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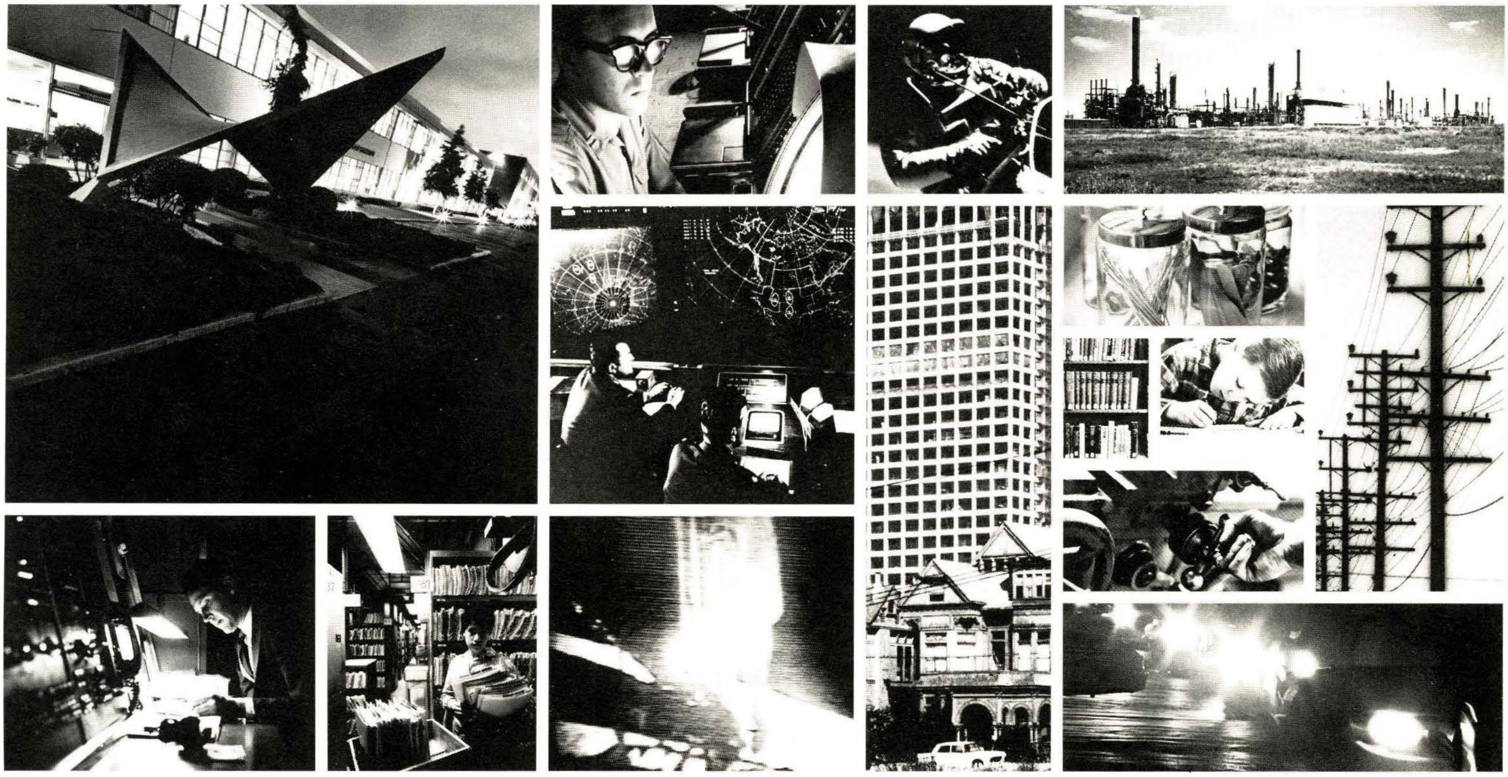

MACHINE-AIDED VALUE JUDGMENTS USING FUZZY-SET TECHNIQUES

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ABSTRACT

This paper describes a decision-aiding tool embedded within a man-machine interactive system. It is an attempt to augment and sharpen man's judgment in evaluating proposed designs or plans of actions in terms of their possible consequences (desirable and undesirable).

Man's judgment of alternative plans typically becomes less reliable when multiple criteria of varying importance must be simultaneously considered. The difficulty increases when different value orientations must be taken into account and somehow must be settled in group decision-making that affects many segments of our society.

Techniques derived from the "fuzzy-set" concept, which allow systematic and explicit treatment of fuzziness (a type of impreciseness), are employed to guide the users during the evaluative process. The interactive techniques provide immediate feedback and ease of adjusting criteria for exploring complex trade-off possibilities. Users will be able to examine a much larger number of alternatives, weighing many different factors, than they normally might before a final decision has to be made. In addition, systematic techniques for direct involvement of people (experts as well as those representing a variety of value systems) are also possible.

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INTRODUCTION

The major concern in this paper is how to evaluate programs with value-laden issues such as those that are directed toward improving the "quality of life"--any programs, in fact, having socioeconomic, ecological, political, or psychological implications. We all know that technology has given us mixed blessings and that we are paying a high price for some of the "benefits" gained. Because technology often intermeshes intimately with the social fabric, we are becoming more and more aware of the necessity for long-range planning and for assessing possible consequences of our actions. It is in this planning and problem-solving context that I am going to discuss a technique of evaluation.

To place the evaluative process in a proper setting, I shall first present a simple characterization of the four decision steps commonly found in problem solving. They are:

- Define the objectives and set appropriate criteria.
- Generate alternative courses of action.
- Identify or estimate possible consequences of each alternative.
- Evaluate the consequences in terms of the criteria and choose the alternative which best achieves the objectives.

Since the initial attempt at defining objectives and criteria is often inadequate and incomplete, these steps are usually repeated. The iterative nature of the process is shown schematically in Figure 1.

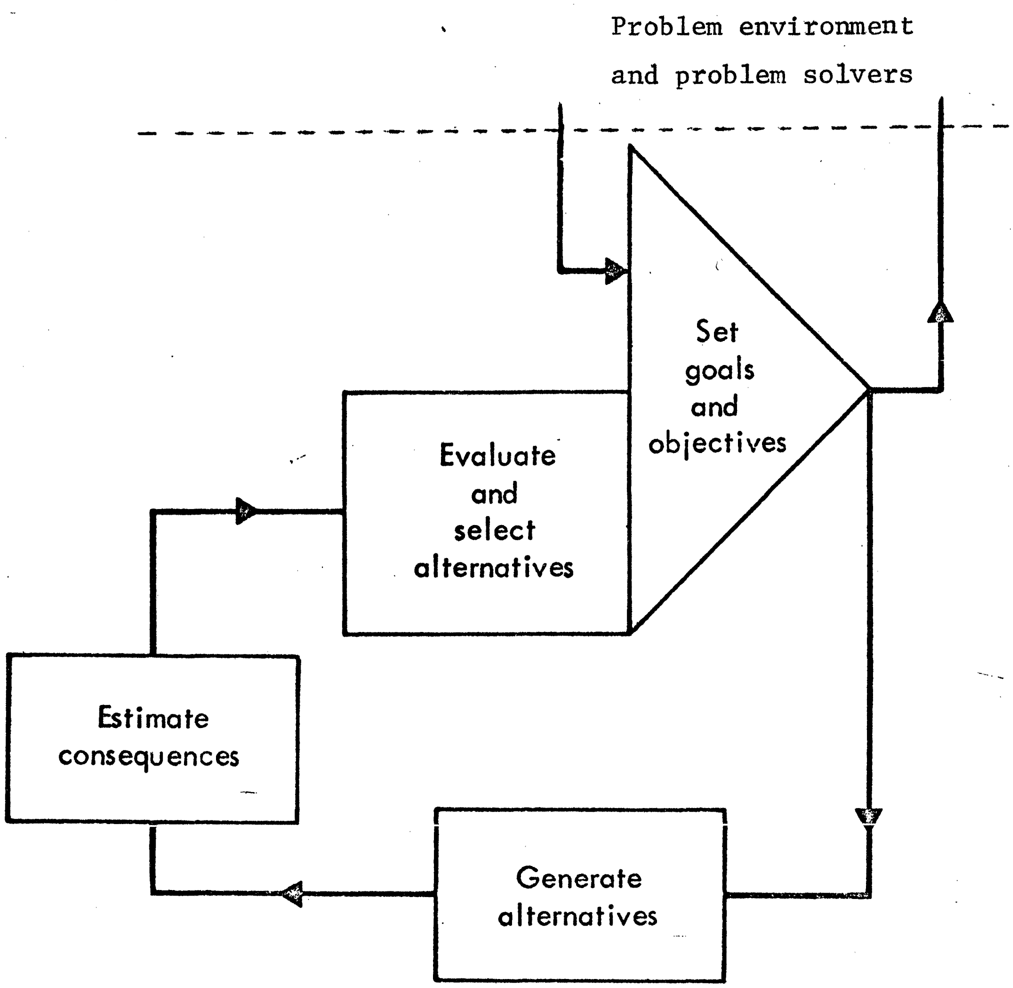

Figure 1. Iterative Decision Steps

The man-machine system, Gaku, which is currently being developed deals with these steps in detail and in many levels of planning, from a vague and aggregated conceptual stage to a concrete and detailed action-oriented stage (see Hormann [1971], Part I and II). With this background, let us assume that many alternatives have been generated and their possible consequences estimated and focus our attention on the evaluation phase of planning.

Difficulty in evaluating alternatives. Problem situations that are complex and ill defined often defy conventional cost/benefit analyses in evaluating alternative courses of action.

- In matters affecting society, criteria for evaluation of both "costs" and "benefits" are usually expressed in terms of "undesirable consequences" and "desirable consequences" and they are seldom well defined, much less quantified.

- Even if they are made explicit and quantified, a single "quantitative measure of effectiveness" is seldom adequate to summarize the issues that arise because of the variety of impacts.

- Differences in individual value orientation cause both obvious and subtle divergences in judgmental decision. Furthermore, such value systems do change over time and in different contexts, even for the same individual.

- Trade-off implications are complex and confusing even to an experienced decision maker because of the many attributes and their incommensurable values. Intuitive judgment is seldom reliable in such a situation. When the complexity of the situation exceeds the capacity of man to cope with it, oversimplification and premature conclusion often result (see reference to "cognitive economy" in Hormann [1971], part I).

<u>The approach taken and the rationale</u>. My approach to this fuzzy evaluation task is to use Gaku, the man-machine interactive system, which includes a set of techniques and programs as a tool incorporating the "fuzzy-set" concept (Zadeh [1965]). Use of this tool is the major topic of the discussion. A description of the "fuzzy-set" concept will be given later; its meaning suggested by its name will be sufficient now to permit one to understand the rationale behind our approach.

- Although the value-laden issues will never be "solved," i.e., complete agreement on all the issues or universal acceptance of proposed programs is not possible, the problems are here today and must be dealt with. We must act on the information available with techniques available now and do the best we can. The approach proposed here is an attempt to assist man to evaluate systematically and judiciously where purely analytical or purely intuitive methods are inadequate. However, we must adjust as we proceed and remain open to new ideas and techniques.

- Man-machine interactive facilities and techniques can provide immediate feedback and a flexible means of adjusting criteria for evaluation. Man will be able to examine a much larger number of alternatives, weighing many different factors, than he normally can before a final decision has to be made.

Man's judgment of alternatives typically becomes less reliable when multiple criteria of varying importance must be simultaneously considered. The machine can "evaluate" many alternatives rapidly <u>once</u> criteria for evaluation are precisely specified. In the man-machine context, man is the specifier of criteria, which he can change as he makes different interpretations of objectives and as he examines trade-off implications in the light of new findings. Immediate feedback and the ease of adjusting his previous evaluation will encourage him to explore effects of changing values on criteria settings.

- Systematic analyses of the situation supplemented by intuitive judgment is emphasized. The procedure presented here attempts to achieve consistency and comparability by explicit treatment of indeterminacy. (These points will be discussed later.) Systematic methods, such as the Delphi technique, for the direct involvement of experts as well as those representing a variety of value systems will also fit naturally into the man-machine setting.

- This approach allows inclusion of many criteria in various degrees of imprecision and at differing levels of abstraction. It may be far more serious to omit a criterion that is believed to be important, just because it cannot be made precise, than to include it at a low level of accuracy.

DESCRIPTION OF EVALUATION PROCESS

Many areas of application are in sight and I can talk about the technique in completely general terms, but an example may help to make the concept a little more clear. Suppose a group of commissioners (evaluators) are evaluating a number of proposed plans for developing a park (local, state, or national). There are many criteria for determining the desirability of such plans, but let us say that "peaceful atmosphere" and "utility to the public" are the two important ones. Since these are very general, such criteria are usually described in terms of component attributes such as "number of acres of vegetation or foliage," "number of feet or miles of streams," "variety of flowers," for the first one; and other attributes such as "number of picnic tables," "number of benches," "number and sizes of parking lots," for the second one. The latter group is relatively easy to evaluate for appropriateness since a set of "standard" numbers (per acre of park) is known. But the general criterion of "peaceful atmosphere" is much harder to represent since the total effect cannot be perceived readily from the components of the first group.

Scale models of proposed plans are often useful for visual overall evaluation, but it would be prohibitively expensive and time consuming to provide models for all the alternative designs, A_1, A_2, ... A_n, submitted.

One useful tool is a visual input/output display scope connected to a computer for man-machine interactive use.*

Here, the terrain characteristics of the park-to-be area are displayed (preferably in color) to the group of evaluators and then a proposed design of the park is displayed with an option of enlarging any part of it for display.** Some verbal descriptions and numerical information such as cost and those attributes mentioned earlier (number of picnic tables, variety of plants and flowers, etc.) can be added.

Each evaluator is now asked to give his opinion of the design A_i in relation to the criterion, "peaceful atmosphere." This is expressed as "grade of membership" (in the set of all alternatives for which the criterion applies) in terms of a number in the interval [0, 1]. If the number is close to 1, say 0.9, then A_i has a high grade of membership as far as this attribute is concerned; if it is close to 0, say 0.1, it is not a highly valued member. Since

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*See INTUVAL (Kamnitzer and Hoffman [1970]). This work concerns interactive design in urban planning, but the same facility and the technique can be extended to assist evaluators who may not be professional designers. It may be desirable to have a mixed group of specialist-designers, government officials, representatives of diverse civic groups, etc., to avoid personal biases as much as possible.

**Ideally, each evaluator should be provided with an interactive facility. The evaluators work independently but can interact with each other through the system.

To approach realism in evaluation, an existing park of similar size and purpose (if possible, one that nearly everyone likes) may be chosen. Photographs of this actual park and a display of how it looks in abstraction will facilitate understanding of how a proposed park will be expected to look.

comparability is important in qualitative judgment, other alternative designs from A_1, A_2 ... A_n can be displayed one or two at a time for comparison. The evaluator can change his mind about the values he previously chose. The "grade of membership" he gives for the first design alternative he considers may be more or less arbitrary, but as he proceeds in the comparing process, the values tend to indicate the relative merits of the proposed designs.

All evaluators in the group make their evaluations independently of each other, so the set of values collected may differ greatly. Group interaction with or without anonymity and reevaluation of the set of values can be the subsequent step, using the on-line or off-line Delphi technique* (more about this will be discussed later), or the evaluators can proceed to another attribute, still independently of each other. The only thing they must agree on first is the initial set of attributes. These can be changed later, but the group must agree on the changes.

Fuzzy-set concept. I have tried to set a stage for an intuitive understanding of the "fuzzy-set" concept in the above discussion. Let us now clarify the notion of "grade of membership." Suppose X is the set of all alternatives. Let

*See Dalkey [1969] and Helmer [1966]. The technique was initially used for soliciting and collating experts' opinions in long-range forecasting, but many experiments have been conducted with members of the public for estimating desirability of certain programs, and understanding people's attitudes and value orientations. The major characteristics of the technique are anonymity, iteration and controlled feedback, and statistical group response.

A be a subset of X for which attribute α applies. In our park example, α may be "peaceful atmosphere." A person's subjective preference judgment can be represented by a preference relation which associates A_i with a number in the interval [0, 1]. To this relation, I have assigned the symbol R. The value $R_\alpha(A_i)$ represents the "grade of membership" of A_i in set A (see Figure 2).*

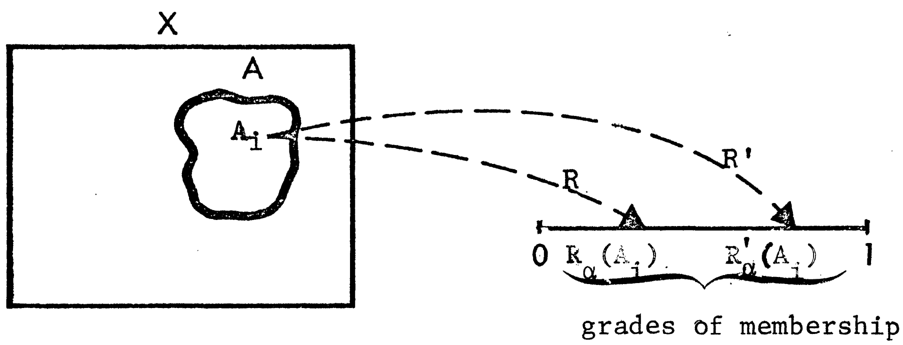


Figure 2. Fuzzy-Set Association

The two values, R_α and R'_α show a possible difference in two persons' judgments about A_i on its grade of membership for attribute α. This tends to make more visible subtle individual differences in value orientation.

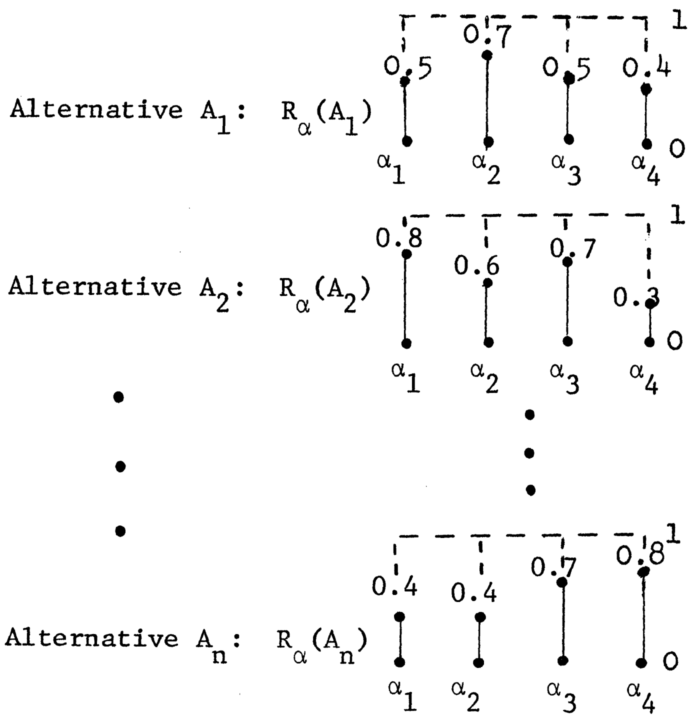
*If an attribute can be defined in a non-fuzzy fashion for which a "yes" or "no" answer (1 or 0 value) can be given, then its membership function becomes identical with the characteristic function of a nonfuzzy set.

Trade-off considerations. One of the most important benefits we get from the use of this notion is that trade-off concepts can now be dealt with quantitatively. Suppose in our example of the park design, "utility to the public" has also been graded for each alternative. One factor of utility to the public may be "accessibility to many parts of the park by car." But many people feel strongly that this requirement will be in conflict with "peaceful atmosphere." It is true, but exclusive concentration on "peaceful atmosphere" and little accessibility will deprive some segments of the public (e.g., those who are infirm) from enjoying the total facility. Then, trade-off implications must be explored. Questions such as "How much 'peaceful atmosphere' can be traded for how much 'public utility'?", which were meaningless in conventional evaluation, can now be treated sensibly because the two attributes are now comparable, represented by the same unit of measurement (see Figure 3).

Even if all attributes were quantified (e.g., number of picnic tables, number of flowering plants, etc.), they are still incommensurable and the trade-off concept does not apply. It is, therefore, important to evaluate grades of membership for all the attributes, even though some attributes are naturally quantifiable, such as "cost of developing the park" and "cost of maintenance." Here, costs are still evaluated on a comparative basis.

The essence of this approach can be stated as follows: If it is inappropriate to quantify everything and reduce the measures to one single "measure of effectiveness", then change everything into value-oriented judgment.

Figure 3 shows the comparability of alternatives and attributes*



α_1 = peaceful atmosphere

α_2 = utility to the public

α_3 = cost of development

α_4 = cost of maintenance

Figure 3. Trade-Off Comparison of Attributes and Alternatives

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*In Figure 3, costs are shown in their grades of membership as the "preference" measure. Therefore, the lower cost, which is usually preferred, is rated high (the longer vertical line), and the higher cost is rated low (the shorter vertical line); this may be counterintuitive. The evaluators may prefer to group together as "cost" all the attributes that should be minimized (e.g., pollution and noise) and as "benefits" all the attributes that should be maximized. Then these two groups are displayed separately (side-by-side but grouped together) and new values, $R'_\alpha = 1 - R_\alpha$, will be used for "cost" attributes (then a high cost shows a high vertical line).

There can be interesting derivatives of this kind of exercise. As the evaluators made trade-off studies, new insights may be gained into the issues at hand and new ideas on modifications or compromises may be proposed. The designer then may be consulted to check the feasibility and the cost of such changes. Or, the insight may be in the recognition that new attributes should be added: old ones deleted, expanded, subdivided, or several combined into one.

Even after all the attributes have been considered for all the alternatives, those values and vertical lines, though comparable, do not constitute the making of an overall judgment. One way to facilitate it is to calculate the summation $S_j = \sum_{i=1}^{m} w_i R_{\alpha_i} (A_j)$ of all the weighted "grade of membership" values over m attributes for each alternative.* Now comparing the summations is a meaningful operation and can be done by the computer very rapdily.** These S_j's are called summary values.

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* w_i is a weighting specification to represent the relative importance of α_i (ranking of attributes and weighting will be discussed later).

** This form of getting a single value for each alternative is not the only way. Some nonlinear or nonuniform ways may be used to account for different contributions of attributes.

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