expected value of this utility over the r.v. c is,

$$E[u(r,c)] = E[u(b(r),t(r)) * u(b(c),t(c))] \quad . \qquad [2]$$

This distinction of morbidity and mortality aside (i.e., forgetting $b(\cdot)$ and $t(\cdot)$; and saying $u(r,c) = u(r + c)$, still,

$$E[u(r + c)] \neq u(r + E[c]) \qquad [3]$$

which is the "burden" measures of Avenhaus, Häfele and McGrath. Following from the previous discussion, I would go further to say that since r and c map differently into morbidity and mortality, what we really are concerned with is $E[u(r,c)]$, and not $E[u(r + c)]$, which would equal the r.h.s. of #3 only if morbidity and mortality were quantitative differences along the same attribute, and the utility function over this attribute were linear.

Recommendations

1. Probe in assessments to uncover preferential differences between increases in morbidity and mortality, whould they exist.

2. Try to assess utilities over these basic attributes and relate them to radiation exposure through probabilistic functions. If this is not possible, or if the decision-maker does have a feeling for the "meaning" of radiation exposure in preferential terms, then we can assess directly over exposure.

3. In either case, the effects of continual and accidental release can be combined only after utilities are assessed.

Maximize Beneficial Economic Impact

In bulk, concepts of direct cost (i.e., capital investment and operation costs) are straightforward. While we face the old problem of time discounting, the whole question has received attention in previous decision problems.

Transport Accidents

The conclusion of our discussions is that transport accidents have dimensions beyond cost: something we termed "inconvenience." Upon reflection, I can break the total accident impact along four dimensions: cost, radiation risk, political impact, and disruptions of public service and smooth-running of the economy. (As a side point, if the last two were of sufficient importance one could construct special and exclusive transshipment facilities for nuclear products; this represents an upper limit or "opportunity cost" on the importance of these considerations, and could be considered as an economic input.)

I think we have two options. The first is to transfer cost to the general "cost" attribute and radiation risk to the individual and society exposure attributes, then for political and disruption aspects of a transportation accident use a subjective index assessed over various scenarios of accidents. Probabilities of accidents would be estimated from historical and network data and possibly modified by subjective probability assessments. The second alternative is to assume that the disruptive aspects of accidents can be adequately handled as an economic good. If this is the case, everything except the political impact of an accident can be transferred to other attributes. The political attribute could be transferred to the "political opposition" objective, but given the two attributes we choose under "political opposition," this would require making it a three attribute objective. The best avenue for us, if we elect option 2, is perhaps to drop political aspects of accidents altogether as not being of sufficient importance relative to other impacts.

Recommendation

For the time being, let us leave our options open, and allow the dynamic nature of the assessment process to answer this question for us by telling us whether or not "disruption" actually is important relative to other attributes. If it is, then we must go with option 1; if it is not, then we can go with option 2 and lessen our attribute space by one dimension.

Regional Development

Traditionally, "regional development" has been seen as a positive impact along a single economic dimension. Typically, an attribute like,

$$(\text{salaries} * \text{multiplier}) - (\text{opportunity cost of other use})$$

has been used to measure this impact, although one could easily come up with a long list of similar attributes.

However, such indicators are not sufficient in our "enlightened age." Even the goodness of development is now brought into question. My conversations with Prof. Perloff, and some feedback from Harry Swain indicate only the depth of the difficulty, and have not clarified even a "set of principles" which should be considered (i.e., not even in an intuitive way).

Being pragmatic, let me summarize in a few items some of the things we might consider.

i) Direct and indirect economic impact,
ii) Desirability of development from the perspective or local residents,
iii) Compatibility with national settlement policies.

The first and third of these are attributes (i.e., indices), and the second is a preference over some unstated attribute. My suggestion is that we do one of two things:

a) Make regional development a two attribute objective using economic impact and consistency with national settlement policies as the attributes. However, in order to include local preference in this, for the utility function over economic development, we would use inferred local group preferences. This utility would be negative if local groups opposed development. Economic impact could be scaled along any of the traditional measures, and consistency of settlement policies could be a subjective index unless a more objective index could be developed.

b) Make regional development a one attribute objective using only consistency with settlement policies. There is a very strong rationale for using attribute 3, as national settlement policies represent decisions which have already been made over a much larger set of goals and attributes than we could ever consider for this one impact. Therefore, the degree to which direct and indirect development impacts conform to these policies is a rough measure of the degree to which they are optimal in the sense of that larger set of goals.

Recommendation

Use a subjective index over the degree to which direct and indirect development impacts conform to national settlement policies. Do not consider economic impact of development, except as it relates to that larger group of interrelated objectives.

Ecological Disruption

After some thought, there seem to be two options for specifying attributes for the objective of minimizing ecological damage:

i) Select some objective measure and use it in lieu of, or as a surrogate for, a rigorous accounting, hoping that changes in this measure are positively correlated with the integral over all changes of importance in the ecosystem. Although indices, like fish or wildlife population, have been used in publised studies, measures relating to diversity in the ecosystem have been pointed out by members of the ecology group as they deal with a broader set of data and might, therefore, be more highly correlated with total impact.
One difficulty with such measures, however, is that they often may be meaningless to the decision-maker in terms he is familiar with (i.e., the attributes are not very basic).

One such set of measures is based on "Shannon's entropy."

$$H = -\sum_i p_i \log p_i$$

where p_i = the population frequency of the i^{th} population group

$= m_i/M$

m_i = number of individuals in group i

M = total number of individuals $\left(\sum_i m_i\right)$.

In conception, it would not be hard to evaluate this function over a chosen set of species, but in reality, this may not be the case. If estimates of impact are hard to make in terms of diversity, we may resort back to a simpler, yet similar attribute such as single species population.

ii) A second alternative would be to apply one of the "environmental matrix" techniques which are emerging in the literature (e.g., Leopold's work with the U.S.G.S.). Let me say that for the present I do not think this is a realistic option. Yet, I would give serious thought to this approach as it captures much of the complexity of ecosystem disruption. In essence, these methods try to display varieties and interactions of impact as related to each separate development or construction activity, then weight their importance. At present, the weighting schemes are not based on any rigorous theory of utility, or are the impact entries made with much thought of independence. Nevertheless, a little effort might go a long way in improving these techniques, and may lead to utility functions over the large set of hierarchically ecosystem impacts. But this is future work.

Recommendation

In the long run, the second approach may prove most fruitful, but it requires further theoretical work before it will have a rigorous basis and will require substantial information from ecologists. Therefore, for our first attempt at the decision-tree, I suggest we try a diversity measure like entropy. If this proves too difficult, we may fall back on population prediction for single species or on a subjective index assessed over descriptive scenarios of impacts. In either case, the result must then be weighted by some uniqueness measure of the ecosystem which might be handled subjectively.

Aesthetic Impact

Aesthetic impact may prove to be difficult, but I suspect that "benevolent dictator" utility functions may place low weight on this attribute and thus for the present it may be of little importance.

In past work, aesthetic impact has usually been defined as relating to visual quality. Practically, this has been handled by establishing a subjective scale over possible development schemes (0, for the least attractive; 1, for the most attractive), and placing options along this scale. Having subjectively developed the scale, the person being assessed has a strong feeling for its relationship to visual quality, and his preference over other attributes.

A broader approach to aesthetic impact, however, might deal with all the senses, as this is a fuller definition of aesthetic. Although each scenario in a subjective rating scale would now have multiple characteristics, defining a single attribute "aesthetic" scale over them might not be much more difficult than before. An alternative would be to relate impact to the sense of disruption the plant causes on other "aesthetically related" activities (e.g., outdoor recreation). This latter approach would include noise, smell, and the avoidance of perceived risk, as well as visual quality.

Recommendation

In the long run, I suspect we must consider some sort of aesthetic impact--if only on visual quality. For our first assessment, we might initially determine whether the decision-maker gives significant importance to aesthetics. If he does, then we should hypothesize a set of reasonable impact scenarios and attempt to assess this preference over them.

Flexibility in Future Options

This goal is straightforward conceptually, although related to tough questions of societal energy policy. The only attribute we can consider is a subjective one comparing the future development potentials of the sites in question in a (0/1) variable.

Minimize Political Risk

Having spent thirteen years within the Washington community, Prof. Perloff has several comments on the relationship between decision models of varying types and the actual political environment of decision. He very strongly made the point that if one were to order the considerations which a decision-maker in that context uses the primary one would be avoiding unexpected and politically damaging reactions to a decision. In other words, he would want to minimize the risk that an impact strongly disliked by a vocal or politically potent group is overlooked. In this context, "strongly disliked" means that level of feeling which would lead to active protest, political or otherwise. To the politician, such an outcome is different in kind, and not only in degree, from other outcomes since it relates to "losing the war" (e.g., being driven from office). In the reprocessing plant example such an outcome might mean abandoning the plant completely or having impossible technical restrictions placed upon it which would mean redesign. Clearly, a decision-maker would be highly averse toward this risk, so in a less cynical way this relates to the "opposition density" factor brought up at the Portland ANS meeting, and is perhaps more important than we have given it credit to be. Since all important impacts must be considered in an analysis--otherwise no decision-maker would ever use it--by definition, political risk must be included.

The conclusion from our discussions is to use two attributes: delay in opening the plant due to opposition, and the probability of redesign. Preferences would be assessed over these two attributes and combined with subjective probability functions to yield an expected value of utility (or disutility since the decision-maker would prefer not to have delay or to redesign) based on possible opposition.

Recommendation

1. Assess preference over delay,
2. Assess preference over redesign,
3. Assess subjective p.d.f. over delay given information on opposition,
4. Assess subjective probability of redesign given information on opposition,
5. Combine preference with probabilities to compute expected utilities.

References

[1] Avenhaus, R., W. Häfele, and P. McGrath. Large Scale Nuclear Fuel Cycle Deployment Consideration. IIASA Internal Paper, 1975.

[2] Leopold, L.B., et al. A Procedure for Evaluating Environmental Impacts. U.S.G.S. Circular No. 645, 1971.