A CHOICE SYSTEM FOR ENVIRONMENTAL DESIGN AND DEVELOPMENT

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ABSTRACT

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Submitted to the Department of City and Regional Planning on January 13, 1969 in partial fulfillment of the requirement for the degree of Doctor of Philosophy in City and Regional Planning.

This research has been directed towards the development of a computer-aided evaluation system for use in environmental planning and design. The system is called CHOICE.

An introduction to utility and social welfare theory as well as an understanding of the nature of environmental design problems provides the basis for representing choice. Measurement models of design and evaluation are suggested as the formal construct on which the system is based.

CHOICE may be thought of as an urban accounting system which permits the planner to rapidly compare and analyze proposed actions and objectives. The planner may perform complex cost/benefit analysis with respect to more than one group or individual. He may check alternative programs for fulfillment of absolute criteria and test alternative objectives for conflicting specification.

CHOICE is implemented on M.I.T.'s CTSS time-sharing computer system. This allows the planner to have a flexible method for specifying alternative evaluation schemes. He may define each evaluation account, the relative preferences and absolute goals associated with each evaluation, and the parameters on which evaluations are to be performed.

The consequences to be evaluated may be directly specified by the planner or accessed from other simulation or design models. The planner may input these consequences in either an ordinal or cardinal form, thus allowing him to represent judgments as well as measured parameters. He may combine cardinal and ordinal representations to obtain a variety of measurement scales. The use of multiple accounts allows the planner to represent time-series outcomes. Operations for computing cumulative totals, rates of change, and discounted present value are available. Operations also permit statistics of mean and standard deviation to be performed. The

planner may employ matrix and arithmetic operations such as weighted sum, difference, total, and number of occurrences. Expected values can be computed by specifying probability of an event's occurrences. CHOICE permits the planner to define and test alternative benefit, cost, effectiveness, or utility functions. He may design social welfare functions and voting schemes. The flexibility of the system permits the planner to rapidly alter evaluation arguments such as weighting assumptions, probabilities, interest rates, and definitions of the accounts.

Experiments in the use of alternative choice rules provide a demonstration of different types of evaluation schemes.

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CHAPTER 1. INTRODUCTION

1.1 Purposes and Outline of Research

The purpose of this research is to identify some basic operations of evaluation and choice which can represent part of the decision-making process of environmental planning and design. Such an identification provides the basis to develop a computer-aided system for performing these operations rapidly, precisely, and consistently.

Problems of environmental planning and design are characterized by many criteria for evaluation and choice. Often these criteria are non-economic, lying outside the private marketplace for determining efficiency of resource allocations. Public decision-making assumes the additional burden of equity or distribution of consequences as well as efficiency or total level of results. In general, many groups and individuals are concerned about the consequences of implementing a proposed set of actions. Each evaluator seeks to bring its own set of objectives, aspirations, and needs to bear on the problem.

This research seeks to provide a structure for representing such multiple evaluation and choice criteria. No specific procedure or criterion shall be championed. Rather, the objective is to generalize a common set of operations from alternative evaluation schemes in order to construct a computer-aided system which allows different choices to be derived.

The introductory section of this research outlines the various positions held by different proponents of evaluation schemes. It shall be argued that the problem of stating rational choice has been conceptually solved, but the provision for a generalized framework for choices which do not satisfy its conditions has not been stated. In addition to the remarks about rigorous evaluation and choice, the introduction shall include a summary of the types of measurement scales and kinds of measurement operations. These form the basis for the computer-aided system of evaluation and choice.

The second section of this research deals with representing a planning or design project for evaluation and choice. A "measurement model of design" shall be suggested. This model is extended to represent the project over time and under uncertainty.

The third section describes a "measurement model of evaluation and choice." Operations of evaluation and accounts for making choices are defined and related to the design model. The explicit framework for deriving choice criteria is defined.

The next section presents the computer-aided evaluation system called CHOICE. This system provides a data structure and set of commands which allows a planner to define criteria, measure and compare alternative proposals, and generate consequences of choice by specifying different preference orderings. CHOICE permits one to design the evaluation scheme and learn about consequences of choice which the model produces. The system is introduced by illustrating different evaluation schemes and operations. Finally, an experiment using the system to generate different choices is presented.

The last section points to additional uses of CHOICE as a planning management tool for use in program budgeting and control. The experiences of using the system are noted for areas in which CHOICE can be extended and improved in terms of new or easier operations.

1.2 Design Evaluation and Choice

Bross,[1] in his discussion of decision-making, entitles a section, "The Problem of Choice: Alternative Futures and Conflicting Values." Alternative futures are represented as the different possible results which one may expect from an implemented set of actions. Conflicting values indicate the limited resources and the various objectives and needs of different evaluators.

There are three components to Bross' decision model: a prediction system for projecting, estimating or predicting future results from proposed actions; a value system for determining the desirability of

[1] Irwin D. Bross, Design for Decision, Free Press, New York, 1953, p. vii.

predicted outcomes; and a choice rule for selecting among the different desirabilities of alternative outcomes.

Manheim[2] groups these components of prediction, evaluation, and choice into the problem-solving activity of "selection." He couples selection to a second set of operations called "search." Search represents the specification of alternative actions.

To Bross' scheme for describing the problem of choice, one must add the condition of alternative sets of proposed actions, each one of which may precipitate an uncertain set of possible futures.

Such a scheme of proposing alternative actions, predicting distributions of possible consequences from each action, evaluating these consequences, and choosing the preferred action-consequence combination is very familiar to the literature of decision theory.[3] Much criticism exists regarding the irrelevance of such a structured decision-making approach in the

[2]Marvin L. Manheim, "Problem-solving Processes in Planning and Design," Technical Paper P-67-3, Department of Civil Engineering, M.I.T., January, 1967.

[3]As a reference to this model applied to planning, see Paul Davidoff and Thomas A. Reiner, "A Choice Theory of Planning," Journal of the American Institute of Planners, Vol. XXVII, No. 1, February, 1962, pp. 103-115. For extensive references to decision theory, see John W. Dyckman, "Planning and Decision Theory," Journal of the American Institute of Planners, Vol. XXVI, No. 4, November, 1961, pp. 333-345.

pragmatic world of actual choice. Braybrooke and Lindblom[4] call the formal approach "synoptic" and criticize its requirements for inadaptability in a changing problem setting and its severe informational requirements from which choices are derived. They argue that incremental choices, remedial and serial in nature, are more appropriate in actual planning situations.

In a sense, the dichotomy between synoptic and incremental approaches is the same raised by Ackoff's definition of evaluative and developmental research.[5] An evaluative problem is one in which the alternative courses of action are completely specified in advance and the solution consists of selecting the "best" of these. A developmental problem, on the other hand, involves searching for (and perhaps construction or synthesis of) instruments which yield a course of action that is better than any available at the time.

This dichotomy may seem strained to anyone with planning and design experience. One would assume that many choices take place throughout the developmental process of suggesting and selecting actions to be

[4]D. Braybrooke and C. W. Lindblom, A Strategy for Decision, Free Press, New York, 1963.

[5]Russell L. Ackoff, Scientific Method: Optimizing Applied Research Decisions, John Wiley and Sons, Inc., New York, 1962, p. 24.

implemented. However, choice by definition only occurs when alternatives are available from which to choose. The CHOICE system presented in this research is evaluative in nature, dealing with a set of existing alternatives from which to choose. The system, however, is structured in such a way to be available for use whenever choices must be made during the developmental process of planning and design. Consequences of selection for a given set of alternatives and evaluation schemes can be used as new information in an ongoing decision process. CHOICE is viewed as but one set of operations available in an unspecified process of determining appropriate future actions.

CHAPTER 2. UTILITY AND SOCIAL WELFARE THEORY

2.1 Interpretations

Theories of utility and social welfare deal with people's choices and judgments of preference. The literature pertaining to this concern is extensive,[1] but generally can be discussed in either prescriptive (normative) or predictive (behavioral) interpretations. The prescriptive theory emphasizes how choices ought to be made based on a set of consistent assumptions for computing preferences.

The primary purpose of prescriptive utility theory is in helping a decision-maker explicitly identify preferences. The prescriptive structure can help one to learn about his preferences among complex alternatives. The effect of most assumptions in prescriptive utility theory is to give order and structure to an individual's preference. His initial preference statements are transformed into corresponding numerical data which is manipulated to derive numerical utility comparisons between actual alternatives. One must assume the comparison of complex alternatives in terms of preferences. This does not mean such comparisons are easy to make. It does imply, however, that such operations are helpful in discovering preferences between alternatives which are difficult to compare.

[1]For a complete review, see Peter C. Fishburn, "Utility Theory," Management Science, Vol. 14, No. 5, January, 1968, pp. 335-378. In this article, Fishburn cites 315 references to utility theory. The above introductory remarks are based on his summary.

If, as Fishburn suggests, a utility theory consists of a set of assumptions about the available courses of action and preference statements assigned to properties of these actions, then such familiar evaluation schemes as cost-benefit analysis and statistical decision theory are forms of a utility theory. Both provide a set of consistent assumptions and preference rules for selecting preferred actions.[2] The range of arguments surrounding the construction of choice rules leads one to believe no claims for the set of rules to be used for evaluation.

2.2 Optimal Choice

The classical prescriptive for choice based on a single criterion is well documented.[3] The formal theory of the firm is based on profit maximization which occurs when marginal revenue equals marginal costs. Mathematical derivation of this argument indicates that a firm should utilize each resource input to a point where the value of its marginal productivity equals its price. Similarly, the basic postulate of consumer theory is that he maximizes utility. With limited income, the consumer maximizes utility subject to a budget constraint. Mathematically, the ratio of the marginal utilities of each commodity consumed must be equal to the price

[2] For a collection of writings on various theories and assumptions on which they are based, see Utility Theory: A Book of Readings, edited by Alfred N. Page, John Wiley and Sons, Inc., New York, 1968.

[3] A comprehensive mathematical development of consumer behavior and the firm is available by James M. Henderson and R. E. Quandt, Microeconomic Theory, McGraw-Hill, New York, 1958, Chapters 1 and 2.

ratio of the commodities. Analogous arguments for optimal level public expenditures are developed for the maximization of net benefits, a form of social profit. When both the level and distribution of net benefits is of concern, the optimal conditions are met when the marginal contribution of relaxing each budget constraint is equal.[4] Such a cursory treatment is given to the formal development of utility because the conceptual problem has been solved as indicated by the references and the mathematical conditions necessary for their relevant application are so severe.

2.3 Welfare Analysis and CHOICE

Rothenberg identifies the following elements in a structure of welfare analysis:[5]

(1.) The subjects referred to by the analysis (i.e., the individuals or groups whose welfare is of concern).

(2.) The set of assertions, E, defining the welfare ends or goals.

[4] Robert Dorfman, "Basic Economic and Technological Concepts: A General Statement," in Design of Water-Resource Systems, Arthur Maass, et al, Harvard University Press, 1966, pp. 88-158. Also see Chapters 2 and 4, Stephen A. Marglin, for optimal conditions for budget constrained project design.

[5] Jerome Rothenberg, The Measurement of Social Welfare, Prentice-Hall, Englewood Cliffs, New Jersey, 1961, pp. 6-7.

(3.) The particular set of alternative policies, P, whose ordering is the basis for choice.

(4.) The set of consequence states, S, deriving from policies, P.

(5.) The laws, L, relating the derivation of S from P.

(6.) The criterion, C, by which the consequence states are ordered in terms of the degree to which they fulfill the welfare ends, E.

He suggests that a particular policy is chosen if the set of welfare ends, E, and the criterion for choice, C, are accepted by the decision-maker. The ends and criterion for choice are not absolute truths. Ends are definitions; choice criteria are rules. They cannot be proved or disproved by observation. Both the welfare ends and criterion for choice are value judgments. Welfare analysis, therefore, consists of generating the choice implications from the value judgments of ends and criteria for describing how well different alternatives fulfill these ends.

The approach taken in developing the CHOICE system is one of devising a structure for operating on the value judgments of ends and criteria. The facility allows one to explicitly state the preferences, measurements, and utility or welfare functions in order to generate a prescriptive choice. The system does not contain a behavioral or predictive capability. It could, however, be viewed as a logical equivalent to a behavioral process of choice. In that respect, the CHOICE SYSTEM can be used to construct a set of definitions and rules which allows an explicit representation of making a choice. This representation may assist the decision-maker in his understanding of the choice problem.

CHAPTER 3. MEASUREMENT

3.1 Definition

The literature of measurement seems to have grown rapidly during the early 1950's when the attention of contributors was focused on qualification versus quantification in the field of perception and psychology. The following is a summary of that discussion and conclusions drawn to help understand the issues of evaluation in environmental design. This introduction provides the necessary conditions to perform computer-aided evaluation and choice.

Measurement is defined as "the assignment of numerals to objects or events according to rules -- any rule."[1] Only random assignment of numbers is excluded measurement. Stevens' basic point is that once a set of items is measured by numerical assignment according to rules, the assignments may be transformed by whatever functions will preserve the empirical information contained in the measurement scale. Hodge,[2] however, suggests that problems of measurement in city planning stem from a lack of adherence to the rules for constructing and operating on

[1] S. S. Stevens, "Measurement, Psychophysics, and Utility," Measurement: Definitions and Theories, edited by C. W. Churchman and P. Ratoosh, John Wiley and Sons, New York, 1959, p. 19.

[2] Gerald Hodge, "Use and Mis-Use of Measurement Scales in City Planning," Journal of the American Institute of Planners, Vol. XXVIII, No. 2, pp. 112-121.

measurement scales. The CHOICE system represents a set of measurement scales and operations for performing evaluation. Its use, however, is also limited to the same rules of measurement.

3.2 Types of Measurement Scales

Torgerson's[3] discussion of measurement will serve well in outlining the range of measurement concerns. He suggests that we cannot "measure" objects or systems of interest, only properties which define the system. With little disagreement among the various contributors to the field, three types of scales are identified by the following characteristics:

(1.) order

(2.) difference

(3.) origin.

Torgerson continues:

> "For some, but not necessarily all properties, it is possible to give empirical meaning to one or more characteristics which are analogous to the characteristics of numbers listed above (order, difference, origin). It is then possible to establish a one-to-one relationship between objects possessing this property and those characteristics of numbers. Numbers are then assigned to the objects so that the relations between numbers reflect the relations between the objects themselves with respect to the property. Having done so, we have measured the property; i.e., established a scale of measurement."

[3]Warren S. Torgerson, Theory and Methods of Scaling, John Wiley and Sons, Inc., New York, 1958, Chapters 1, 2, and 3.

Nominal scales have no order, distance, or origin. Values assigned to such scales represent classifications. Correspondence between numeral and object is all that is required. Counting is the only available operation. Numerals on players' uniforms is a nominal measurement.

Ordinal scales describe the relation of differences between pairs of objects. Assigned numbers represent the order of magnitude of the property. The relationships of "greater than, less than, or equal to," describe rankings of objects relative to each other. No arithmetic operations are permitted; any monotonically increasing transformation is order preserving. Ranking contestants of a race in the order of their finishing is an example.

An interval scale includes ordinal information as well as a measure of the distance between pairs of objects. Multiplication and division are permitted as well as addition and subtraction of these differences; any linear transformation ($y = ax + b$) preserves both the order and distance relationships of the original assignment. Interval scales have an arbitrary origin. Temperature scales are examples of interval measurement.

Ratio scales include order and distance relationships as well as having a fixed origin for permitting addition of assigned values. All arithmetic operations can be performed on values; transformations which do not change the origin (y = ax) preserve order, distance, and ratio characteristics.

Additional scales of measurement are summarized by Fishburn.[4] These include partially ordered, bounded interval and ordered metrics. It is sufficient to say that these additional scales can be formed by using combinations of ordinal, interval, and ratio scales. Their use seems to be beyond the scope of most evaluation efforts, even though Fishburn maintains such scales represent an evaluator's sense of "relative value" between different consequences.

3.3 Kinds of Measurement Functions

Types of measurement scales are based on characteristics of order, distance, and origin. The type of scale indicates how much information about the property is contained in the numerical representation. Kinds of measurement functions, however, deal with the operations which assign values to a particular scale. The kind of measurement function describes how the representation was formed or valuation was made. It should be noted that values assigned to a particular scale can be a mixture of different kinds of measurement functions.

[4]Peter C. Fishburn, Decision and Value Theory, John Wiley and Sons, New York, 1964, Chapter 4. He suggests that many scales are needed in order to represent an evaluator's different states of information and certainty regarding the worth of alternative actions.

Torgerson suggests three types of measurement functions:

(1.) Derived measurement.

The property represented on a scale derives its meaning through laws relating the property to other properties. For example,

Density = mass/volume.

A derived measurement is an explicit transformation which accepts measured properties as arguments (mass, volume) and assigns the value to a dependent scale (density) by a set of operations or functions such as division in the above example.

(2.) Fundamental measurement.

Fundamental measurement is a means by which numbers can be assigned according to natural laws to represent the property but does not presuppose the measurement of any other variable.

Length = units of length observed

(3.) Definitional or arbitrary measurement.

Measurement by definition depends on a presumed relationship between some set of observed property and the measured property. Definitional measurement has no set of natural laws by which the indice's relation to different quantities can be tested. Definitional measurement is a looser form of derived measurement.

Socio-economic Index = arbitrary function of income, job status, educational level, etc.

3.4 Measurement and the CHOICE System

All types of measurement scales and kinds of measurement functions described above can be represented in the CHOICE system. It should be noted, however, that most operations are performed on ordinal or ratio scales. The nominal scale is a more general type of classification scheme not readily used in evaluation except to check for the existence of a property. CHOICE does not work well as a descriptive system for design.

In CHOICE, interval and ratio scales are represented as floating-point numbers; ordinal rankings as integers. Because values assigned to different scales may be represented simultaneously, ordering the differences between pairs of objects (i.e., both ordinal and interval measurements) permits all types of scales to be represented as combinations of measurements.

The task of evaluation and choice in environmental design is often more complicated than the explicit kinds of measurement functions just described. One may not be able to explicitly define the rule which, according to Stevens, is essential to measurement. Fundamental and derived measurements may be implicitly represented by the evaluator's judgments. In CHOICE, he may explicitly derive measurements or assign values to scales after making judgments which imply rules that cannot be represented by formal means.

CHAPTER 4. A MEASUREMENT MODEL OF DESIGN

4.1 The Dimensions of Design

The description of a design project at any particular moment or the dynamics of the project over any given time interval takes a large number of aspects into consideration. The choice of qualities referred to in the design project depends on the persons making the description (e.g., designer, client, customer, contractor, etc.). These qualities used to describe the design project will be referred to as "the dimensions of design." The dimensions of design are different measurement scales as previously defined.

The number and types of design dimensions in community-scale projects is very large. Roger Lewis[1] attempts to list these dimensions and classify them according to shared characteristics. His research points up the open-ended quality of specifying a set of design dimensions. One's ability to generate an exhaustive set of dimensions is by no means certain. It is assumed, therefore, that some subject of all dimensions is sufficient for any one description of design. It is further assumed that the number of dimensions necessary for making choices about the design project is finite.

[1]Roger K. Lewis, Community-Scale Design Variables, Master's Thesis in Architecture, M.I.T., July, 1967.

From Lewis' point of view, some of the sets of relevant dimensions describing community design are summarized as follows:

A. CONTEXT VARIABLES

Physical Site

Geography
Topology
Climate
Composition

Population

Behavioral
Cultural
Social
Political
Economic
Composition

B. PARTICIPANTS

Designers
Consultants
Clients
Underwriters
Producers

C. GOALS

Performance

Comfort
Safety
"Fit"
Activity

D. PHYSICAL CONSTRUCTS

Structures

Surfaces
Volumes
Lineals
Conduits
Connections

Landforms

Earth
Water
Vegetation

4.2 Design as Dimensional Transformation and Value Specification

In an attempt to describe the development of an engineering project, Ramstrom and Rhenman[2] define project dimensions of needs, control, engineering and product. The design process can be formally described as "a transformation of the problem defined in the space formed by the need dimensions to the solution given in the space formed by the product dimensions."

[2] D. Ramstrom and E. Rhenman, "A Method of Describing the Development of an Engineering Project," IEEE Transactions on Engineering Management, Vol. EM-12, No. 3, September, 1965.

The problem-solving process involves choosing relevant product dimensions and assigning values to these dimensions. In order to choose the relevant product dimensions, a transformation of need to product takes place by utilizing control and engineering dimensions as outlined below:

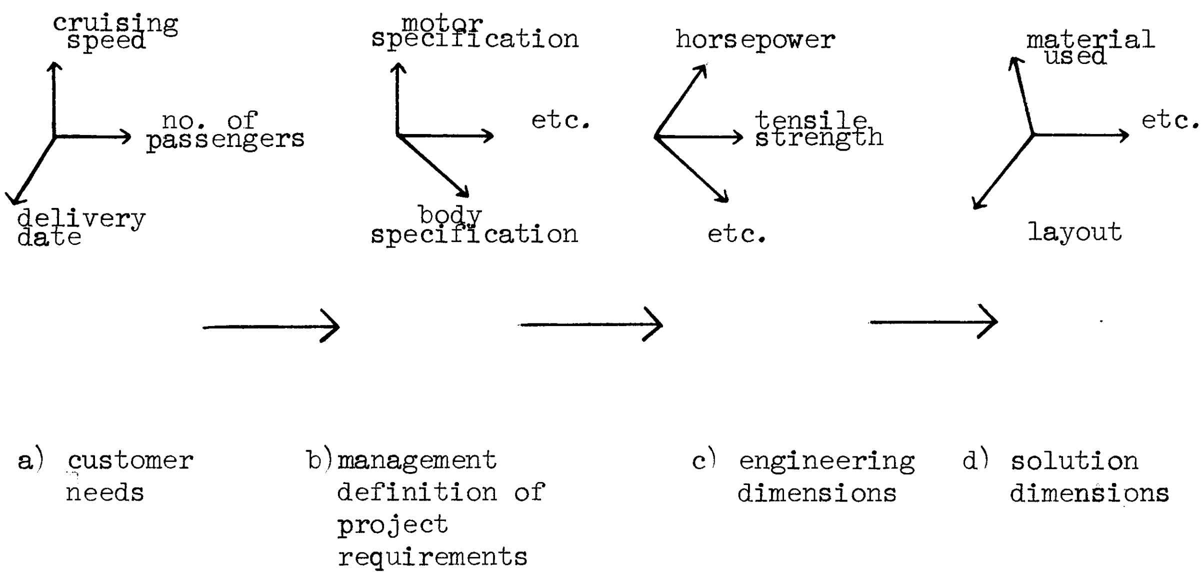


Fig. . Transformation from "need space" to "product space." (a) The case where N_1, N_2, and N_3 are the dimensions used to describe "the needs of the customer." (b) Management uses N_1 and N_3 in combination with two control dimensions C_1 and C_2, which may be regarded as a reformulation of N_2. (c) The engineers apply engineering dimensions E_1, E_2, etc., in the translation of need to product dimensions. (d) The design is ultimately described in three product dimensions P_1, P_2, and P_3.

Ramstrom and Rhenman recognized that such a transformation is not linear, but includes reformation of the various dimensions and values as new information is generated in design.

From these two examples, one sees the vast number and types of dimensions that can be considered in community design projects and the changing transformations from one set to another as problems and solutions are recognized and specified. The remainder of this section shall be devoted to a formal presentation of the dimensions of design. Two forms of the dimensionsl model shall be defined. The first, a parametric form, shall include all possible types of dimensions much like the Lewis example. The second, a metric form, shall be restricted to dimensions where distance can be measured in the spirit of the "spaces" discussed by Ramstrom and Rhenman.

4.3 Two Dimensional Representations: Parametric and Metric Forms

Two forms of representation will be used to introduce the measurement model of design. The first form will be called "parametric"; the second, "metric." The parametric form is more inclusive, for it merely classifies a project by values on any type of dimension or measurement scale. A parameter is defined as an arbitrary constant characterizing a particular element by each of its values. The metric form presents a model of design where distances and origins of measurement scales are defined. The metric form is a special case of the parametric form, limited to those dimensions which have distance defined (at least an interval scale.) The metric form is useful, because it permits a design project to be visualized as points in a space of design dimensions.

4.4 The Parametric Form

Let us assume that many important aspects of a design project can be identified at least by a name. These aspects of a design shall be referred to as the "parameters of design."

One can see that the set of design parameters encompasses the many considerations of environmental quality, costs, distributions of benefits, responsibilities, jurisdictions, locations, etc., which are familiar to persons dealing in urban planning and design. One can also see that the set of parameters represent different types of measurement scales, some indicating existence or absence, quantity or quality, of the various aspects of a design project.

> Definition 1: A design parameter, p_j, is a measurement scale of some aspect of the design. It is assumed that a design project can be represented by values assigned to a finite number of parameters, p_1, p_2, p_n.

P is the set of all design parameters.

A design project, however, is more complex than a single set of values assigned to the design parameters. A design is in fact a set or sets of values assigned to the design parameters. There are many different specifications used to represent the many different elements of a project. Environmental design projects are characterized by a multiplicity of parameters and many sets of values assigned to these parameters.

> Definition 2: A design element, e_1, is a set of values assigned to the design parameters, p. A design element, e_i, $= p_{i1}, p_{i2}, \ldots, p_{in}$ where p_{ij} is the i-th value of the j-th parameter.

E is the set of all design elements.

A design element, e_i, is a unique assignment of at least one design parameter, p_j. If two "elements", e_i and e_j, have the same values on every parameter, they are defined as the same element.

A design project, D_m, is a set of design elements. Each element is uniquely defined by an n-tuple of parameter values; each design project is merely a collection of such elements.

> <u>Definition 3</u>: A <u>design project</u>, D_m, is the set of all design elements, E. $D_m = (e_1, e_2, \ldots, e_m)$ where each element, $e_i = p_{i1}, p_{i2}, \cdots, p_{in}$, is an n-tuple of values assigned to the design parameters.

A design project, D_n, is distinguishable as an <u>alternative</u> from design, D_m, if one of the following conditions occurs:

(1.) Different values are assigned to the same set of design parameters.

$$D_m = (e_1, e_2, \ldots, e_k, \ldots, e_m)$$

$$\text{where } e_k = p_{k1}, p_{k2}, \cdots, p_{kn}$$

and

$$D_n = (e_1, e_2, \ldots, e_k, \ldots, e_m)$$

$$\text{but } e_k = p_{k1}, p_{k2}{}^{*}, \cdots, p_{kn}$$

such that $p_{k2} \neq p_{k2}{}^{*}$.

Thus, $(e_k)_m$ does not correspond to $(e_k)_n$.

(2.) Different parameters define different sets of design elements.

$$D_m = (e_1, e_2, \ldots, e_k, \ldots, e_m)$$

$$\text{where } e_k = p_{k1}, p_{k2}, \ldots, p_{kn}$$

and

$$D_n = (e_1, e_2, \ldots, e_k, \ldots, e_m)$$

$$\text{but } e_k = p_{k1}, p_{k2}, \ldots, p_{kn}, p_{kn+1}.$$

Thus, $(e_k)_m$ does not correspond to $(e_k)_n$ because different parameters define the elements. This is a special case of (1.) in which the value of a non-specified parameter is assumed to be zero.

(3.) Different elements simply define different designs.

$$D_m = (e_1, e_2, \ldots, e_m)$$

and

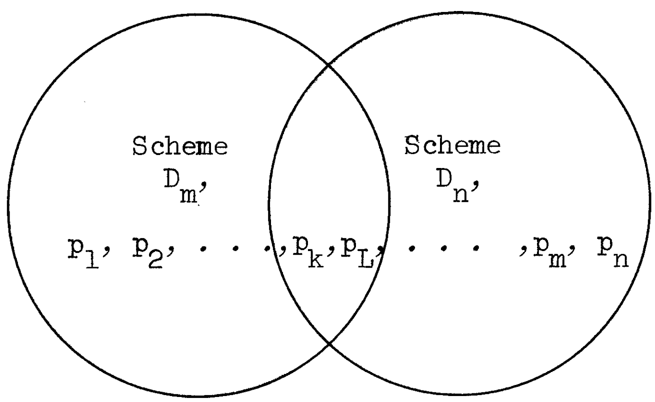
$$D_n = (e_1, e_2, \ldots, e_{m+1})$$

This is also a special case of (1.) in which all values of the missing element in D_m are assumed to be zero.

> <u>Definition 4</u>: A design, D_n, is a distinct <u>alternative</u> to design, D_m, when the values assigned to each parameter for each element do not correspond.

A designer's use of the term "alternative" usually refers to "schemes" or designs which have easily recognized sets of obviously different parameters (2.) or elements (3.). In the field of technological research and development this type of alternative scheme is often generated by parallel design efforts such as Boeing versus Lockheed in the SST competition. Case (1.) is a more subtle form of presenting alternative designs. This type of alternative is often the result of sequential specification of several values on the same parameter in order to evaluate their implications.

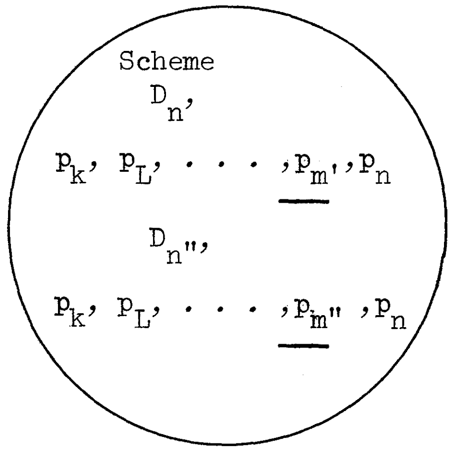
At any stage of specification, all types of alternatives may exist. This situation can be represented as follows:



where the elements of D_m are defined by values of parameters p_1, ... , p_L, and the elements of D_n by values on parameters p_k, p_L, ... , p_n.

Both schemes share assignment of values on common parameters, p_k, p_L.

Each scheme, however, may have alternative specifications on its own set of design parameters. This can be represented as a common element, e_i, having two alternative specifications on one parameter, p_m.



where the element e_i of D_n' has some
value $\underline{p_m}'$ on the m-th parameter, and
the same element of $D_n"$ has a different
value $\underline{p_m}" \neq \underline{p_m}'$.

In further discussions no distinctions shall be made between schemes and alternatives of a particular scheme. It shall suffice that an "alternative" design does not have a 1:1 correspondence of values for each element on each parameter. Both types of noncorrespondence discussed above shall be termed <u>alternative</u> specifications.

4.5 The Metric Form

The metric form of the measurement model of design is more restricted. A "metric" is an aspect of a design which can be defined in terms of a quantity. The term metric shall be used to denote a dimension on which distance or interval between values is defined. In this more limited sense, a design metric defines a Euclidean or vector space.

Gerard Debreu[3] uses such a concept to construct a choice framework in an economic setting. Although the formal treatment is well beyond the scope of this research, his definition of dates, locations, and commodities fit this discussion of the metric form.[4]

(1.) Time: The interval of time over which an activity takes place is divided into a finite number of compact elementary intervals of equal length. These elementary intervals are numbered in chronological order; the origin is the present. The unit length is chosen small enough for all the instants of an elementary interval to be indistinguishable from the point of view of the analysis. An elementary interval is called a date.

[3] Gerard Debreu, Theory of Value: An Axiomatic Analysis of Economic Equilibrium, Monograph #17, Cowles Foundation, John Wiley & Sons, Inc., New York, 1959.

[4] Debreu. Ibid. pp. 29-30. The discussion on time, location, and commodities is paraphrased for compactness.

(2.) Location: A region of geographic space over which an activity takes place is divided into a finite number of compact elementary regions. These regions are chosen small enough for all the points within one of them to be indistinguishable from the points of view of the analysis. An elementary region is called a location.

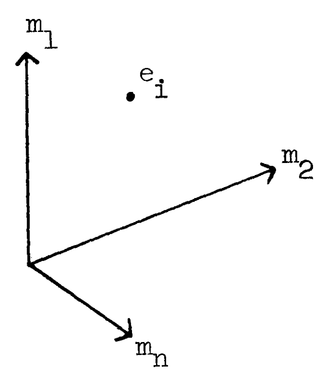
(3.) Commodity: A commodity is defined by a specification of all its physical characteristics, its date, and location. A quantity of a commodity is expressed by any (non-negative) real number. It is assumed that there is a finite number of k distinguishable commodities. The space R^k is called the commodity space. An action is a specification for each commodity of the quantity. An action is a point, a, in space, R^k.

Definitions 1, 2, and 3 can be rephrased in a metric form as follows:

Definition 1B: A design metric, m_j, is a measurement scale of some aspect of the design. It is assumed that such a scale is at least an interval (or ratio) scale on which distance is a meaningful representation of a quantity. It is further assumed that a design can be partially represented

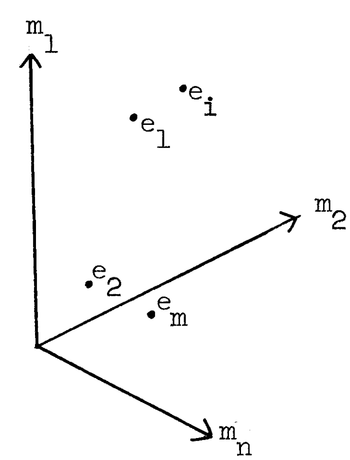
by a finite number of such dimension, m_1, m_2, ... , m_n.
M is the set of all design metrics.
M is a subset of P, the set of all design parameters.

Definition 2B: A design element, e_i, is a point in the space formed by the design metrics, M. The quantity of each metric specified by the element, e_i, is the projection of the point e_i on the metrics, M. An element, e_i, is a vector of quantities of M.



No two elements e_i and e_j may exactly correspond. If they do, $e_i = e_j$. In the metric form, one point would represent both e_i and e_j.

<u>Definition 3B</u>: A design, D_m, is also the set of points $(e_1, e_2, \ldots, e_m)$ in the metric space, M, where each element e_1 is a vector of quantities of M_i.



A design is a set of actions in Debreu's terms.

Definition 4B: A design, D_n, is a distinct alternative to design D_m when different sets of points in the space, M, define each design.

There is a corresponding example for different schemes being specified in spaces defined by different metrics (values along unshared metrics being equal to zero in one alternative). Similarly, more elements (points or actions) may be specified in one alternative than another.

4.6 Operations on Elements

There are two methods for naming a set. The first is to name its members. An element, e_i, is defined by the list of values assigned to each parameter, as in Definitions 2 and 2B. Similarly, a design, D_m, is defined by naming its members, the list of elements, E, as in Definitions 3 and 3B.

The second method of naming a set is to condition set membership by some property which characterizes the members of the set. Such a set might be the collection of elements which have a particular value (or range of values) on a specified parameter. A set which includes other elements either by naming or conditioning the list of elements is a partial design. It is a subset of E, whereas a design is the set, E.

> Definition 5: An including element, e_{m+1}, is a set of elements whose members are specified $(e_1, e_2, \ldots , e_m)$, or meet a condition for inclusion such as p_{ij} must be equal to some prescribed value. Operations for naming or conditioning such including elements merely construct sets of elements or partial representations of the project. The design, D_m, actually includes all combinations of including elements as well as the set $E = (e_1, e_2, \ldots , e_m)$. The most inclusive element is the design $D_m = (e_1, e_2, \ldots , e_m)$.

The design, D_m, can be thought of as a hierarchy of all possible including elements:

$$
\begin{aligned}
E &= (e_1, e_2, \ldots, e_m) \\
\text{where } E_1 &= (e_1, e_5) \\
E_2 &= (e_1, e_8, \ldots, e_k) \\
\text{and } E_k &= (E_1, E_2), \text{ etc.} \\
\text{so that } D_m &= (E, E_1, E_2, E_3, \ldots, E_m)
\end{aligned}
$$

4.7 Operations on Parameters

Parameters may be derived from other parameters in much the same way that elements may be derived from other elements (4.6). A parameter, however, does not "include" another parameter as a set relation. A parameter is "derived" from other parameters in terms of functional dependency. If a particular parameter, benefit, and a second parameter, cost, are used to define some design elements, a third parameter, cost/benefit ratio, can be derived from the first two parameters. It was shown that this type of operation is defined as a "derived measurement." In the metric form, a "basis" is composed of the including (independent) dimensions. The derived dimensions are those formed by some linear combination of the basis.

Definition 6: A derived parameter, p_{n+1}, is a dependent parameter functionally related to the set of independent or basis parameters, $p_1, \ldots, p_n$. Elements defined with respect to the basis parameters are also defined with respect to the derived parameters, even if the value of the derived parameter is assumed to be zero.

4.8 Parameters of Including Elements

An including element (Definition 6) refers to a set of elements, each of which satisfy some membership condition. An including element is merely a set of elements, and is formally the same as a design, D_n. It is also true, however, that an including element may have a set of values on parameters which refer to the including elements. These parameters refer to macro characteristics of the included elements taken as a whole. Parameters of including elements can be viewed statistics of the included elements.

Typical examples of derived parameters can be stated as follows:

If the including element is $e_{m+1} = (e_1, e_2, \ldots, e_k)$ and $e_i = (p_1, p_2, \ldots, p_j, \ldots, p_n)$ for $i = 1, \ldots, k$,

then (a.) <u>mean</u> of p; for including element,

$$e_{m+1} = \frac{1}{k} \bullet \sum_{i=1}^{k} p_{ij}$$

(b.) <u>variance</u> of p_j for including element,

$$e_{m+1} = \frac{1}{k} \bullet \sum_{i=1}^{k} (p_{ij} - \text{mean of } p_j \text{ for } e_{m+1})$$

or

$$\frac{1}{k} \bullet \sum_{i=1}^{k} (p_{ij} - (a.))$$

(c.) <u>range</u> of p_j for element e_{m+1}

is the difference between the largest and smallest value of p_{ij}, $i=1, 2, \ldots, k$.

(d.) <u>extreme</u> of p_j for element e_{m+1}

is the largest or smallest value of p_{ij}. It represents the positive or negative <u>mode</u>.

(e.) <u>median</u> of p_j for element e_{m+1}

is the value of the i-th element's j-th parameter when the i-th element represents the 50 percentile of all elements' j-th parameter.

(f.) <u>total number</u> of included elements having membership in the including element, e_{m+1}, is the number of included elements.

(g.) <u>total value</u> of a particular parameter, p_j, for all included elements,

$$e_i \ (i=1, 2, \ldots, k) = \sum_{i=1}^{k} p_{ij}$$

The idea of inclusion is central to Manheim's hierarchically-structured decision process.[5] In Manheim's model, the designer attempts to assign values to parameters in an optimal sequence from most inclusive to elemental based on Bayesian decision rules. No such assumptions are presented in the measurement model of design. Rather, it is assumed that many different "levels" of the design are derived or assigned in order for the decision-maker to specify appropriate actions. The only aspect of the designer's efforts which is sequential is the obvious time dimension in which he operates. The "level" of specification, however, need not be assumed to be sequentially specified in the hierarchical direction from most inclusive to least. In order to operate in Manheim's model, the designer must be able to specify all elements (actions) at a particular level of inclusion that make up a design. It is easier to assume that the designer makes partial specifications at various "levels" of the design. These specifications, although sequential because of the designer's time dimension, need not be thought of as "derived" or included from the previous specification.

[5]Marvin L. Manheim, Highway Route Location as a Hierarchically-Structured Sequential Decision Process, Department of Civil Engineering, M.I.T., May, 1964, pp. 39-47. (Also published as Hierarchical Structure: A Model of Design and Planning Processes, M.I.T. Report 7, M.I.T. Press, 1966)

CHAPTER 5. CONSEQUENCES OVER TIME

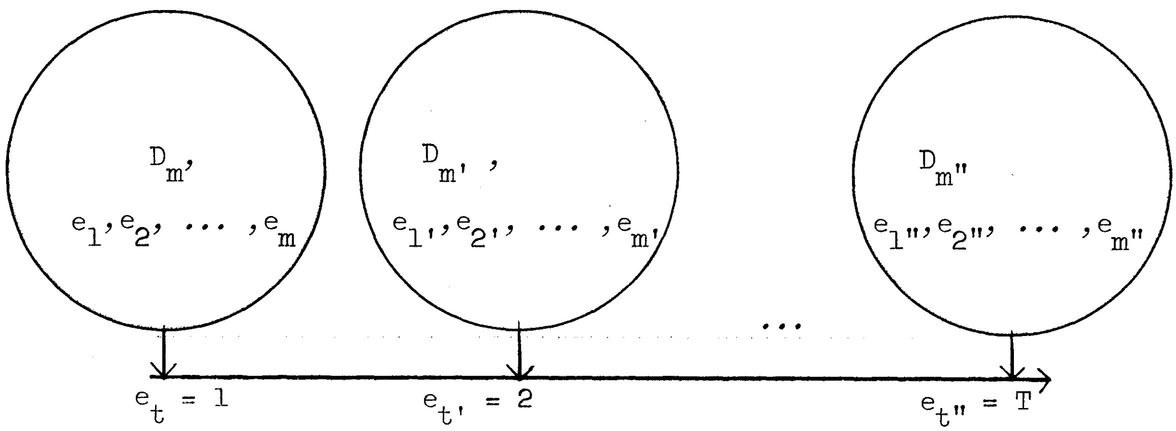
5.1 Dynamics of Design

Given a design, D_m, a set of values assigned to one can represent the life of a project in the following way. As in Debreu, (pp. 35), a parameter, p_t, is defined as the "time" dimension. The remaining values of the n-1 parameters for all elements are specified for each "date" or unit specified on the time dimension. At any particular value of p_t, the other values on each of the remaining n-1 design parameters for all elements represent the "state of the design." This representation is analogous to a phase space in physics. From the preceding definitions (4 and 4B), each state of the design is actually an alternative, for at least the value of one parameter, p_t, changes for every design state.

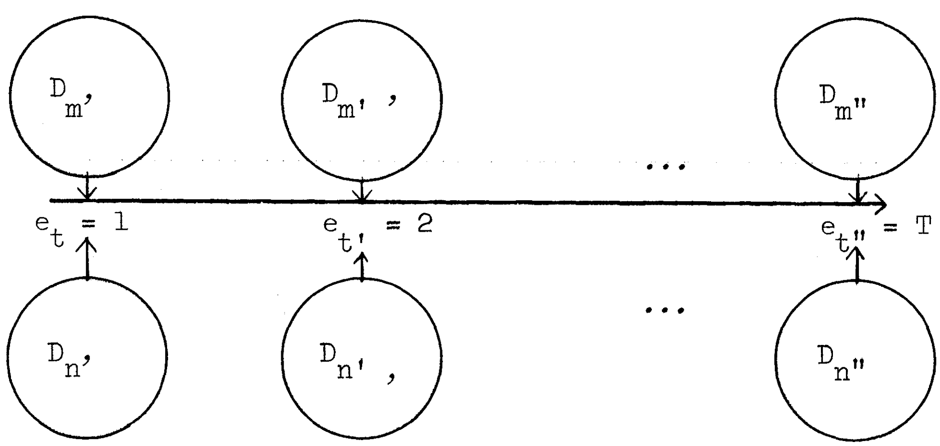
However, this definition is not an alternative in its usual sense. In fact, it is just the opposite. Alternatives generally refer to more than one set of actions which are expected to occur at the same time. Consequently, a choice must be made among alternatives for they are mutually exclusive and cannot occur simultaneously.

Alternatives are defined by the difference occurring among sets of elements and the values assigned to their parameters <u>at the same time</u>.

It is also of great interest to describe streams of design states as they change over time. At a particular time, design D_m is a set of elements; over several periods, D_m is a set of sets of elements. This can be illustrated as follows:



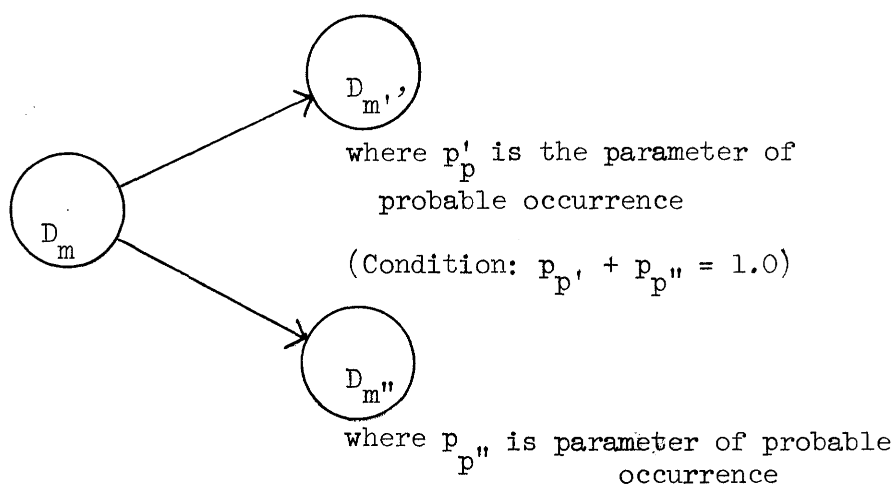
Alternative streams of design states can be diagrammed as follows:



The condition required for two design states to be part of the same stream is that the state with a higher value on p_{tr} is reachable from the state with $p_t > p_{tr}$. This use is appropriate for it is meant that a transformation of values assigned to parameters for all elements of D_{m1}, exists which produces the values of D_{m2}.

5.2 Uncertainty and Time

It is well documented in the literature of decision theory[1] that the models for choice under uncertainty involve the indetermination resulting D_{m2} from the transformation at D_{m1}. Thus, the reachability condition must be relaxed to include an expectation of reachability. Under uncertainty, the stream of design states which can be part of an "alternative" stream can be diagrammed as follows:



[1] N. M. Smith, "A Calculus for Ethics: A Theory of the Structure of Value - Part I," Behavioral Science, April, 1956, pp. 111-142. The value of a particular design state is equated to the expected values reachable from that state.

5.3 Derived Parameters for Streams of Design States

Typical examples of derived parameters can be stated as follows:

(a.) The change or difference in value of some p_j between two time periods.

Actually, because this temporal representation is the same as the representation of alternatives, D_m and D_n, the operation of difference is a very important comparative technique in evaluation.

(b.) The rate of change in value of some p_j between two time periods.

If the function relating p_j to changes in alternatives is assumed to be continuous, this operation denotes the derivative or marginal contribution or change.

(c.) Cumulative total is the summation of a particular value of p_j for each time period.

(d.) Discounted present value is a function which maps values of each p_j for future time periods to t=0.

Further characteristics of relations on the time dimension include sequence, precedence, simultaneity, etc. Because we are interested in evaluating strategies of choice over time, this particular dimension is very important.

CHAPTER 6. A MEASUREMENT MODEL OF EVALUATION AND CHOICE

6.1 Goals and Constraints

Typical goals and objectives in planning literature include such phrases as "use land efficiently, protect natural resources, maintain large open spaces, provide efficient transportation, and encourage greater variety of living environments."[1] Other lists include phrases such as "functional adequacy, optimum communication, least cost, adaptability and image quality."[2] On the other hand, standards such as maximum families per net housing acre equals forty, or families per gross acre of total development between 20 and 24"[3] can be found in zoning manuals and performance specifications.

Robert C. Young[4] makes the distinction between these two types of statements, calling the general type a "goal" and the specific standard an "objective" which contributes to the satisfaction of a goal. He

[1] General Plan for The Maryland-Washington Regional District, The Maryland-National Capital Park and Planning Commission, 1962, pp. 16-19.

[2] Kevin Lynch, Site Planning, M.I.T. Press, 1962, pp. 11-13.

[3] Proposed Minimum Standards for Permanent Low-Cost Housing, Division of International Affairs, Department of Housing and Urban Development, Washington, D.C., May, 1966, p. 12.

[4] Robert C. Young, "Goals and Goal-Setting," Journal of the American Institute of Planners, Vol. XXXII, Number 2, March, 1966, pp. 76-85.

considers goals as providing a direction for choice, but objectives as being capable of obtainment and measurement.

It seems to me that the distinctions between goals and objectives or goals and constraints tends to be both arbitrary and misleading. The following chapter shall show the equivalence among goals, constraints, and objectives.

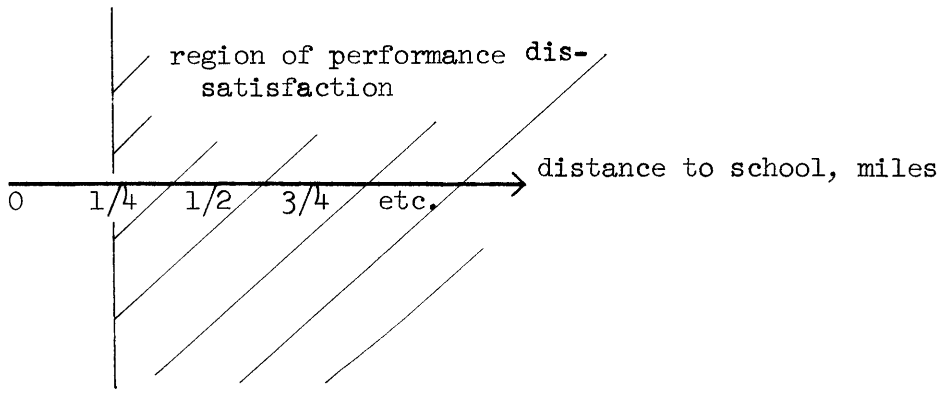
6.2 Absolute Comparison

Intermingled in these phases are two basic ideas. The first is a sense of absolute comparison between an expected outcome of some action and a set of desired or required results. Often budget constraints and performance standards are phrased in this way. Such an absolute statement prescribes a set of values assigned to parameters which must be obtained. If the prescribed values of the goal and the expected outcome of an action correspond, then the design is acceptable relative to that absolute criterion.

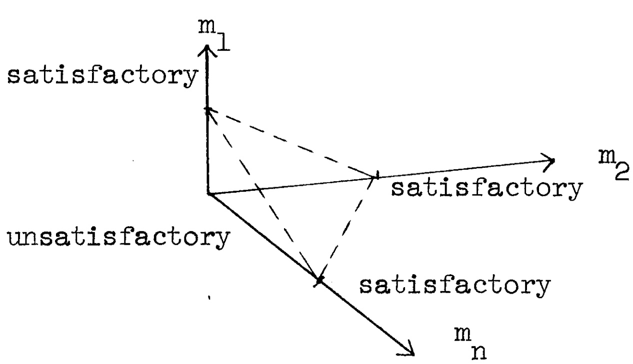
This idea is most easily described in the metric form of design. In the space defined by the set of design parameters, goals or constraints are desired, required, or forbidden regions on some of the parameters.

If, for instance, "distance to school" was a parameter of the project, a goal could be that the value obtained on this parameter must be "less than one-quarter of a mile."

Graphically, this can be illustrated as follows:



The constraints of linear programming problems fit this metric form of design. Feasible and infeasible regions are those locations in which an element may or may not be specified. Simon[5] also defines such regions of acceptability in his model of satisficing behavior.



[5] Herbert A. Simon, Models of Man, John Wiley and Sons, New York, 1957, pp. 241-260.

It is easy to note that a goal or performance standard stated positively (greater than 50) is the equivalent to a negatively stated constraint (less than 10). It is generally held that goals tend to indicate positive aspirations and constraints mean negative conditions. They are, however, both prescriptions of a desired or required design state. Whether the system is striving towards some state or away from some state does not change the logical equivalence between goals and constraints. Perhaps they should be called prescriptions regardless of their positive or negative connotation.

6.3 Relative Comparison

The second type of evaluation addresses the question of which design is preferred from a set of designs being considered.

The prescriptions such as "more" of a particular design quality or the "maximum" amount from among all feasible alternatives are types of preference statements which rank one design relative to another. The absolute scheme compares a given design alternative to a set of points or regions which were defined as desired, required, satisfactory, etc. The relative scheme compares a given design alternative to other alternatives and relates their differences to a preference ordering.

The objective function of the linear programming example is used to measure one alternative relative to another. Such a function provides a score for each design alternative. The prescription for choosing the largest of these scores (maximum) or smallest (minimum) indicates which design is preferred.

Having both absolute and relative goals partitions the selection of a preferred solution to those which do not violate any absolute constraints. Linear programming provides such a scheme for mixed prescriptions if a single objective function is specified.

6.4 Implied Preference

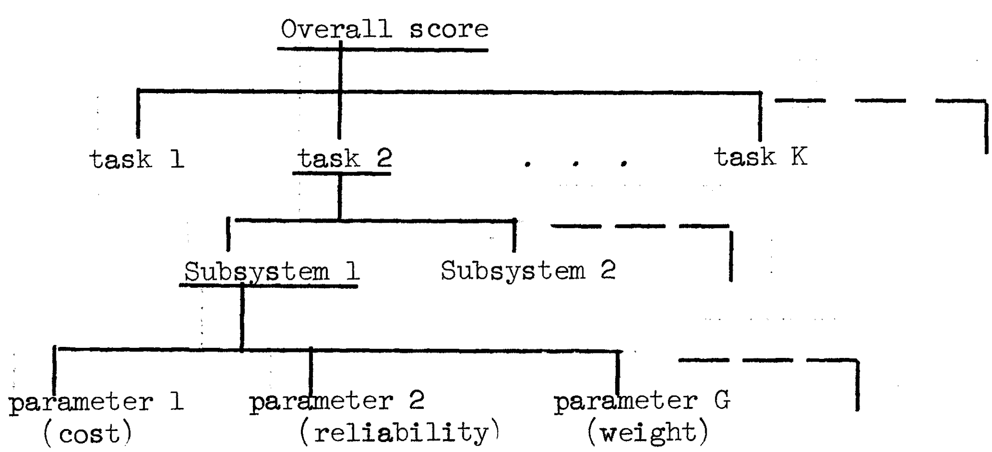
Goal statements which describe a desired or required outcome are merely a special form of the design state. It is a sort of ideal alternative. Absolute comparison describes the difference between the desired state and the expected state. If several alternatives are being evaluated, relative comparison describes the proximity of each alternative to the desired state. If an absolute statement such as "greater than 50" is satisfied by more than one alternative (or not satisfied by any), an ordering of the alternatives relative to their proximity to an absolute constraint can be used to imply preferences among those alternatives considered.

The implied preference is "less travel time is preferred to more," even though the existing alternatives do not satisfy the absolute criteria.

6.5 Goal Relationships as Derived Measurement

Most of the authors concerned with the relationships among goals have viewed their linkages as hierarchies of means and ends. The hierarchy of evaluation often follows the division of the project into subsystems, each of which contributes to the design's overall effectiveness. An example of such an evaluation scheme is contained in POED[6], a technique for computing performance of complex systems.

It can be described as follows:



[6] D. R. J. White, D. L. Scott, R. N. Schulz, "POED - A Method of Evaluating System Performance," IEEE Transactions on Engineering Management, December, 1963, pp. 177-182. For a similar scheme, see James R. Miller, III, "The Assessment of Worth: A Systematic Procedure and Its Experimental Validation," Ph.D. Dissertation, M.I.T. Sloan School of Management, June, 1966.

6.6 Special Cases of Derived Measurement

Although such a goal hierarchy may be an appropriate scheme for describing the relationships among goals, a more general statement is made by Hall.[7] He recognizes that such a tree of relationships requires independence of subsystems or subgoals which is unrealistic in most complex problems.

His scheme accommodates the view of goal relationships as a semi-lattice rather than a tree.

This semi-lattice consists of the following four types of relationships:

(1.) means-end

(2.) particularization-inclusion

(3.) value-wise independence, dependence

(4.) vector-connected.

Although I concur with the view that goal relationships can be most generally described as a semi-lattice, the effort to distinguish among types of linkages seems misleading. It can be shown that all such relationships are merely special cases of viewing the semi-lattice as a set of derived measurements.

[7] Fred L. Hall, "A Method for Dealing with Complex Goals and Indefinite Utilities in Decision Problems," Master's Thesis, Sloan School of Management, M.I.T., 1967.

The means-end relationship is defined as levels of goals each specified in such a way to be complementary in the preference sense to a "higher-level" goal. Hall uses the example of the goal "to decrease travel time" as a means to the higher order end of "increased mobility within a region," which in turn may lead to an "increase in economic opportunity."

These goals can be written as the following functions:

(a.) Economic Opportunity is some function, f, of mobility,

$$EO = f(M)$$

(b.) Mobility is some function, g, of travel-time,

$$M = g(TT)$$

Thus, economic opportunity is some complex function, h, of travel-time,

$$EO = f(g(TT)) \quad \text{or}$$

$$EO = h(TT).$$

Economic opportunity is a derived measurement of travel-time and mobility.

Particularization-inclusion (p-i) is a definitional type of relationship. It means that the "lower-level" goal is some particularization (more finely defined) than the including element. This distinction was central to Manheim's hierarchical structure model of planning and design. Referring to Hall's example, he suggests that "decrease fatalities" and "decrease property damage" are particularizations of the goal "improve safety." Let us use the same terminology as the means-end example.

(a.) Safety is a function of fatalities and property damage,

$$S = f(F, PD).$$

It seems apparent that the same type of derived measurement relationship exists between means-end and particularization-inclusion.

Hall recognizes this similarity and suggests that Simon and many others would argue the particularization-inclusion is really a means-end relation. I would maintain they are both derived measurements.

The third type of relationship is value-wise independence or dependence. This distinction is the basis for Fishburn's[8] work in the use of additive utilities. It is also an assumption that underlies the aggregation function in Rittel's[9] scheme.

Fishburn defines value-wise independence as follows:

> If the two variables X and Y are <u>value-wise independent</u>,
> then $V(x,y) = V_x(x) + V_y(y)$
> where V_x is a value function over X
> and V_y is a value function defined over Y.

The derived measurement is a particular function, a summation.

(a.) $V = f(x, y)$

[8] Peter C. Fishburn, <u>Decision and Value Theory</u>, John Wiley and Sons, New York, 1964.

[9] This scheme is fully discussed in Chapter 9.2.

Vector-connection is Hall's fourth distinction. It denotes a situation where the results on different parameters have no defined connection such as "minimize operating cost" and "increase regional growth." In this case, the decision-maker must act as the derived measurement function, producing a choice by reviewing the various alternatives. The first three types of derived measurement can be explicitly represented; the fourth is an implicit function.

It seems clear that the information of interest for evaluation and choice is one of a derived measurement. When properly defined, all characteristics of goal relationships can be collapsed to this concept. It does not seem useful to labor over naming the derivations.

CHAPTER 7. EVALUATORS AND ACCOUNTING FOR CHOICE

7.1 Evaluators

One characteristic of environmental design is the multiplicity of individuals or groups whose needs and aspirations are derived from the same set of consequences. A separate outcome for each evaluator during each of its roles would eliminate conflicts among aspirants. However, different sets of goals and needs are applied to the same outcome at the same time.

An evaluator is defined in two ways. First, by a set of goals or preferences associated with the roles performed by the individual or group. For each evaluator there can be one or more sets of absolute or relative statements representing different needs and aspirations. From the preceding discussion of goals, we see that the evaluator's objectives can be assigned to regions of the design parameters.

The second aspect of an evaluator is its own description. This includes its membership, its physical location in time, activities, jurisdiction, etc. We also see that an evaluator's description can be represented as an element or a set of elements in the measurement model of design. The relative location of an evaluator often determines the incidence as well as level of alternative consequences.

7.2 Conflict of Goals

If one characteristic of environmental design is the multiplicity of evaluators and their goals or needs, another characteristic is the invariance of the environment relative to the changing needs of the evaluators. It is impossible to service all evaluators along every criterion simultaneously. The indivisibilities of providing services, long-term capital investment, and many other characteristics dictate an environment which is less changeable than the daily needs of its many users playing their multiple roles. The resulting conflicts among goals and requirements can be thought of in two ways.

First, the prescription of different values for the same parameter, may result in mutually exclusive goals that cannot be satisfied by one set of actions and their consequences. Two evaluators or one evaluator specifying goals to satisfy two different activities may prescribe an outcome to be both greater than X and less than X on the same parameter. Similarly, prescriptions of outcomes equal to both X and equal to Y on the same parameter might require mutually exclusive results.

Second, the prescription of different values assigned to different parameters, may result in conflicting goals. The values prescribed by evaluators may require mutually exclusive results because the desired outcomes are functionally dependent on the same set of actions or consequences. For example, a city council may wish to increase its tax revenue but the urban dweller desires to maintain a high net income; simultaneously, the urbanite may require greater municipal services but the city government is required to reduce its spending due to a diminishing taxable base. These aspirations conflict because they all depend on the costs of urban services to determine tax rates which effect net income of the urbanite as well as the revenue of the city.

7.3 Partial and Complete Choice

Choice is the selection of some alternative(s) from among a set of alternatives relative to some criterion or criteria. For instance, one may choose the alternative which has the most (or least) of a particular quality, or all alternatives which satisfy a performance standard.

Luce and Raiffa[1] partition the field of choice making by whether the decision is made by an individual or a group. Their distinction between group and individual choice is drawn on functional lines. An individual is considered to be some decision making organization which is thought of having a unifying motive for its decision. Any organization having conflicting interests to be resolved is considered a group.

[1]R. Duncan Luce and Howard Raiffa, Games and Decisions, John Wiley and Sons, New York, 1957, p. 13.

This type of distinction is very difficult to make. Obviously, most types of complex choices involve the resolution of conflicting preferences along different criteria. It seems more appropriate to define an individual choice as a "singular" or "partial" choice which is made relative to a single criterion. Similarly, group choice can be seen as a "complete" choice made with respect to many criteria.

7.4 Accounting for Choice

The evaluator and the set of outcomes at a particular time are defined as an account from which a choice is required. The purpose of defining an account is to provide a framework for making choices. Charles Leven[2] defines a set of accounts as:

> "an empirical framework corresponding to a theoretical structure which postulates the nature of relationships between various aspects of some particular phenomenon. Sometimes the structural relationships are referred to as 'accounts,' i.e., the accounting framework itself. In other circumstances the term is meant to refer to the set of values set forth within the framework."

[2]Charles L. Leven, "Regional Income and Product Accounts: Construction and Applications," Design of Regional Accounts, W. Hochwald, ed., Resources for the Future, Inc., Johns Hopkins Press, Baltimore, 1961, p. 148.

A partial choice relative to an account is the selection of an alternative based only on some subset of all evaluation parameters. For instance, ordering the row of alternatives costs from less to more will rank the outcomes with respect to only one important parameter.

A complete choice requires a selection with respect to the whole account. If all partial choices select the same alternative, a strictly dominant complete choice exists. This condition however would be rare in complex problems. A complete choice can be obtained by deriving new parameters and more inclusive partial choices until only one choice remains. For example, two parameters of cost and benefit are derived from many parameters of travel time, operating expenses, revenues, etc. Finally, a single criterion of effectiveness is derived from the parameters of cost and benefit. The partial choice and the complete choice correspond if all initial parameters were derived to a cost or benefit. If some considerations remain to be taken, either more parameters must be derived, or a choice must be made by implicitly considering the alternatives.

A social choice is made when the selections of individual accounts are considered for the selection of some alternative to be implemented for all accounts. The social account is derived from the individual accounts. It is an account of accounts.

CHAPTER 8. CHOICE - A COMPUTER-AIDED EVALUATION SYSTEM

8.1 Overview of the System

The preceding model of evaluation and choice has been incorporated into a time-sharing computer system to facilitate a highly interactive method for specifying and operating complex evaluation schemes. The importance of the previous chapters was to present a structure for understanding evaluation and choice. Such a structure provides the basis for representing evaluation and choice in the computer. CHOICE is based in this structure, although implementing the ideas helped to fashion the underlying measurement model.

The basic characteristics of the system include the following:

(1.) The ability to define accounts which consist of alternative outcomes on many parameters;

(2.) The ability to perform operations on these accounts, derive new parameters or new accounts, and order alternatives with respect to criteria of choice;

(3.) The ability to define files of goals, constraints, and preferences for evaluation and choice.

The uncertainty which surrounds a designer's evaluation activities requires that the system demand few predetermined operations by the designer. The types of parameters and the definition of their measurement functions, the relative weights or prices assigned to different schemes, the number of parameters or alternatives considered, etc., can be developed by the designer as he performs evaluation. There is nothing inherently final about operations of evaluation. Many choices must be made in design development. Therefore, the system is available for performing operations on a set of options regardless of whether these options represent a complete design or some aspect of the design. Changes may be made in preferences, alternatives may be dropped from consideration, new parameters may be added and the evaluation performed with new information. The system is designed to describe the consequences of various evaluation schemes to the designer. In order to describe the system and its use, a small illustration will be followed for demonstration purposes.

8.2 Data Bases for Evaluation

As previously defined, an account represents some evaluator's view of a set of alternative design consequences. For each account, a set of evaluation parameters of interest to the evaluator may be defined. CHOICE allows the designer to specify up to ten alternatives on one hundred parameters for fifty accounts. These are limitations arbitrarily established as sufficient and could be modified if required. In the following illustration, let us suppose a two account evaluation, one for Jones and one for

Smith. We shall further assume that three alternatives are being considered, example, example 1, and example 2, represented to the designer as EXP, EXP 1, and EXP 2. Each account is concerned with three parameters of the alternatives, rent, travel time to work, and amount of recreation area within ten minutes walk from residence. The names of these parameters appear to the designer as RENT, TTW, and RECA. Although there may be many more parameters used to describe the environment, the evaluation operations are interested in a subset on which preferences or goals are assigned. Values assigned to this subset furnish arguments for evaluation functions and comparison.

Values assigned to these accounts for each alternative can be arrived at in several ways. The time-sharing system used for this research[1] permits files to be defined and edited as a data base. Let us assume the designer has described each alternative with respect to its rent in dollars per month, its travel time to work in minutes per trip, and its available recreation area in acres. Jones and Smith are described as receiving different amounts of each alternative due to their location relative to proposed action.

[1]CHOICE is operational on M.I.T.'s CTSS central time-sharing system and being adapted to the Urban System Laboratory's IMB 360-67-E experimental facilities for use in urban research.

Assume for Jones the alternative rents in dollars are 150, 125, and 225; travel times in minutes are 25, 30, and 40; and recreation areas in acres are 1/2, 1, and 2. Similarly, for Smith, alternative rents in dollars are 180, 150, and 125; travel times in minutes are 15, 25, and 35; and finally, recreation areas in acres are 0, 5, and 2. These values may be filed in the computer as primary data from which evaluations will be made. It is data assumed to be known for evaluation purposes, so the designer must dimension the account with respect to the number of alternatives and parameters considered. Filing this primary data takes place using the following format:

```
Account name:      JONES TWO

Account size:      SIZE = 3 3
Alternatives:      COLNAM = EXP  EXP1  EXP2
Parameters:        RENT * 150.0 125.0 225.0
                   TTW * 25.0  30.0  40.0
                   RECA * 0.5  1.0  2.0
End of File:       $
```

Similarly, for Smith:

```
                   SMITH ONE

                   SIZE = 3 3
                   COLNAM = EXP  EXP1  EXP2
                   RENT * 180.0  150.0  125.0
                   TTW * 15.0  25.0  35.0
                   RECA *  0.0  5.0  2.0
                   $
```

These primary data files are stored in the CTSS file capability. They are defined and changed in the "edit" mode of the central system.

It is obvious that the designer is acting as if a measurement function were assigning the rents, travel times, and recreation areas for each account. The designer may be performing the task by manually computing such values as distances, or he may be assuming basic market conditions which would result in the types of rents indicated. The data may also be supplied independently by consultants or other members of the design staff. In terms of the measurement model previously described, the parameters of the illustration are ratio scales and the types of measurement functions are not specified to the evaluator; the data is in a primary or fundamental form.

A second capability for supplying these values is an explicit set of measurement functions whose computations will output the various rents, travel times, or recreational areas. The DISCOURSE system[2] provides such measurement capabilities. DISCOURSE is described elsewhere and shall not be a topic of this illustration. It is sufficient to say that characteristics of the measurement model can be implemented in DISCOURSE. The concern this author had in the development of DISCOURSE was to satisfy the need for providing a measurement capability from which evaluation and choice may be made.

[2] William Porter, DISCOURSE - Between Computer and City Designer, paper presented at first international Design Methods Group Conference, M.I.T., June, 1968. Also in forthcoming doctoral dissertation by Mr. Porter.

An alternative design may be represented in DISCOURSE for each proposal considered. For this illustration, <u>plan exp</u> is considered. The data file represents physical locations on a grid which is threesquares by two squares in size. Each location is defined by grid coordinates such as (2,1). At each location a list of attributes and their values may be associated. Location grid (2,1) has attributes 5, 8, 14, and 10. The names of these attributes appear in the second file called <u>exp names</u> in this example. Attribute 5 is rent, 8 is travel time, etc.

```
PLAN     EXP        11/07   0932.0

SETUP/PLEX
SIZE = 3 2
0,0 3 11 12 $ 1,0 22 $
2,0 4(3 SLATY 5) 11 12 $ 3,0 4(1 NSALTY NOINFO) 11
1,1 3 11 $
2,1  5(150) 8(25) 14(0.5) 10 $
3,1 22 10 11 $
0,2 22 7(4) $
1,2 22 5(180) 8(15) 14(0.0) $
2,2 3 11 8(30) $
3,2 11 5(110) *
R 1.416+.433
```

```
EXP  NAMES       11/07   0932.8

HOOK
21 - LAND* SHOW HAT = 3 1
22 - SLOPE*
4 - WATER A B C * DEPTH COLOR = 4. BLUE
5 - RENT A*
7 - FACTORIES C O* VALUE = 10000
8 - TRATIME A*
14 - RECAREA A* QUIT
READ/CONSOLE
R 1.083+.433
```

CHOICE acts as a condensation of all descriptive parameters of an alternative to a subset of evaluation parameters. This selection is accomplished by defining a command which sequentially reads the requested values for each evaluation parameter from a set of named alternatives for each account specified. The command compares data files of DISCOURSE with respect to alternative designs on each of a set of parameters. In this illustration, the alternatives EXP, EXP1, and EXP2 are specified for Jones and Smith. Values of attributes at given grid locations of each design are requested and named RENT, TTW, and RECA.

```
print acount jones
W 911.6

ACOUNT   JONES       11/07   0911.7

    00010    COMPARE/PLEX
    00020    DEFINE GRIDS
    00030    EXP PLAN
    00040    EXP1 PLAN
    00050    EXP2 PLAN
    00060    *
    00070    DEFINE VALUE
    00080    5(1 2,1) * RENT
    00090    8(1 2,1) * TTW
    00100    14(1 2,1) * RECA
    00110    *
R .933+.200
```

Reading data from alternative DISCOURSE representations of an environment is accomplished by using the command <u>read/disk</u> with respect to some account file whose format was described in the preceding paragraph. The designer may name the condensed data as the example illustrates by "...<u>Jones one</u>." After each account has been read from DISCOURSE, the designer may enter the CHOICE system by answering "yes" to the computer's query, "Do you wish to enter the CHOICE system?" This set of operations is described as follows:

```
read/disk acount jones
 NAME OF CHOICE PRIMARY MATRIX ...  jones one
   EXP     PLAN HAS BEEN PLACED IN CORE
  EXP1     PLAN HAS BEEN PLACED IN CORE
  EXP2     PLAN HAS BEEN PLACED IN CORE
 JONES   ONE  HAS BEEN CREATED
DO YOU WISH TO ENTER THE CHOICE SYSTEM ...       no
 MAKE REQUESTS
END OF FILE WHILE READING REQUESTS
READ/CONSOLE
read/disk acount smith
 NAME OF CHOICE PRIMARY MATRIX ...  smith one
   EXP     PLAN HAS BEEN PLACED IN CORE
  EXP1     PLAN HAS BEEN PLACED IN CORE
  EXP2     PLAN HAS BEEN PLACED IN CORE
 SMITH   ONE  HAS BEEN CREATED
DO YOU WISH TO ENTER THE CHOICE SYSTEM ...       yes
```

So far two ways of representing an account have been shown. One allows primary data to be designated in a file which can be manipulated in the CHOICE system. The second provides for the generation of these values from a set of measurement operations or assumptions in DISCOURSE. One can also imagine a set of operations such as an econometric model to provide possible rents, or a trip generation and network model to compute travel times.

8.3 Creation of Accounts

The next type of operation required before evaluations may be made is to create the account in the CHOICE system itself. CHOICE is a set of commands and a data structure to accommodate the accounting operations discussed in the measurement models previously described. The data structure is designed to facilitate comparative operations. It is based on a matrix format because alternative values for the same parameter provide the basis for comparison. Secondly, the accounts are most generally concerned with more than one parameter. Multiple alternatives and multiple parameters are easily accommodated in matrices. Most operations are performed on all alternatives.

The actual accounts for manipulation in CHOICE are generated by a create command. The two data bases discussed in 8.2 comprise two different procedures. If an account is to be created from the DISCOURSE data, the command reads as follows:

The create operation arrays the data into the familiar account format. This format is similar to a payoff matrix in decision theory literature.[4] A show statement will printout the requested information. To see the accounts in their primary form, a show request can be made as follows:

```
create jone2-p from jones two(c) with jo2-o jv2-v
PRIMARY MATRIX =    JONE2
ORDER MATRIX =        JO2
VALUE MATRIX =        JV2

R  1.2*   2.3

show jone2

                          EXP      EXP1      EXP2


  RENT                 150.00    125.00    225.00
   TTW                  25.00     30.00     40.00
  RECA                    .50      1.00      2.00
```

[4]For example, see Robert Schlaifer, Probability and Statistics for Business Decisions, McGraw-Hill Book Company, Inc., 1959, p. 3. The primary account differs from a traditional payoff matrix because it represents a set of mutually exclusive alternatives as certainties rather than a distribution of mutually exclusive events with a probability of occurrence assigned to each. Later in this illustration the representation of probable outcomes will be discussed.

Primary data may also be placed in accounts without previously defining them in either DISCOURSE or the general data files of the system. An account ca be created without a prior data file by the command:

```
create jones-p (3 ,3)
```

Names can be placed on the rows and columns by use of the <u>name</u> command:

```
name jones(1,) rent

name jones (,1) exp
```

Values may be assigned to each alternative for each parameter by using an equality symbol (=). For instance,

```
jones (rent,exp) = 125
```

will enter 125 as the <u>rent</u> for alternative <u>exp</u> for account <u>Jones</u>. Another representation using row and column notation can be used for referencing the account.

```
jones (1,1)= 125
```

8.4 Comparison

The account's matrix format arrays alternative values of a parameter as a row. This means that column names represent alternatives and rows represent the evaluation parameters. This format is used because it is more likely to have a greater number of parameters than alternative values assigned to them. The practicalities of printing out information warrants such a convention. Further, the number of parameters tend to be openended because new ones are added as derived measurements of the initial set. Thus, the structure of the system is more limited in terms of the number of alternatives (columns) considered during a set of evaluations, but extendable in terms of the parameters (rows) defined. There is, however, no stipulation that the accounts have to be so designated. Only experience has indicated that it works more effectively as the conventions indicated.

CHOICE has a general set of arithmetic operations which allows the designer to add (+), subtract (-), multiply (*), and divide (/). Comparison of alternatives for a particular account can be represented as finding the difference between alternatives (subtraction between columns). The designer can create comparisons for account Jones, calling it any five letter name such as CMJ for comparison, Jones.

The comparison may be requested as follows:

```
cmj(,1)= jones(,1)-jones(,2)
R  0.1*   5.9
cmj(,2)= jones(,1)-jones(,3)
R  0.0*   5.9
cmj(,3)=jones(,2)-jones(,3)
```

Having performed the operation on all three combinations of alternatives, one may show the comparison as follows:

```
show cmj

                                        25.00    -75.00   -100.00
                                        -5.00    -15.00    -10.00
                                         -.50     -1.50     -1.00
```

The arithmetic operations can be performed on single entries of the accounts, whole rows or columns, and on a complete matrix. The accounts of Jones and Smith can be compared by finding the difference between values on all parameters for each alternative. The basic operations are the same as the comparisons within a single account.

```
comp=jones-smith
R  0.1*   5.4
show comp

                                -30.00     -25.00     100.00
                                 10.00       5.00       5.00
                                   .50      -4.00       0.

R  0.0*   5.5
```

8.5 Derived Parameters

CHOICE permits the designer to derive new parameters from the primary data accounts. Such derived parameters may represent the evaluation criteria on which a choice will be based. Although derived parameters may be the result of any type of arithmetic operations, the typical examples are weighting parameters by relative importance or associating prices with cost and benefit parameters. The weights or prices may be defined by creating an independent "value" matrix and assigning the weightings as column arrays. Alternative weighting schemes or different prices for various costs and benefits may be arrayed as a matrix with each alternative consisting of a column.

In addition to the value matrix containing such prices, a value matrix is associated with the initial primary account. When the account for Jones was created, a space for recording operations was also generated. First, the price vector is defined. Let us suppose a value of 1 is assigned to the rent, 2 to the travel time, and 100 to the recreation.

The primary account and its value matrix already exist from the initial create commands. The weighted results of multiplying the prices times the initial data is recorded in the value matrix. Jones' value matrix was arbitrarily named jv by the designer.

The designer may then define two new parameters which he calls bene and cost for his definitions of benefit and costs.[5] In this illustration, the designer defined benefits as the sum of the weighted values for recreation area. Costs were defined as the sum of the weighted values of rent and travel time. He creates a benefit cost matrix which he named bcj for Jones and computed the weighted sum.

```
create price-v (3 1)
VALUE MATRIX =     PRICE


price(3,1)=100.0
```

etc.

```
show bcj

                          EXP       EXP1       EXP2


BENE                     50.00    100.00     200.00
COST                    200.00    185.00     305.00
```

[5]Discussions for deriving such measurements as benefits and costs are extensively noted. For a complete review, see A. R. Prest and R. Turvey, "Cost-Benefit Analysis: A Survey," The Economic Journal, Vol. 75, No. 300, December, 1965, p. 683. CHOICE also includes discount, a common function in such analysis for discounting streams of cost and benefits to present value. For alternative functions, see M. Wohl and B. V. Martin, Evaluation of Mutually Exclusive Design Projects, Special Report 92, Highway Research Board, 1967.

Finally, a new parameter deriving a measure of effectiveness is defined by the designer. This he names BCR for benefit cost ratio and computes it for each alternative.

```
bcrj(1,1)=bcj(1,1)/bcj(2,1)
R  0.1*    3.8
bcrj(1,2)=bcj(1,2)/bcj(2,2)
R  0.0*    3.8
bcrj(1,3)=bcj(1,3)/bcj(2,3)
R  0.0*    3.9
show bcrj

                        EXP     EXP1     EXP2

    BCR                 .25      .54      .66
```

We are now in a position to combine the comparative operations of 8.1 and the derivations of 8.2. Performing a similar set of calculations for Smith as well as Jones produces two sets of benefits and costs. If the designer wished to compute total benefits and costs for both accounts, he could by the following operations:

1. create totbc-p to represent total benefit cost.
2. name rows, columns such as exp, bene.
3. calculate the following:

```
totbc (bene,exp)=bcj(bene, exp) + bcs(bene,exp)
totbc (cost,exp)=bcj(cost, exp) + bcs(cost,exp)
....etc.  for all alternatives.
```

Total net benefits for both accounts:

```
totnb (1,exp) = totbc(cost,exp)-totbc(bene,exp)
....etc.  for all alternatives.
```

Total benefit cost ratio.

```
totr(1,exp) = totbc(bene,exp)/totbc(cost,exp)
....etc.  for all alternatives.
```

8.6 Ordering

Computing particular values on parameters of interest to an evaluator is but one set of operations. A second type of operation is that of ordering the values assigned to each parameter. In the illustration one could be interested in the order of benefit cost ratios. The evaluator may wish to act on the consequence of which alternative provided the largest bcr. He may use the order command to rank the alternatives with respect to bcr from greatest to least. The command is written as follows:

```
order bcrj row grt
```

Show the ordered results as follows:

```
show ordr05
          *  EXP  * EXP1  * EXP2

*  BCR        3       2       1

R  0.0*   4.1
```

8.7 Ordinal Input

The illustration of Jones and Smith has been confined to representation and manipulation of primary data that is cardinal in nature. The values assigned to parameters of rent, travel time, and recreation area are measurements on ratio scales. Deriving costs and benefits or comparing various alternatives or accounts provided additional parameters on ratio scales. Ordering operations transformed these measurements to values on ordinal ranking scales. Many parameters of environmental design, however, have no explicit measurement functions which provide arguments for comparison or order measurements. CHOICE, therefore, provides an opportunity for rankings to be input by the designer rather than output by the order command. Inputing such rankings implies the designer acting in a measurement function by observing characteristics and deriving ordered consequences from them.

Ranks of alternatives with respect to a particular parameter can be assigned to an order matrix created by the designer. The ranking of an alternative is itself a parameter, "rank of alternative x on parameter y relative to alternatives x, y, and z."

Let us assume that two additional parameters were relevant to evaluation of policies EXP, EXP 1, and EXP 2. One parameter represents the expected visual amenities resulting from each alternative; the other parameter represents the expected degree of political participation from each proposal. These parameters are named visam and polpa in the illustration. It is assumed that no explicit measurement has been defined by the designer. The designer, however, is willing to judge each policy in an ordinal sense, ranking the alternatives from most to least of each parameter. The operations can be performed as follows:

```
create new-p (2,3)
PRIMARY MATRIX =      NEW
ORDER MATRIX =     ORDR02
VALUE MATRIX =     VALU03

R  0.1*   1.9

name new(1,) visam

R  0.0*   2.0

name new(2,) polpar

R  0.0*   2.0

name new(,1) exp

R  0.0*   2.1

name new(,2) expl
```

etc.

Ranks may then be input to the order matrix of these new parameters.

The additional parameters based on implicit measurement by the designer can be combined with the ordered results of the explicitly measured rent, travel time, and recreation area.

A total order matrix is created. Its elements correspond to those from Jones order (first three parameters) and new order (last two parameters).

show to	*00000	*00000	*00000
*00000	2	1	3
*00000	1	2	3
*00000	3	2	1
*00000	2	1	3
*00000	3	1	2

R 0.0* 1.2

8.8 Ordinal Operations

Morris Hill,[6] in his discussion of a "goal achievement matrix," provides an example of operating on ordinal judgments in order to make a choice. Hill defines many measurement functions to be used as evaluation parameters. As is the case with quantification of measurement, he ultimately relied on an ordinal judgment to assign values to evaluation parameters. It is possible to think of measuring "number of households displaced" or "present value of property siezed" and then transforming such data to an ordinal scale. The following example describes Hill's scheme from a point at which all measurements have been transformed to an ordinal scale.

[6] Morris Hill, "A Method for Evaluating Alternative Plans: The Goal Achievement Matrix Applied to Transportation Plans," Ph.D. dissertation, University of Pennsylvania, 1966. Example of the technique was applied to alternative proposals for Cambridge, England. Case study was based on earlier evaluation of same proposals by Nathaniel Litchfield, "Spatial Externalities in Urban Public Expenditures: A Case Study," The Public Economy of Urban Communities, edited by Julius Margolis, Resources for the Future, Washington, 1965, pp. 207-250.

Summary of Hill's approach to be found in "A Goal-Achievement Matrix for Evaluating Alternative Plans," Journal of the American Institute of Planners, January, 1968, pp. 19-29.

For illustrative purposes let us consider only eight of the nineteen parameters defined by Hill. These are listed with their CHOICE representation as follows:

(1.) Traffic noise = noise

(2.) Air pollution = airp

(3.) Unpleasant visual effects = visl

(4.) Accident rate = accr

(5.) Separation of pedestrians and vehicles = vehop

(6.) Focus of city on university setting = focus

(7.) Number of households displaced = displ

(8.) Present value of net loss to owners = netls

Three alternatives are implied in the evaluation study. Plana represents a proposal made by Cambridge University. Planb was a counter proposal made by the county. Planx represents the projected existing situation.

Accounts are defined for general types of land uses. Each type is subdivided into particular locations of users. To illustrate the classifications, three types are considered. Colleges of the university are called coll; three specific colleges are named mag for Magdalene, jes for Jesus, and joh for St. John's. Commercial areas of town are named comm and include districts cm for Magdalene, ck for King's, and cf for Fitzroy. Residential areas are denoted as res; they include districts e, rese, f, resf, and g, resg.

A hierarchy of partial choices is made in order to obtain a final preference ordering over all accounts. Initial data represents the order of each plan with respect to the amount of each parameter expected for that location. For instance, account mag representing Magdalene College has the following values assigned to parameter noise:

mag

	Plan A	Plan B	Plan X
noise	2	1	2

Such a score indicates planb has more noise expected (rank 1) than either plana or planx. The latter are judged to be the same in amount of noise expected. In cases where a tie occurs with planx, no change is expected between existing and proposed.

Figures 8-1 through 9 represent the nine accounts and the judgment of expected outcomes on each parameter for that location. These results are ordered in terms of preferences, less noise preferred to more, more university focus preferred to less, etc. The results of ordering the expected outcomes are displayed below respective accounts.

show mag

	PLANA	PLANB	PLANX
NOISE	2.00	1.00	2.00
AIRP	2.00	1.00	2.00
VISL	1.00	1.00	1.00
ACCR	1.00	2.00	1.00
VEHSP	2.00	1.00	2.00
FOCUS	1.00	1.00	1.00
DISPL	1.00	1.00	1.00
NETLS	1.00	1.00	1.00

R 0.2* 1.0

show mago

	*PLANA	*PLANB	*PLANX
*NOISE	1	3	1
* AIRP	1	3	1
* VISL	1	1	1
* ACCR	2	1	2
*VEHSP	2	1	2
*FOCUS	1	1	1
*DISPL	1	1	1
*NETLS	1	1	1

R 0.4* 1.4

Figure 8-1. Magdalene College.

show jes

	PLANA	PLANB	PLANX
NOI	2.00	1.00	2.00
AIRP	2.00	1.00	2.00
VISL	1.00	1.00	1.00
ACCR	2.00	1.00	2.00
VEHSP	1.00	2.00	1.00
FOCUS	1.00	1.00	1.00
DISPL	1.00	1.00	1.00
NETLS	1.00	1.00	1.00

R 0.2* 2.4

show jeso

	*PLANA	*PLANB	*PLANX
* NOI	1	3	1
* AIRP	1	3	1
* VISL	1	1	1
* ACCR	1	3	1
*VEHSP	1	3	1
*FOCUS	1	1	1
*DISPL	1	1	1
*NETLS	1	1	1

R 0.3* 2.8

Figure 8-2. Jesus College.

show joh

	PLANA	PLANB	PLANX
NOISE	2.00	1.00	2.00
AIRP	1.00	2.00	1.00
VISL	1.00	1.00	1.00
ACCR	1.00	1.00	1.00
VEHSP	1.00	1.00	1.00
FOCUS	1.00	1.00	1.00
DISPL	1.00	1.00	1.00
NETLS	1.00	1.00	1.00

R 0.2* 4.0

show joho

	*PLANA	*PLANB	*PLANX
*NOISE	1	3	1
* AIRP	2	1	2
* VISL	1	1	1
* ACCR	1	1	1
*VEHSP	1	1	1
*FOCUS	1	1	1
*DISPL	1	1	1
*NETLS	1	1	1

R 0.3* 4.4

Figure 8-3. St. John's College.

```
show cm
```

	PLANA	PLANB	PLANX
NOISE	1.00	2.00	1.00
AIRP	1.00	2.00	1.00
VISL	1.00	1.00	1.00
ACCR	1.00	2.00	1.00
VEHSP	2.00	1.00	2.00
FOCUS	2.00	1.00	2.00
DISPL	2.00	1.00	3.00
NETLS	2.00	1.00	3.00

R 0.2* 5.4

```
show cmo
```

	*PLANA	*PLANB	*PLANX
*NOISE	2	1	2
* AIRP	2	1	2
* VISL	1	1	1
* ACCR	2	1	2
*VEHSP	2	1	2
*FOCUS	2	1	2
*DISPL	2	3	1
*NETLS	2	3	1

R 0.3* 5.8

Figure 8-4. Commercial District, Magdalene.

show ck

	PLANA	PLANB	PLANX
NOISE	1.00	1.00	2.00
AIRP	2.00	1.00	2.00
VISL	2.00	1.00	2.00
ACCR	3.00	1.00	2.00
VEHSP	1.00	1.00	1.00
FOCUS	2.00	1.00	2.00
DISPL	2.00	1.00	3.00
NETLS	2.00	1.00	3.00

R 0.2* 7.1

show cko

	*PLANA	*PLANB	*PLANX
*NOISE	2	2	1
* AIRP	1	3	1
* VISL	1	3	1
* ACCR	1	3	2
*VEHSP	1	1	1
*FOCUS	2	1	2
*DISPL	2	3	1
*NETLS	2	3	1

R 0.4* 7.5

Figure 8-5. Commercial District, King's.

show cf

	PLANA	PLANB	PLANX
NOISE	1.00	2.00	2.00
AIRP	1.00	2.00	2.00
VIS	1.00	2.00	2.00
ACCR	2.00	1.00	1.00
VEHSP	1.00	2.00	2.00
FOCUS	2.00	1.00	1.00
DISPL	2.00	1.00	3.00
NETLS	2.00	1.00	3.00

R 0.2* 8.5

show cfo

	*PLANA	*PLANB	*PLANX
*NOISE	3	1	1
* AIRP	3	1	1
* VIS	3	1	1
* ACCR	1	2	2
*VEHSP	1	2	2
*FOCUS	3	1	1
*DISPL	2	3	1
*NETLS	2	3	1

R 0.4* 8.9

Figure 8-6. Commercial District, Fitzroy.

show re

	PLANA	PLANB	PLANX
NOISE	2.00	1.00	2.00
AIRP	2.00	1.00	2.00
VISL	1.00	1.00	1.00
ACCR	1.00	1.00	2.00
VEHSP	1.00	1.00	1.00
FOCUS	1.00	1.00	1.00
DISPL	2.00	1.00	3.00
NETLS	2.00	1.00	3.00

R 0.2* 10.0

show reo

	*PLANA	*PLANB	*PLANX
*NOISE	1	3	1
* AIRP	1	3	1
* VISL	1	1	1
* ACCR	2	2	1
*VEHSP	1	1	1
*FOCUS	1	1	1
*DISPL	2	3	1
*NETLS	2	3	1

R 0.4* 10.5

Figure 8-7. Residential Area e.

show rf

	PLANA	PLANB	PLANX
NOISE	1.00	1.00	1.00
AIRP	0.	0.	0.
VISL	1.00	1.00	1.00
ACCR	2.00	1.00	2.00
VEHSP	1.00	1.00	1.00
FOCUS	1.00	1.00	1.00
DISPL	2.00	1.00	3.00
NETLS	2.00	1.00	3.00

R 0.2* 11.6

show rfo

	*PLANA	*PLANB	*PLANX
*NOISE	1	1	1
* AIRP	1	1	1
* VISL	1	1	1
* ACCR	1	3	1
*VEHSP	1	1	1
*FOCUS	1	1	1
*DISPL	2	3	1
*NETLS	2	3	1

R 0.2* 11.9

Figure 8-8. Residential Area f.

show rg

	PLANA	PLANB	PLANX
NOISE	1.00	2.00	1.00
AIRP	1.00	2.00	1.00
VISL	1.00	1.00	1.00
ACCR	1.00	2.00	1.00
VEHSP	1.00	1.00	1.00
FOCUS	1.00	1.00	1.00
DISPL	2.00	1.00	3.00
NETLS	2.00	1.00	3.00

R 0.4* 14.2

show rgo

	*PLANA	*PLANB	*PLANX
*NOISE	2	1	2
* AIRP	2	1	2
* VISL	1	1	1
* ACCR	2	1	2
*VEHSP	1	1	1
*FOCUS	1	1	1
*DISPL	2	3	1
*NETLS	2	3	1

R 0.2* 14.4

Figure 8-9. Residential Area g.

A second level of choice is derived from the preferences assigned to each parameter. The ranks of each plan are totalled for each account. This assigns a score for each plan based on ranks of each parameter.

Figures 8-10, 11, and 12 represent the total rank scores for each college, eachc; each commercial district, ecom; and each residential area, eres.

Smaller rank totals are preferred. The same results could be obtained if the number of rank 1, 2, etc., were counted. Rankings of the initial totals are below each account.

```
show eachc

                              PLANA     PLANB     PLANX


   MAG                        11.00      9.00     11.00
   JES                        11.00      9.00     11.00
   JOH                         9.00      9.00      9.00

R  0.2*  16.6
```

```
show eaco
E   11
show eacho


        *PLANA  *PLANB  *PLANX

*  MAG       2       1       2
*  JES       2       1       2
*  JOH       1       1       1

R  0.0*  16.7
```

Figure 8-10. Rank scores for each college.

```
show ecom

                          PLANA     PLANB     PLANX

  CMAG                    12.00     11.00     14.00
 CKING                    15.00      8.00     17.00
  CFIN                    12.00     12.00     16.00

R  0.2*  18.2




show ecomo


        *PLANA  *PLANB  *PLANX

* CMAG       2       1       3
*CKING       2       1       3
* CFIN       1       1       3

R  0.0*  18.2
```

Figure 8-11. Rank scores for each commercial district.

```
show eres
```

	PLANA	PLANB	PLANX
RESE	12.00	8.00	15.00
RESF	10.00	8.00	12.00
RESG	10.00	11.00	12.00

```
R  0.2*  19.7
```

```
show ereso
```

	*PLANA	*PLANB	*PLANX
* RESE	2	1	3
* RESF	2	1	3
* RESG	1	2	3

```
R  0.0*  19.7
```

Figure 8-12. Rank scores for each residential area.

Figure 8-13 indicates totals for all uses, allu; the college accounts, coll; residential accounts, res; and commercial districts, comm. Again, ordering from less to more, the preferences for each group of uses are displayed below account for all uses.

Figure 8-14 displays the final total of orderings and its preferred ordering. Planb is the choice.

Figure 8-15 shows the results of weighting the choice of each landuse by assigning a value of 4 to the commercial interests. Using a weighted sum, the total weighted ranking is as follows:

	Plan A	Plan B	Plan X
Total	12	6	17

Final preference still indicates planb is chosen.

```
show allu


                        PLANA     PLANB     PLANX

  COLL                  31.00     27.00     31.00
   RES                  39.00     31.00     47.00
  COMM                  32.00     27.00     39.00

R  0.2*  21.0


show allo


          *PLANA   *PLANB   *PLANX

* COLL        2         1         2
*  RES        2         1         3
* COMM        2         1         3

R  0.0*  21.0
```

Figure 8-13. Total scores for all uses.

```
show final

                              PLANA     PLANB     PLANX

 TOTAL                         6.00      3.00      8.00
R  0.0*  22.0
```

```
show finao

        *PLANA   *PLANB   *PLANX
*TOTAL       2        1        3
R  0.1*  22.1
```

Figure 8-14. Final total ranking.

```
show w2

                              VALUE


  COLL                         1.00
   RES                         1.00
  COMM                         4.00

R  0.0*  25.5

show finw2



                              PLANA      PLANB      PLANX


 TOTAL                        12.00       6.00      17.00

R  0.1*  25.7




show fin0#o2


          *PLANA   *PLANB   *PLANX

*TOTAL         2        1        3

R  0.1*  25.8
```

Figure 8-15. Weighted total ranking.

8.9 Goal Files

One may define a goal file in order to represent a preference ordering or required value on a given parameter. Such a file may contain the parameter's name and two statements. The first statement is a relative preference, les, for less is preferred, grt, for more is preferred, and equ for equality is required. After such a statement, an absolute value may be defined. Inclusion of a number and a relative statement may denote a requirement such as "rent (must be) less than 160 (dollars monthly)." An example of a goal file for Jones is displayed below. In this case a relative preference of "less is preferred" is designated for the parameter of travel time, ttw. No absolute criterion is defined.

```
print jone2 goal
W 1109.7

 JONE2    GOAL       11/07   1109.7

   00010     RENT LES 160
   00020     TTW LES *
   00030     RECA GRT 1
   00040     E
R .850+.350
```

The score command compares the goal file with a designated account. For instance, if the above goal file were named jone 2 goal, the satisfaction of account jp can be tested by the following command:

```
score jp into jps wrt jone2 goal
SCORE MATRIX =       JPS
```

The results of comparing a goal file and an account produces a 1 for criteria satisfied, a 0 for requirements not satisfied, and a 3 for parameters which cannot be absolutely scored. If the comparison were placed in jps, the results are shown as follows:

```
show jps
          *   EXP   * EXP1   * EXP2

* RENT         1        1        0
*  TTW         3        0        0
* RECA         0        0        1
```

8.10 Summary of CHOICE Commands

(1.) create

The create command allows the planner to define an account which represents an evaluator, a set of alternative proposals, and a set of evaluation parameters. Initial accounts are called "primary," denoted with a -p. Accounts can be created from (data file names) the file system of CTSS. Accounts created from other sources are denoted (c) for CHOICE and (d) for DISCOURSE.

create jones-p from jones one (c) or (d)

Accounts can be created without reference to another system. Dimensions of the account must be specified, but no reference is made to (d) or (c).

create jones-p (i j)

Accounts can be created with a given order and value matrix accompanying them. If order and value matrices are not named, CHOICE provides a numerical name for each working space.

create jones-p (i j) with joneo-o jonev-v

Simple order and value arrays can be created independently from a primary account. These can be used to store values, prices, ranks, etc. for operations.

create joneo-o (i j)

create jonev-v (i j)

(2.) <u>name</u>, <u>rename</u>

The flexibility of the system requires the ability to name and change names of accounts, parameters, and alternatives for primary, order, and value matrices.

If an account is created completely with the CHOICE system, its columns and rows are unnamed. To define them, use <u>name</u> accompanied by the name of the account and the i or j designation for which row or column to bear the name.

<u>name</u> jones (, j) <u>rent</u>

designates the j-th column of account jones is called rent.

One may also rename an account, row or column.

<u>rename</u> jones resj

could change account jones to a title denoting results of jones evaluation, resj.

(3.) <u>=, +, *, /</u>

Arithmetic operators can be performed by designating the location for the answer, the arguments for the function, and the operators. A group of calculations can be sequenced, but only in serial fashion from left to right. Operations can also be performed by rows or columns, or by complete matrices.

city (taxrr, exp 1) = jones (tax, exp 1) +
smith (tax, exp 1)

An equality sign, =, allows values to be entered into an account.

jones (tax, exp 1) = 280

Equality also allows data from one account or matrix type to be shifted to another.

resj = jones

(4.) total, average, sdev, occurrence, discount, and wsum Operations appearing often in evaluation literature or used frequently in development of CHOICE have been combined into single commands. Each must be given a designated place to put an answer of the operation.

res (jones, exp 1) = total jone (, expl)

could indicate the results of an alternative for jones may be the total of entries in the account column called exp 1.

Similarly, for average and sdev, standard deviation.

A weighted sum can be performed by using wsum. This operation multiplies two arrays element by element and then adds the products.

tcost (jones, exp 1) = wsum jones (, exp 1) *
wghts (, cost)

These commands will be used frequently in the experiment in Chapter 9.

The number of incidences of a particular value can be counted by occurrence. To determine the number of first ranks an alternative may receive in a preference ordering,

vote (first, exp 1) = occurrence of 1 jones (, exp 1)

Finally, a discounting exists which allows the planner to compute present values of outcomes. The command also permits him to rapidly change and test different interest rates and time horizons.

presv (jones, exp 1) = discount jones (, exp 1)
r = 5 (.05)
t = 20 (years)

(5.) order

The order command ranks primary accounts by rows or columns from "greater to less" or "less to greater." This is used to express preference and implies a choice for rank 1. In case of ties, the ranks are equal, signifying indifference of preference and the next rank is a number representing the next level of preference. If, for a set of three elements ranked from greater to less, there is a tie for highest value between two alternatives, they receive 1 and the third alternative receives a rank of 2. The results go into the order matrix associated with the account being ordered.

order jones row grt

One may also specify the matrix into which ranks should be filed.

<u>order</u> jones <u>row grt</u> <u>into</u> reso

(6.) <u>score</u>

The <u>score</u> command checks goal files against a specified account. Goal files (see 8.9) are called by the planner in the following way:

<u>score</u> jones <u>into</u> res <u>wrt</u> goal file

where <u>wrt</u> means with respect to the goal file name.

Results indicate satisfaction of requirement (1), unsatisfied requirement (0), and also indicates goals which are only relative in nature. <u>Score</u> also orders those parameters which have only relative commands, <u>grt</u> or <u>les</u>.

(7.) <u>show</u>

All accounts, or elements of accounts can be displayed by the command <u>show</u>.

<u>show</u> jones

<u>show</u> jones (rent, exp 1)

CHAPTER 9. EXPERIMENT IN SCORING

9.1 Scores

Deriving measurements on ratio scales such as costs or directly inputing ordinal judgments (Chapter 8) are two forms of evaluation. A third type of scheme will be demonstrated in the following experiment. Design alternatives can be evaluated by defining measurement scales on which scores are assigned to represent how well a design is expected to perform with respect to a given parameter. Such scores are intermediate representations between actually measuring the consequence of a particular design and ordinally judging its relative merit. These scoring scales are interval in type.

9.2 Performance Measurement

Measurements of performance indicate how well an alternative satisfies objectives assigned to different design parameters. How well a design "performs" is always relative to a particular criterion and the degree to which it is accomplished. Musso and Rittel build a complete argument for performance measurement.[1] They suggest performance transformations

[1]Arne Musso and Horst Rittel, Measuring the Performance of Buildings, Washington University, St. Louis, Missouri, September, 1967. Presentation develops model of evaluation which can be implemented in CHOICE. Although many kinds of scales are discussed, empirical work was based on the additive scoring scheme. Their behavioral work produced evidence which supports the assumptions of the model and the practical feasibility of the procedure. The scheme was also used to arrive at a consensus about relevant parameters and scores, another potential use of CHOICE.

from the performance parameter to the scoring scale which map the property of the design to an interval of real numbers with the following properties:

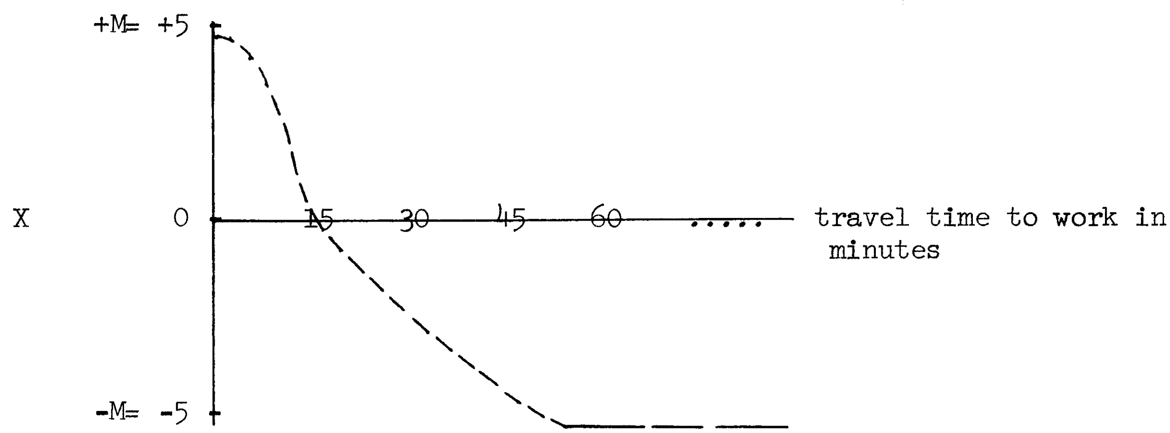
(1.) X is an interval of real numbers between -M and +M;

(2.) "0" means neither well nor poorly accomplished objective;

(3.) "+M" means excellent or could not be better accomplished;

(4.) "-M" means could not be worse.

Numbers assigned to this interval were chosen to be between +5 and -5. The transformation was viewed as follows:



Such a transformation indicates best solution in terms of travel time (for this evaluator) occurs at 0 time and decreases until the worst performance is reached at forty-five minutes.

Each parameter is considered to be weighted according to how important its performance is to the total performance of the design. A weighted sum of the importance weight and the performance score determines the total score. This conforms with the familiar additive utility concept and is open to all its well-known criticisms.

9.3 Relative Value

A second type of scoring scheme also deals with weighted sums, but the method for determining the relative importance of different parameters is more rigorous. As an extension of his interest in additive utility as a rule for choice, Fishburn logically deduces the conditions for independence of evaluator preferences and presents the following example of his scheme:[2]

He assumes that a young job seeker is able to assign numerical values (Table II) to a set of expected consequences (Table I) deriving from three alternative company offers.

Table I

Evaluation Criteria		Alternatives	
	Company A	Company B	Company C
1. annual salary	$10,000	$8,000	$6,000
2. fringe benefits	Package A	Package B	Package C
3. location of job	Boston	New York	Philadelphia
4. nature of work	Technical	Adm-Tech	Administrative
5. working conditions	tolerable	excellent	good

[2]Peter C. Fishburn, "Independence in Utility Theory with Whole Product Sets," Operations Research, Vol. 13, No. 1, January-February, 1965, pp. 28-45. For a rebuff to his arguments and a rebuttle in their defense, see "Note on Fishburn's Independence in Utility Theory with Whole Product Sets," by F. S. Dryer and "A Reply to Dryer's Note on Fishburn's Article," Operations Research, Vol. 13, No. 3, May-June, 1965, pp. 494-499.

Table II

		Company A	Company B	Company C
1.	annual salary	10	7	5
2.	fringe benefits	1	3	4
3.	location of job	3	2	2
4.	nature of work	2	4	3
5.	working conditions	0	2	1
	TOTALS	16	18	15

This transformation from Table I to II can be described in terms of performance transformation (9.2). For example, annual salary can be scored by assuming the following function:

However, one would be even harder pressed to describe such a function for location.

From a mathematical point of view, independence and additivity allow further transformations according to the following rules:

(1.) A constant may be added to (or subtracted from) all numbers in any row. Different constants may be added to different rows.

(2.) Every number in a row may be multiplied by a constant.

Fishburn is interested in ascertaining the degree to which each alternative differs from the available set along each parameter. If all three companies offered the same annual salary, the relative value of this criterion on the overall choice would be zero. This is because each criterion is treated independently. The degree to which the alternatives differ is the most important aspect of his scheme.

First, each row of scores for a particular criterion is transformed to the same scale. A zero is assigned to the lowest score; a ten is assigned to the best. Intermediate scores are assigned a relative score proportional to its distance between the best and worst. In the case of annual salary,

Company A	10	=	10
Company B	7	=	4
Company C	5	=	0

Table III indicates this standardization of scores:

		Company A	B	C
1.	annual salary	10	4	0
2.	fringe benefits	0	6.7	10
3.	location of job	10	0	0
4.	nature of work	0	10	5
5.	working conditions	0	10	5

The degree of difference between scores in Table II comprise the weighting vector of relative importance.

For annual salary, it is the difference 10-5=5; fringe benefits, 4-1=3; location, 3-2=1; nature of work, 4-2=2; and working conditions, 2-0=2. Multiplying this column of weights by corresponding scores of each alternative and adding produces a total weighted sum. For Company A, (10*5) + (0*3) + (10*1) + (0*2) + (0*2) = 60.

Totals are summarized as follows:

	Company A	B	C
Total relative value	60	80	50

9.4 Parameters for Evaluation

Ten architecture students at the Boston Architectural Center were asked to evaluate a small design project that each student had completed. The project was to design a small chapel for a summer camp. The students defined the following reasons and criteria for evaluating the project:

(1.) The structure must be adaptable to either a flat site or a sloping site of no more than two foot rise in ten feet.

(2.) The structure must be adaptable to heavily wooded sites and minimum destruction of natural geographic features is requested.

(3.) Most sites have at least one desirable viewing orientation, this may be a lake, mountain range, or other geographic features. The design shall lend itself to take full advantage of these features.

(4.) The structure shall be timber construction and all materials must be available at local lumber yards.

(5.) All structural and finish materials shall have a low maintenance requirement characteristic.

(6.) The local lumber yard will provide minimum construction services, however, it is desirable that Boy Scouts and their leaders can perform the majority of construction services, to minimize cost. You may assume that adult leaders, Explorer Scouts (16-19 years) and Boy Scouts (13-16) participate in the construction.

(7.) Although no code restrictions are applicable at any of the sites, it is expected that the chapel will encompass all safety characteristics for the well-being of the occupant.

(8.) The chapel must provide a high degree of vandalism security during the winter months.

(9.) Although the chapel is non-denominational each religious group during the religious service shall be able to identify the environment as being related to their religious preference.

(10.) The chapel is to accommodate a maximum of 400 people for major religious events.

(11.) In addition to the scheduled services it shall be possible for individual families, adults or scouts to visit the chapel at all times.

(12.) All spaces required by the program must be provided and function efficiently.

(13.) Electricity and water are the only utility services available at the camp site and must be provided in such a manner to neither destroy the landscape or cause excessive soil disturbance.

(14.) Minimal heating must be provided in the chapel.

(15.) The policy of group cohesiveness with the BSA shall be provided for in the chapel.

(16.) The psychological factors are very important in this chapel for the individual as well as the religious ritual. Lighting, interior design and use of material shall contribute towards these goals.

(17.) It is important that an individual whether scout or adult can meditate in private without being readily observable by others.

(18.) The presentation must communicate.

(19.) The structure must be adaptable to location of existing trails and natural circulation paths.

Each student independently proposed a chapel design. This parallel generation of alternatives provides a sample of ten options which could be evaluated. For convenience of notation, the alternatives are denoted as A, B C D, E, F, G, H, I, J. The parameters are numbered 1 through 19. The CHOICE system permits these titles to be up to five letter words. More complete notation is used where appropriate.

Each student scored the performance of each alternative on a scale from 0 to 10. The higher the score, the more satisfactory the alternative with respect to performing the given objective. The scoring scheme is similar to Rittel's performance scales, except the origin has been shifted.

Because the designer is acting as a measurement function and the scales all represent "more preferred to less performance," ordering from greater to less on each scale indicates the ranking of choices for each evaluator. The consequences of four different choice rules are generated by using the CHOICE system.

The four choice rules can be summarized as follows:

(1.) <u>Prior</u> evaluation of the complete project by indicating a single score (from 0 to 10) on the objective of total performance. This score was made before each designer analyzed each project with respect to the other 19 criteria.

(2.) <u>Total</u> of the individual scores assigned to each criterion for each project.

(3.) <u>Weighted Total</u> of the individual scores multiplied by a set of weights assigned to represent the relative importance of each parameter. This is analogous to Rittel's scheme (9.1).

(4.) <u>Fishburn's</u> scheme of relative value computed as indicated above (9.2).

Both Rittel's and Fishburn's schemes assume value-wise independence of scores. The following example indicates how such evaluations can be performed using CHOICE. It also substantiates the correspondence between using interval-type scales and the operations of Chapter 8. Finally, it further demonstrates the types of information that can be obtained by using CHOICE.

9.5 Prior Scores

The prior score of each alternative was indicated on a scale from 0 to 10. These scores were arrayed in an account called PRIOR. Each row represents the scores assigned by the designer, whose name is represented by its first three letters.

For example, Mr. Zolon scored the alternatives as follows:

Zol

A	B	C	D	E	F	G	H	I	J
8	4	6	8	5	5	7	6	8	4

The prior scores were arrayed in the CHOICE system and several operations were performed on the account.

Figure 9-1A shows the prior scores arranged in rows by designer.

Figure 9-1B indicates the order of preferred alternative from most preferred (rank 1) to least preferred (rank 10). Ties in preference are given the same ranking.

Figure 9-2A shows the results of computing the average score for each alternative, as well as the totalling prior scores.

Figure 9-2B shows the order of average and total scores from greater to less. Obviously, they are the same because one is a linear function of the other.

show prior

	A	B	C	D	E	F	G	H	I	J
ZOL	8.00	4.00	6.00	8.00	5.00	5.00	7.00	6.00	8.00	4.00
FOU	5.00	3.00	8.00	9.00	7.00	4.00	5.00	6.00	8.00	3.00
BRO	9.00	3.00	9.00	7.00	5.00	7.00	4.00	5.00	9.00	4.00
FAR	10.00	1.00	8.00	4.00	2.00	6.00	2.00	3.00	7.00	5.00
DAY	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BAR	7.00	3.00	5.00	6.00	8.00	5.00	7.00	9.00	6.00	5.00
RIC	7.00	6.00	9.00	8.00	7.00	6.00	7.00	7.00	8.00	8.00
MAR	7.00	4.00	4.00	6.00	5.00	6.00	5.00	6.00	9.00	5.00
BER	1.00	10.00	3.00	4.00	7.00	5.00	5.00	5.00	1.00	7.00
KIR	8.00	6.00	8.00	8.00	6.00	7.00	6.00	8.00	7.00	7.00

R 1.1* 3.8

Figure 9-1A. Prior scores arranged in rows by designer.

order prior row grt

R 0.0* 4.2

show prio

*	A	B	C	D	E	F	G	H	I	J
* ZOL	1	9	5	1	7	7	4	5	1	9
* FOU	6	9	2	1	4	8	6	5	2	9
* BRO	1	10	1	4	6	4	8	6	1	8
* FAR	1	10	2	6	8	4	8	7	3	5
* DAY	1	1	1	1	1	1	1	1	1	1
* BAR	3	10	7	5	2	7	3	1	5	7
* RIC	5	9	1	2	5	9	5	5	2	2
* MAR	2	9	9	3	6	3	6	3	1	6
* BER	9	1	8	7	2	4	4	4	9	2
* KIR	1	8	1	1	8	5	8	1	5	5

R 0.8* 5.0

Figure 9-1B. Order of preferred alternative from most preferred to least preferred.

show jury

	A	B	C	D	E	F	G	H	I	J
AVERP	6.20	4.00	6.00	6.00	5.20	5.10	4.80	5.50	6.30	4.80
TOTP	62.00	40.00	60.00	60.00	52.00	51.00	48.00	55.00	63.00	48.00

R 0.2* 7.2

Figure 9-2A. Average and total score for each alternative.

```
order jury row grt

R  0.1*   7.3

show juryo
```

	A	B	C	D	E	F	G	H	I	J
*AVERP	2	10	3	3	6	7	8	5	1	8
* TOTP	2	10	3	3	6	7	8	5	1	8

```
R  0.2*   7.6
```

Figure 9-2B. Order of average and total scores from greater to less.

9.6 Relative Weights

Each evaluator assigned a number representing his estimation of the relative importance of performance on each evaluation parameter. An average of these scores for each parameter based on assignments by all evaluators could represent some overall assignment of importance.[3] The amount of disagreement among evaluators about the relative importance of each parameter can be measured by the standard deviation of these scores. Such a measure describes the variation of values assigned by different evaluators.

Figure 9-3 displays the value weights assigned to each parameter by each evaluator.

Figure 9-4A displays the average and standard deviation of these weights for each parameter.

Figure 9-4B shows the order of average and standard deviation. The largest average score represents most important; the smallest standard deviation indicates the least amount of disagreement about the parameter's importance.

Except for the relationship between the most important scores (averages of rank 1, 2, 3, 4 corresponding to rank of agreement of 2, 5, 4, and 3 respectively) there seems to be little structure between importance and agreement.

[3]Perhaps a better scheme would be to standardize the scores assigned to a common scale in order to diminish the propensity of some evaluators to group all scores at the high end of their performance measurement.

```
r choice
W 1456.9

   * Choice System * 10/28

R  0.0*    0.0

create eval-p from value weight(c)
PRIMARY MATRIX =     EVAL
ORDER MATRIX =     ORDRO2
VALUE MATRIX =     VALU03

R  1.3*    1.3

show eval-p
```

	ZOL	FOU	BRO	FAR	DAY	BAR	RIC	MAR	BER	KIR
1	8.00	10.00	3.00	9.00	10.00	5.00	9.00	9.00	8.00	8.00
2	9.00	8.00	10.00	10.00	10.00	7.00	5.00	7.00	9.00	7.00
3	4.00	5.00	5.00	5.00	6.00	5.00	7.00	2.00	8.00	8.00
4	6.00	5.00	1.00	8.00	8.00	10.00	8.00	9.00	5.00	6.00
5	5.00	5.00	6.00	6.00	4.00	9.00	4.00	6.00	5.00	6.00
6	7.00	8.00	5.00	10.00	10.00	10.00	7.00	10.00	7.00	10.00
7	6.00	10.00	9.00	2.00	10.00	10.02	0.	6.00	9.00	10.00
8	4.00	8.00	5.00	5.00	3.00	2.00	2.00	4.00	5.00	7.00
9	3.00	8.00	3.00	2.00	5.00	1.00	3.00	1.00	6.00	8.00
10	8.00	10.00	10.00	8.00	10.00	8.00	9.00	0.00	2.00	10.00
11	8.00	8.00	8.00	7.00	9.00	3.00	1.00	0.00	4.00	9.00
12	7.00	10.00	9.00	6.00	10.00	9.00	9.00	0.00	10.00	9.00
13	3.00	2.00	7.00	2.00	1.00	8.00	2.00	1.00	3.00	2.00
14	5.00	2.00	7.00	2.00	5.00	5.00	2.00	1.00	4.00	2.00
15	4.00	8.00	0.00	6.00	9.00	1.00	5.00	6.00	6.00	8.00
16	6.00	5.00	4.00	10.00	10.00	7.00	8.00	8.00	8.00	8.00
17	7.00	5.00	0.00	8.00	9.00	2.00	9.00	6.00	2.00	10.00
18	8.00	10.00	8.00	5.00	10.00	10.00	10.00	8.00	6.00	8.00
19	7.00	10.00	10.00	0.	0.	0.	0.	0.	0.	8.00

```
R  2.0*    3.4
```

Figure 9-3. Relative weights assigned to represent importance of parameters (rows) by evaluators (columns).

show stat

	AVER	SDEV
1	7.90	2.12
2	8.20	1.60
3	5.50	1.75
4	6.60	2.46
5	5.60	1.36
6	8.40	1.74
7	7.20	3.46
8	4.50	1.86
9	4.00	2.49
10	8.10	2.39
11	6.30	2.61
12	8.50	1.50
13	3.10	2.30
14	3.50	1.86
15	5.90	2.17
16	7.40	1.85
17	6.40	2.65
18	8.30	1.68
19	3.50	4.36

R 0.4* 0.9

Figure 9-4A. Average and standard deviation of relative weights by parameters.

```
order stat(,1) grt

R  0.0*   0.9

order stat(,2) les

R  0.0*   1.0

show stato



        * AVER  * SDEV

*    1      6     10
*    2      4      3
*    3     14      6
*    4      9     14
*    5     13      1
*    6      2      5
*    7      8     18
*    8     15      8
*    9     16     15
*   10      5     13
*   11     11     16
*   12      1      2
*   13     19     12
*   14     17      8
*   15     12     11
*   16      7      7
*   17     10     17
*   18      3      4
*   19     17     19

R  0.4*   1.4
```

Figure 9-4B. Order of average rank (from greater to less importance) and standard deviation (from less to more disagreement).

9.7 Parameter Scores by Evaluators

Accounts were formed for each designer's assignment of scores to each alternative on every parameter. The score represents the transformation of a measurement on each parameter to a scale from 0 to 10 which indicates how satisfactorily the alternative performs the given objective as estimated by the evaluator.

Figures 9-5A - 9-14A indicate each evaluator's scores.

Figures 9-5B - 9-14B show the rank order of the individual scores based on the preference of "more performance preferred to less."

If a decision rule were based on a single parameter's performance, the rank of "1" in any row specified would indicate the preferred choice. More than a single "1" indicates indifference between alternatives ranked first. For example, Mr. Farrell's scoring of the first parameter (the site adaptability of the structure) indicates a preference for alternative A. It can be noted that several accounts assign scores of 0 to parameter 19. This is caused by the addition of that parameter on several accounts, but not universally held by all evaluators. Ranking such accounts gives a row of 1's indicating equal preference (indifference) as prescribed by Fishburn.

Operations required to produce Figures 9-5A, B to 9-14A, B are summarized as follows:

(1.) Creation of data file for each account using CTSS to <u>edit</u> from score sheets found in Appendix 1.

(2.) Creation of primary account using CHOICE to <u>create</u> matrices <u>Zolon</u>, <u>Fourn</u>, etc.

(3.) Ranking accounts by using CHOICE <u>order-row grt</u> to produce order matrices <u>Zolo</u>, <u>Fouro</u>, etc.

(4.) Using CHOICE <u>show</u> to display <u>Zolon</u>, <u>Zolo</u>, etc.

show zolon

	A	B	C	D	E	F	G	H	I	J
1	9.00	3.00	9.00	9.00	3.00	5.00	5.00	7.00	9.00	2.00
2	10.00	2.00	10.00	7.00	3.00	4.00	6.00	10.00	8.00	2.00
3	5.00	2.00	7.00	5.00	4.00	4.00	4.00	6.00	5.00	5.00
4	7.00	8.00	6.00	8.00	8.00	4.00	8.00	6.00	8.00	5.00
5	8.00	8.00	8.00	8.00	6.00	8.00	8.00	9.00	8.00	4.00
6	9.00	6.00	9.00	9.00	5.00	4.00	8.00	9.00	8.00	3.00
7	6.00	4.00	6.00	6.00	6.00	7.00	6.00	7.00	7.00	6.00
8	4.00	8.00	4.00	9.00	8.00	7.00	9.00	4.00	5.00	5.00
9	5.00	4.00	5.00	9.00	4.00	5.00	8.00	4.00	8.00	5.00
10	10.00	10.00	6.00	10.00	7.00	8.00	7.00	6.00	7.00	7.00
11	7.00	5.00	7.00	10.00	6.00	5.00	4.00	7.00	7.00	6.00
12	7.00	4.00	5.00	10.00	6.00	8.00	4.00	7.00	7.00	6.00
13	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
14	1.00	5.00	1.00	9.00	5.00	2.00	9.00	1.00	4.00	6.00
15	6.00	3.00	10.00	8.00	6.00	6.00	6.00	10.00	8.00	6.00
16	8.00	4.00	8.00	8.00	8.00	6.00	7.00	4.00	6.00	10.00
17	7.00	1.00	7.00	8.00	5.00	4.00	5.00	6.00	5.00	6.00
18	6.00	5.00	6.00	8.00	7.00	3.00	6.00	7.00	8.00	6.00
19	10.00	1.00	10.00	8.00	3.00	5.00	8.00	9.00	10.00	5.00

R 1.9* 12.1

Figure 9-5A. Assignment of performance scores by Zolon.

order zolon row grt

R 0.1* 12.3

show zolo

	*	A	B	C	D	E	F	G	H	I	J
*	1	1	8	1	1	8	6	6	5	1	10
*	2	1	9	1	5	8	7	6	1	4	9
*	3	3	10	1	3	7	7	7	2	3	3
*	4	6	1	7	1	1	10	1	7	1	9
*	5	2	2	2	2	9	2	2	1	2	10
*	6	1	7	1	1	8	9	5	1	5	10
*	7	4	10	4	4	4	1	4	1	1	4
*	8	8	3	8	1	3	5	1	8	6	6
*	9	4	8	4	1	8	4	2	8	2	4
*	10	1	1	9	1	5	4	5	9	5	5
*	11	2	8	2	1	6	8	10	2	2	6
*	12	3	9	8	1	6	2	9	3	3	6
*	13	1	1	1	1	1	1	1	1	1	1
*	14	8	4	8	1	4	7	1	8	6	3
*	15	5	10	1	3	5	5	5	1	3	5
*	16	2	9	2	2	2	7	6	9	7	1
*	17	2	10	2	1	6	9	6	4	6	4
*	18	5	9	5	1	3	10	5	3	1	5
*	19	1	10	1	5	9	7	5	4	1	7

R 1.8* 14.2

Figure 9-5B. Rank ordering of performance score from greater to less for evaluation by Zolon.

show fourn

	A	B	C	D	E	F	G	H	I	J
1	8.00	2.00	8.00	8.00	8.00	6.00	5.00	6.00	8.00	5.00
2	8.00	2.00	8.00	7.00	6.00	4.00	4.00	7.00	4.00	3.00
3	8.00	4.00	8.00	7.00	5.00	4.00	4.00	6.00	5.00	4.00
4	6.00	5.00	3.00	8.00	8.00	3.00	6.00	2.00	8.00	5.00
5	7.00	3.00	8.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
6	7.00	5.00	6.00	8.00	5.00	6.00	6.00	5.00	9.00	3.00
7	4.00	8.00	7.00	9.00	8.00	7.00	7.00	7.00	8.00	7.00
8	8.00	4.00	9.00	7.00	7.00	6.00	7.00	8.00	7.00	6.00
9	9.00	8.00	9.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
10	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
11	7.00	4.00	7.00	9.00	7.00	4.00	7.00	7.00	7.00	7.00
12	1.00	2.00	1.00	9.00	9.00	2.00	9.00	5.00	9.00	1.00
13	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
14	9.00	9.00	10.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
15	7.00	7.00	8.00	9.00	8.00	6.00	8.00	5.00	8.00	5.00
16	9.00	4.00	9.00	9.00	9.00	6.00	7.00	7.00	9.00	5.00
17	4.00	2,00	7.00	9.00	7.00	4.00	7.00	8.00	7.00	5.00
18	5.00	7.00	8.00	10.00	8.00	6.00	8.00	7.00	8.00	6.00
19	2.00	0.	2.00	1.00	9.00	1.00	3.00	2.00	2.00	1.00

R 1.9* 3.6

Figure 9-6A. Assignment of performance scores by Fournier.

order fourn row grt

R 0.2* 3.8

show fouro

*	* A	* B	* C	* D	* E	* F	* G	* H	* I	* J
* 1	1	10	1	1	1	6	8	6	1	8
* 2	1	10	1	3	5	6	6	3	6	9
* 3	1	7	1	3	5	7	7	4	5	7
* 4	4	6	8	1	1	8	4	10	1	6
* 5	2	10	1	2	2	2	2	2	2	2
* 6	3	7	4	2	7	4	4	7	1	10
* 7	10	2	5	1	2	5	5	5	2	5
* 8	2	10	1	4	4	8	4	2	4	8
* 9	1	3	1	3	3	3	3	3	3	3
* 10	1	1	1	1	1	1	1	1	1	1
* 11	2	9	2	1	2	9	2	2	2	2
* 12	8	6	8	1	1	6	1	5	1	8
* 13	1	1	1	1	1	1	1	1	1	1
* 14	2	2	1	2	2	2	2	2	2	2
* 15	6	6	2	1	2	8	2	9	2	9
* 16	1	10	1	1	1	8	6	6	1	9
* 17	8	10	3	1	3	8	3	2	3	7
* 18	10	6	2	1	2	8	2	6	2	8
* 19	3	10	3	7	1	7	2	3	3	7

R 1.7* 5.6

Figure 9-6B. Rank ordering of performance score from greater to less for evaluation by Fournier.

show brown

	A	B	C	D	E	F	G	H	I	J
1	3.00	4.00	0.	6.00	6.00	0.	6.00	0.	0.	4.00
2	10.00	5.00	10.00	5.00	5.00	7.00	5.00	10.00	7.00	5.00
3	8.00	0.	8.00	4.00	2.00	3.00	3.00	8.00	3.00	2.00
4	2.00	7.00	2.00	5.00	7.00	2.00	7.00	2.00	8.00	6.00
5	5.00	8.00	5.00	5.00	8.00	9.00	8.00	6.00	7.00	6.00
6	6.00	6.00	9.00	6.00	6.00	5.00	4.00	7.00	3.00	4.00
7	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
8	8.00	3.00	10.00	6.00	4.00	7.00	4.00	10.00	4.00	4.00
9	10.00	6.00	10.00	7.00	8.00	8.00	8.00	8.00	8.00	8.00
10	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
11	10.00	3.00	10.00	6.00	3.00	4.00	3.00	9.00	7.00	3.00
12	4.00	7.00	10.00	10.00	4.00	10.00	4.00	4.00	7.00	5.00
13	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
14	0.	10.00	10.00	3.00	10.00	10.00	10.00	0.	0.	0.
15	8.00	3.00	10.00	8.00	5.00	5.00	5.00	7.00	7.00	5.00
16	8.00	7.00	8.00	6.00	8.00	8.00	7.00	7.00	6.00	8.00
17	2.00	2.00	9.00	2.00	7.00	2.00	2.00	7.00	7.00	2.00
18	10.00	10.00	8.00	8.00	6.00	7.00	4.00	10.00	9.00	7.00
19	9.00	1.00	10.00	9.00	1.00	3.00	1.00	6.00	4.00	1.00

R 2.0* 9.0

Figure 9-7A. Assignment of performance scores by Brown.

```
order brown row grt

R  0.4*   9.4

show browo
```

		* A	* B	* C	* D	* E	* F	* G	* H	* I	* J
*	1	6	4	7	1	1	7	1	7	7	4
*	2	1	6	1	6	6	4	6	1	4	6
*	3	1	10	1	4	8	5	5	1	5	8
*	4	7	2	7	6	2	7	2	7	1	5
*	5	8	2	8	8	2	1	2	6	5	6
*	6	3	3	1	3	3	7	8	2	10	8
*	7	1	1	1	1	1	1	1	1	1	1
*	8	3	10	1	5	6	4	6	1	6	6
*	9	1	10	1	9	3	3	3	3	3	3
*	10	1	1	1	1	1	1	1	1	1	1
*	11	1	7	1	5	7	6	7	3	4	7
*	12	7	4	1	1	7	1	7	7	4	6
*	13	1	1	1	1	1	1	1	1	1	1
*	14	7	1	1	6	1	1	1	7	7	7
*	15	2	10	1	2	6	6	6	4	4	6
*	16	1	6	1	9	1	1	6	6	9	1
*	17	5	5	1	5	2	5	5	2	2	5
*	18	1	1	5	5	9	7	10	1	4	7
*	19	2	7	1	2	7	6	7	4	5	7

```
R  1.7*   11.2
```

Figure 9-7B. Rank ordering of performance score from greater to less for evaluation by Brown.

show far

	A	B	C	D	E	F	G	H	I	J
1	10.00	5.00	8.00	9.00	5.00	8.00	6.00	7.00	8.00	3.00
2	9.00	1.00	10.00	5.00	3.00	8.00	6.00	8.00	7.00	1.00
3	8.00	0.	7.00	2.00	1.00	0.	0.	6.00	8.00	8.00
4	10.00	8.00	10.00	6.00	6.00	10.00	10.00	8.00	10.00	9.00
5	8.00	8.00	8.00	8.00	6.00	10.00	9.00	4.00	10.00	7.00
6	10.00	2.00	10.00	6.00	3.00	10.00	7.00	9.00	9.00	4.00
7	8.00	2.00	9.00	8.00	4.00	10.00	2.00	8.00	8.00	6.00
8	9.00	4.00	10.00	8.00	3.00	9.00	7.00	7.00	7.00	5.00
9	3.00	3.00	2.00	3.00	3.00	3.00	4.00	5.00	9.00	2.00
10	9.00	2.00	5.00	7.00	3.00	7.00	3.00	3.00	3.00	3.00
11	10.00	3.00	10.00	4.00	4.00	8.00	3.00	6.00	7.00	4.00
12	8.00	4.00	5.00	6.00	2.00	6.00	0.	4.00	9.00	3.00
13	10.00	5.00	7.00	7.00	5.00	7.00	4.00	4.00	8.00	7.00
14	0.	4.00	7.00	8.00	4.00	0.	10.00	2.00	6.00	8.00
15	6.00	0.	8.00	3.00	3.00	4.00	2.00	3.00	6.00	4.00
16	10.00	0.	7.00	6.00	3.00	8.00	0.	2.00	6.00	2.00
17	8.00	0.	10.00	3.00	4.00	6.00	0.	4.00	6.00	1.00
18	9.00	5.00	9.00	9.00	5.00	6.00	2.00	5.00	8.00	7.00
19	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

R 2.1* 14.4

Figure 9-8A. Assignment of performance scores by Farrell.

order far row grt

R 0.1* 14.6

show faro

	*	A	*	B	*	C	*	D	*	E	*	F	*	G	*	H	*	I	*	J
*	1	1		8		3		2		8		3		7		6		3		10
*	2	2		9		1		7		8		3		6		3		5		9
*	3	1		8		4		6		7		8		8		5		1		1
*	4	1		7		1		9		9		1		1		7		1		6
*	5	4		4		4		4		9		1		3		10		1		8
*	6	1		10		1		7		9		1		6		4		4		8
*	7	3		9		2		3		8		1		9		3		3		7
*	8	2		9		1		4		10		2		5		5		5		8
*	9	4		4		9		4		4		4		3		2		1		9
*	10	1		10		4		2		5		2		5		5		5		5
*	11	1		9		1		6		6		3		9		5		4		6
*	12	2		6		5		3		9		3		10		6		1		8
*	13	1		7		3		3		7		3		9		9		2		3
*	14	9		6		4		2		6		9		1		8		5		2
*	15	2		10		1		6		6		4		9		6		2		4
*	16	1		9		3		4		6		2		9		7		4		7
*	17	2		9		1		7		5		3		9		5		3		8
*	18	1		7		1		1		7		6		10		7		4		5
*	19	1		1		1		1		1		1		1		1		1		1

R 1.9* 16.5

Figure 9-8B. Rank ordering of performance score from greater to less for evaluation by Farrell.

show day

	A	B	C	D	E	F	G	H	I	J
1	10.00	0.	9.00	8.00	1.00	8.00	4.00	9.00	10.00	4.00
2	10.00	0.	10.00	5.00	0.	3.00	4.00	10.00	10.00	0.
3	6.00	1.00	6.00	1.00	0.	0.	1.00	6.00	2.00	1.00
4	5.00	5.00	7.00	4.00	8.00	8.00	7.00	5.00	8.00	7.00
5	1.00	4.00	2.00	2.00	4.00	4.00	3.00	2.00	4.00	4.00
6	10.00	8.00	10.00	10.00	5.00	10.00	10.00	10.00	10.00	3.00
7	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
8	3.00	2.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
9	5.00	4.00	4.00	5.00	5.00	1.00	5.00	4.00	4.00	2.00
10	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
11	9.00	7.00	9.00	7.00	5.00	7.00	7.00	9.00	9.00	7.00
12	10.00	6.00	8.00	10.00	2.00	6.00	2.00	10.00	10.00	9.00
13	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
14	4.00	5.00	5.00	4.00	5.00	4.00	5.00	4.00	4.00	5.00
15	4.00	6.00	9.00	9.00	4.00	3.00	4.00	7.00	8.00	0.
16	10.00	2.00	6.00	8.00	7.00	2.00	5.00	6.00	9.00	7.00
17	9.00	2.00	9.00	2.00	6.00	3.00	7.00	9.00	9.00	8.00
18	10.00	10.00	9.00	10.00	8.00	2.00	2.00	10.00	9.00	5.00
19	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

R 2.0* 19.4

Figure 9-9A. Assignment of performance scores by Day.

order day row grt

R 0.3* 19.7

show dayo

	*	A	* B	* C	* D	* E	* F	* G	* H	* I	* J
*	1	1	10	3	5	9	5	7	3	1	7
*	2	1	8	1	5	8	7	6	1	1	8
*	3	1	5	1	5	9	9	5	1	4	5
*	4	7	7	4	10	1	1	4	7	1	4
*	5	10	1	7	7	1	1	6	7	1	1
*	6	1	8	1	1	9	1	1	1	1	10
*	7	1	1	1	1	1	1	1	1	1	1
*	8	1	10	1	1	1	1	1	1	1	1
*	9	1	5	5	1	1	10	1	5	5	9
*	10	1	1	1	1	1	1	1	1	1	1
*	11	1	5	1	5	10	5	5	1	1	5
*	12	1	7	6	1	9	7	9	1	1	5
*	13	1	1	1	1	1	1	1	1	1	1
*	14	6	1	1	6	1	6	1	6	6	1
*	15	6	5	1	1	6	9	6	4	3	10
*	16	1	9	6	3	4	9	8	6	2	4
*	17	1	9	1	9	7	8	6	1	1	5
*	18	1	1	5	1	7	9	9	1	5	8
*	19	1	1	1	1	1	1	1	1	1	1

R 1.7* 21.5

Figure 9-9B. Rank ordering of performance score from greater to less for evaluation by Day.

show bar

	A	B	C	D	E	F	G	H	I	J
1	10.00	1.00	10.00	3.00	5.00	3.00	8.00	10.00	10.00	3.00
2	10.00	4.00	10.00	4.00	3.00	6.00	3.00	10.00	4.00	1.00
3	10.00	2.00	10.00	3.00	3.00	4.00	3.00	10.00	2.00	2.00
4	5.00	8.00	5.00	5.00	8.00	10.00	8.00	5.00	5.00	8.00
5	2.00	5.00	2.00	2.00	5.00	8.00	5.00	5.00	5.00	5.00
6	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
7	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
8	8.00	8.00	8.00	8.00	8.00	6.00	8.00	10.00	6.00	6.00
9	10.00	6.00	2.00	5.00	5.00	5.00	5.00	2.00	5.00	5.00
10	10.00	10.00	10.00	10.00	10.00	10.00	10.00	7.00	8.00	5.00
11	10.00	8.00	10.00	8.00	6.00	6.00	5.00	5.00	3.00	5.00
12	8.00	8.00	7.00	5.00	4.00	10.00	3.00	8.00	8.00	2.00
13	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
14	0.	0.	2.00	2.00	0.	10.00	0.	10.00	5.00	0.
15	2.00	2.00	8.00	8.00	6.00	6.00	9.00	10.00	9.00	6.00
16	0.	3.00	3.00	3.00	5.00	5.00	4.00	1.00	5.00	2.00
17	2.00	1.00	5.00	3.00	3.00	3.00	0.	10.00	2.00	2.00
18	8.00	6.00	7.00	5.00	6.00	8.00	4.00	4.00	2.00	0.
19	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

R 2.2* 24.8

Figure 9-10A. Assignment of performance scores by Barlow.

order bar row grt

R 0.1* 24.9

show baro

*	A *	B *	C *	D *	E *	F *	G *	H *	I *	J
* 1	1	10	1	7	6	7	5	1	1	7
* 2	1	5	1	5	8	4	8	1	5	10
* 3	1	8	1	5	5	4	5	1	8	8
* 4	6	2	6	6	2	1	2	6	6	2
* 5	8	2	8	8	2	1	2	2	2	2
* 6	1	1	1	1	1	1	1	1	1	1
* 7	1	1	1	1	1	1	1	1	1	1
* 8	2	2	2	2	2	8	2	1	8	8
* 9	1	2	9	3	3	3	3	9	3	3
* 10	1	1	1	1	1	1	1	9	8	10
* 11	1	3	1	3	5	5	7	7	10	7
* 12	2	2	6	7	8	1	9	2	2	10
* 13	1	1	1	1	1	1	1	1	1	1
* 14	6	6	4	4	6	1	6	1	3	6
* 15	9	9	4	4	6	6	2	1	2	6
* 16	10	5	5	5	1	1	4	9	1	8
* 17	6	9	2	3	3	3	10	1	6	6
* 18	1	4	3	6	4	1	7	7	9	10
* 19	1	1	1	1	1	1	1	1	1	1

R 2.0* 26.9

Figure 9-10B. Rank ordering of performance score from greater to less for evaluation by Barlow.

show ri

	A	B	C	D	E	F	G	H	I	J
1	7.00	5.00	7.00	6.00	5.00	9.00	7.00	6.00	9.00	8.00
2	5.00	6.00	9.00	6.00	6.00	6.00	6.00	9.00	7.00	6.00
3	7.00	6.00	7.00	5.00	5.00	7.00	6.00	7.00	5.00	8.00
4	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
5	6.00	6.00	6.00	7.00	8.00	9.00	8.00	7.00	6.00	8.00
6	8.00	7.00	10.00	7.00	7.00	8.00	7.00	9.00	9.00	7.00
7	7.00	5.00	8.00	7.00	8.00	7.00	7.00	7.00	8.00	8.00
8	4.00	8.00	4.00	4.00	7.00	7.00	7.00	3.00	5.00	6.00
9	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
10	8.00	7.00	9.00	7.00	9.00	9.00	9.00	7.00	7.00	9.00
11	9.00	7.00	9.00	9.00	7.00	7.00	7.00	9.00	7.00	7.00
12	7.00	7.00	7.00	6.00	6.00	6.00	7.00	4.00	9.00	7.00
13	5.00	7.00	5.00	5.00	7.00	7.00	7.00	7.00	7.00	7.00
14	5.00	8.00	8.00	7.00	8.00	7.00	7.00	5.00	6.00	7.00
15	9.00	7.00	9.00	9.00	6.00	6.00	6.00	9.00	6.00	6.00
16	6.00	6.00	7.00	6.00	7.00	7.00	8.00	6.00	7.00	9.00
17	7.00	6.00	7.00	6.00	6.00	6.00	6.00	9.00	7.00	9.00
18	7.00	6.00	9.00	10.00	8.00	8.00	7.00	6.00	8.00	10.00
	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

R 2.3* 20.6

Figure 9-11A. Assignment of performance scores by Rich.

order ri row grt

R 0.0* 20.7

show rio

*	A *	B *	C *	D *	E *	F *	G *	H *	I *	J
* 1	4	9	4	7	9	1	4	7	1	3
* 2	10	4	1	4	4	4	4	1	3	4
* 3	2	6	2	8	8	2	6	2	8	1
* 4	1	1	1	1	1	1	1	1	1	1
* 5	7	7	7	5	2	1	2	5	7	2
* 6	4	6	1	6	6	4	6	2	2	6
* 7	5	10	1	5	1	5	5	5	1	1
* 8	7	1	7	7	2	2	2	10	6	5
* 9	1	1	1	1	1	1	1	1	1	1
* 10	6	7	1	7	1	1	1	7	7	1
* 11	1	5	1	1	5	5	5	1	5	5
* 12	2	2	2	7	7	7	2	10	1	2
* 13	8	1	8	8	1	1	1	1	1	1
* 14	9	1	1	4	1	4	4	9	8	4
* 15	1	5	1	1	6	6	6	1	6	6
* 16	7	7	3	7	3	3	2	7	3	1
* 17	3	6	3	6	6	6	6	1	3	1
* 18	7	9	3	1	4	4	7	9	4	1
*00000	1	1	1	1	1	1	1	1	1	1

R 1.8* 22.5

Figure 9-11B. Rank ordering of performance score from greater to less for evaluation By Rich.

show m

	A	B	C	D	E	F	G	H	I	J
1	10.00	4.00	4.00	8.00	4.00	8.00	8.00	10.00	8.00	4.00
2	10.00	4.00	6.00	4.00	6.00	8.00	6.00	8.00	6.00	4.00
3	8.00	2.00	4.00	2.00	2.00	6.00	4.00	8.00	6.00	4.00
4	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
5	4.00	6.00	4.00	4.00	6.00	8.00	8.00	6.00	8.00	4.00
6	10.00	2.00	8.00	4.00	2.00	8.00	8.00	8.00	8.00	2.00
7	4.00	6.00	2.00	4.00	6.00	6.00	6.00	8.00	8.00	6.00
8	4.00	8.00	6.00	2.00	4.00	4.00	2.00	4.00	4.00	4.00
9	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
10	8.00	8.00	4.00	6.00	4.00	6.00	6.00	8.00	4.00	4.00
11	8.00	2.00	6.00	6.00	6.00	8.00	2.00	4.00	6.00	6.00
12	4.00	4.00	2.00	6.00	4.00	6.00	4.00	4.00	6.00	4.00
13	2.00	6.00	2.00	4.00	6.00	9.00	6.00	2.00	4.00	6.00
14	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15	8.00	6.00	6.00	10.00	6.00	8.00	6.00	4.00	6.00	4.00
16	4.00	6.00	4.00	4.00	8.00	4.00	4.00	4.00	6.00	6.00
17	4.00	4.00	8.00	8.00	6.00	4.00	4.00	8.00	4.00	4.00
18	9.00	8.00	4.00	8.00	8.00	6.00	6.00	8.00	9.00	8.00
19	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

R 2.2* 24.7

Figure 9-12A. Assignment of performance scores by Martell.

order m row grt

R 0.0* 24.7

show mo

*	A	B	C	D	E	F	G	H	I	J
* 1	1	7	7	3	7	3	3	1	3	7
* 2	1	8	4	8	4	2	4	2	4	8
* 3	1	8	5	8	8	3	5	1	3	5
* 4	1	1	1	1	1	1	1	1	1	1
* 5	7	4	7	7	4	1	1	4	1	7
* 6	1	8	2	7	8	2	2	2	2	8
* 7	8	3	10	8	3	3	3	1	1	3
* 8	3	1	2	9	3	3	9	3	3	3
* 9	1	1	1	1	1	1	1	1	1	1
* 10	1	1	7	4	7	4	4	1	7	7
* 11	1	9	3	3	3	1	9	8	3	3
* 12	4	4	10	1	4	1	4	4	1	4
* 13	8	2	8	6	2	1	2	8	6	2
* 14	1	1	1	1	1	1	1	1	1	1
* 15	2	4	4	1	4	2	4	9	4	9
* 16	5	2	5	5	1	5	5	5	2	2
* 17	5	5	1	1	4	5	5	1	5	5
* 18	1	3	10	3	3	8	8	3	1	3
* 19	1	1	1	1	1	1	1	1	1	1

R 1.9* 26.6

Figure 9-12B. Rank ordering of performance score from greater to less for evaluation by Martell.

show b

	A	B	C	D	E	F	G	H	I	J
1	8.00	2.00	6.00	6.00	4.00	8.00	8.00	8.00	8.00	6.00
2	7.00	3.00	8.00	6.00	5.00	8.00	5.00	8.00	8.00	5.00
3	10.00	2.00	10.00	4.00	4.00	6.00	5.00	7.00	9.00	5.00
4	8.00	8.00	8.00	7.00	6.00	5.00	7.00	7.00	9.00	7.00
5	8.00	6.00	8.00	8.00	4.00	8.00	7.00	8.00	9.00	8.00
6	8.00	4.00	7.00	8.00	4.00	6.00	7.00	8.00	9.00	6.00
7	8.00	6.00	7.00	8.00	6.00	7.00	7.00	8.00	9.00	6.00
8	8.00	6.00	6.00	8.00	4.00	7.00	7.00	8.00	8.00	5.00
9	4.00	2.00	1.00	6.00	8.00	4.00	6.00	2.00	6.00	2.00
10	8.00	6.00	6.00	7.00	8.00	8.00	7.00	6.00	7.00	7.00
11	4.00	2.00	4.00	7.00	4.00	6.00	3.00	7.00	8.00	6.00
12	6.00	6.00	7.00	7.00	6.00	6.00	6.00	4.00	8.00	6.00
13	5.00	5.00	5.00	5.00	6.00	5.00	5.00	5.00	5.00	5.00
14	4.00	3.00	8.00	5.00	3.00	8.00	3.00	8.00	5.00	3.00
15	6.00	3.00	8.00	5.00	5.00	7.00	5.00	8.00	8.00	5.00
16	8.00	4.00	7.00	6.00	6.00	7.00	6.00	5.00	7.00	6.00
17	4.00	2.00	4.00	6.00	4.00	6.00	4.00	8.00	8.00	4.00
18	9.00	3.00	8.00	7.00	4.00	6.00	6.00	8.00	8.00	6.00
19	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

R 2.1* 28.8

Figure 9-13A. Assignment of performance scores by Bertman.

order b row grt

R 0.0* 28.9

show bo

		* A	* B	* C	* D	* E	* F	* G	* H	* I	* J
*	1	1	10	6	6	9	1	1	1	1	6
*	2	5	10	1	6	7	1	7	1	1	7
*	3	1	10	1	8	8	5	6	4	3	6
*	4	2	2	2	5	9	10	5	5	1	5
*	5	2	9	2	2	10	2	8	2	1	2
*	6	2	9	5	2	9	7	5	2	1	7
*	7	2	8	5	2	8	5	5	2	1	8
*	8	1	7	7	1	10	5	5	1	1	9
*	9	5	7	10	2	1	5	2	7	2	7
*	10	1	8	8	4	1	1	4	8	4	4
*	11	6	10	6	2	6	4	9	2	1	4
*	12	4	4	2	2	4	4	4	10	1	4
*	13	2	2	2	2	1	2	2	2	2	2
*	14	6	7	1	4	7	1	7	1	4	7
*	15	5	10	1	6	6	4	6	1	1	6
*	16	1	10	2	5	5	2	5	9	2	5
*	17	5	10	5	3	5	3	5	1	1	5
*	18	1	10	2	5	9	6	6	2	2	6
*	19	1	1	1	1	1	1	1	1	1	1

R 2.0* 30.9

Figure 9-13B. Rank ordering of performance score from greater to less for evaluation by Bertman.

show kir

	A	B	C	D	E	F	G	H	I	J
1	7.00	1.00	3.00	6.00	3.00	7.00	5.00	7.00	5.00	7.00
2	7.00	1.00	5.00	4.00	4.00	6.00	4.00	7.00	5.00	5.00
3	8.00	0.	8.00	0.	0.	0.	0.	8.00	8.00	8.00
4	6.00	6.00	6.00	6.00	3.00	3.00	6.00	6.00	6.00	6.00
5	6.00	3.00	6.00	6.00	3.00	6.00	6.00	6.00	6.00	4.00
6	10.00	7.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	7.00
7	10.00	3.00	10.00	3.00	4.00	8.00	4.00	10.00	8.00	10.00
8	7.00	7.00	7.00	6.00	4.00	6.00	7.00	7.00	6.00	5.00
9	6.00	8.00	8.00	8.00	7.00	6.00	7.00	7.00	7.00	8.00
10	10.00	10.00	10.00	10.00	7.00	9.00	8.00	10.00	10.00	10.00
11	6.00	4.00	9.00	9.00	3.00	7.00	3.00	9.00	6.00	8.00
12	9.00	7.00	6.00	9.00	6.00	9.00	7.00	9.00	8.00	7.00
13	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
14	1.00	2.00	2.00	0.	0.	1.00	0.	2.00	2.00	0.
15	8.00	6.00	7.00	7.00	6.00	6.00	6.00	8.00	8.00	7.00
16	6.00	3.00	8.00	8.00	4.00	6.00	5.00	8.00	3.00	6.00
17	0.	1.00	10.00	10.00	7.00	3.00	0.	10.00	1.00	3.00
18	8.00	1.00	7.00	8.00	6.00	6.00	6.00	7.00	6.00	6.00
19	8.00	6.00	5.00	8.00	6.00	6.00	6.00	8.00	8.00	6.00

R 2.1* 14.7

Figure 9-14A. Assignment of performance scores by Kirwin.

order kir row grt

R 0.0* 14.8

show kiro

	*	A *	B *	C *	D *	E *	F *	G *	H *	I *	J
*	1	1	10	8	5	8	1	6	1	6	1
*	2	1	10	4	7	7	3	7	1	4	4
*	3	1	6	1	6	6	6	6	1	1	1
*	4	1	1	1	1	9	9	1	1	1	1
*	5	1	9	1	1	9	1	1	1	1	8
*	6	1	9	1	1	1	1	1	1	1	9
*	7	1	9	1	9	7	5	7	1	5	1
*	8	1	1	1	6	10	6	1	1	6	9
*	9	9	1	1	1	5	9	5	5	5	1
*	10	1	1	1	1	10	8	9	1	1	1
*	11	6	8	1	1	9	5	9	1	6	4
*	12	1	6	9	1	9	1	6	1	5	6
*	13	1	1	1	1	1	1	1	1	1	1
*	14	5	1	1	7	7	5	7	1	1	7
*	15	1	7	4	4	7	7	7	1	1	4
*	16	4	9	1	1	8	4	7	1	9	4
*	17	9	7	1	1	4	5	9	1	7	5
*	18	1	10	3	1	5	5	5	3	5	5
*	19	1	5	10	1	5	5	5	1	1	5

R 1.8* 16.6

Figure 9-14B. Rank ordering of performance score from greater to less for evaluation by Kirwin.

9.8 Three Rules of Choice

Three rules of choice were tested for each evaluator in addition to his prior scoring of each design. Each rule computes an overall score from scores assigned to each parameter (Figures 9-5A to 9-14A). The purpose of using different rules is to indicate the variation of choice consequences for each scheme.

Figure 9-15A shows the results of totalling the individual scores for each alternative design. Each row displays an evaluator's total score for each design.

Figure 9-16A indicates the results of a weighted total score using individual scores and a vector of weights assigned by each evaluator. Each row displays an evaluator's weighted score for each alternative.

Figure 9-17A shows the results of performing operations discussed by Fishburn (9.3). Display of these results is in the same format as the above figures.

Figures 9-15, 16, 17B show the results of ordering each set of scores from greater to less.

Operations to obtain Figures 15-17A and B include the following:

(1.) Creation of accounts for total score, weighted total, and Fishburn's relative value respectively named <u>tot</u>, <u>wttot</u>, and <u>fishb</u>.

(2.) Computing entries in account tot by using CHOICE total on columns of each account zolon, fourn, etc. (Figures 9-5 - 15A).

(3.) Computing entries in account wttot by using command wsum to perform vector multiplication of arrays from accounts zolon, fourn, etc. (Figures 9-5 - 14A) and their respective importance from matrix eval (Figure 9-3).

(4.) Obtaining entries for account fishb by a set of operations including arithmetic operators - and / to compute the transformation to a common scale as well as creation of a set of weights representing the difference between largest and smallest values assigned to each design by each evaluator. After obtaining new matrices of transformed scores and weights, wsum was used to obtain relative values in fishb.

(5.) Using ordering command order row grt to produce respective rankings found in toto, wtto, and fisho (Figures 9-15, 16, 17B).

(6.) Show tot, toto, etc.

show tot

	A	B	C	D	E	F	G	H	I	J
ZOL	130.00	88.00	129.00	154.00	105.00	97.00	123.00	124.00	133.00	100.00
FOU	128.00	95.00	137.00	153.00	147.00	108.00	131.00	125.00	142.00	106.00
BRO	133.00	112.00	159.00	126.00	120.00	120.00	111.00	131.00	117.00	100.00
FAR	145.00	56.00	142.00	108.00	67.00	120.00	75.00	95.00	135.00	84.00
DAY	127.00	83.00	127.00	109.00	84.00	85.00	90.00	125.00	129.00	86.00
BAR	125.00	102.00	129.00	104.00	107.00	130.00	105.00	137.00	109.00	82.00
RIC	117.00	114.00	131.00	117.00	120.00	126.00	122.00	120.00	123.00	132.00
MAR	113.00	92.00	86.00	96.00	94.00	115.00	96.00	110.00	109.00	86.00
BER	123.00	73.00	118.00	116.00	91.00	118.00	104.00	123.00	139.00	98.00
KIR	146.00	58.00	140.00	135.00	54.00	93.00	86.00	163.00	137.00	96.00

R 1.2* 3.5

Figure 9-15A. Computational results of <u>total score</u> operations by evaluator (row) for each design alternative (column).

order tot row grt

R 0.0* 3.6

show toto

*	A *	B *	C *	D *	E *	F *	G *	H *	I *	J
* ZOL	3	10	4	1	7	9	6	5	2	8
* FOU	6	10	4	1	2	8	5	7	3	9
* BRO	2	8	1	4	5	5	9	3	7	10
* FAR	1	10	2	5	9	4	8	6	3	7
* DAY	2	10	2	5	9	8	6	4	1	7
* BAR	4	9	3	8	6	2	7	1	5	10
* RIC	8	10	2	8	6	3	5	6	4	1
* MAR	2	8	9	5	7	1	5	3	4	9
* BER	2	10	4	6	9	4	7	2	1	8
* KIR	2	9	3	5	10	7	8	1	4	6

R 0.9* 4.5

Figure 9-15B. Rank ordering from greater to less of <u>total score</u> by evaluator (row) for each design (column).

show wttot

	A	B	C	D	E	F	G	H	I	J
ZOL	838.00	629.00	835.00	923.00	789.00	574.00	619.00	715.00	753.00	765.00
FOU	866.00	648.00	941.00	1082.00	1056.00	740.00	923.00	868.00	1002.00	714.00
BRO	919.00	737.00	1102.00	886.00	751.00	828.00	696.00	919.00	786.00	641.00
FAR	970.00	321.00	918.00	656.00	410.00	807.00	460.00	609.00	820.00	459.00
DAY	1133.00	709.00	1118.00	973.00	705.00	742.00	766.00	1109.00	1155.00	738.00
BAR	812.00	731.00	828.00	671.00	728.00	911.00	701.00	837.00	718.00	551.00
RIC	685.00	636.00	762.00	671.00	667.00	726.00	697.00	681.00	724.00	783.00
MAR	714.00	542.00	532.00	604.00	564.00	681.00	596.00	688.00	682.00	642.00
BER	750.00	426.00	717.00	680.00	531.00	690.00	627.00	710.00	831.00	578.00
KIR	1113.00	405.00	1078.00	1088.00	484.00	760.00	680.00	1238.00	1009.00	749.00

R 1.1* 5.6

Figure 9-16A. Computational results of weighted total score operations by evaluator (row) for each design alternative (column).

```
order wttot row grt
R  0.1*   5.8
show wtto
```

	A	B	C	D	E	F	G	H	I	J
ZOL	2	8	3	1	4	10	9	7	6	5
FOU	7	10	4	1	2	8	5	6	3	9
BRO	2	8	1	4	7	5	9	2	6	10
FAR	1	10	2	5	9	4	7	6	3	8
DAY	2	9	3	5	10	7	6	4	1	8
BAR	4	5	3	9	6	1	8	2	7	10
RIC	6	10	2	8	9	3	5	7	4	1
MAR	1	9	10	6	8	4	7	2	3	5
BER	2	10	3	6	9	5	7	4	1	8
KIR	2	10	4	3	9	6	8	1	5	7

```
R  0.9*   6.7
```

Figure 9-16B. Rank ordering from greater to less of weighted total score by evaluator (row) for each design (column).

show fishb

	A	B	C	D	E	F	G	H	I	J
ZOL	690.60	230.00	690.50	910.60	489.50	360.30	639.80	654.40	693.20	389.70
FOU	478.50	140.20	560.60	722.50	660.00	260.80	490.10	469.80	600.20	240.00
BRO	558.60	350.00	820.20	489.30	429.40	376.00	320.50	659.70	379.20	300.00
FAR	1078.00	377.00	1075.00	807.00	491.00	878.00	528.00	700.00	1007.00	605.00
DAY	830.00	370.00	780.00	600.00	350.20	359.50	410.00	759.20	809.80	331.60
BAR	747.00	517.00	778.00	559.00	560.00	762.00	541.00	865.00	608.00	1490.00
RIC	347.00	344.00	396.00	352.00	360.00	382.00	368.00	348.00	378.00	616.00
MAR	541.00	384.00	384.00	416.00	396.00	530.00	426.00	508.00	501.00	360.00
BER	588.00	310.00	564.00	545.00	417.00	559.00	487.00	593.00	675.00	454.00
KIR	640.00	165.80	662.20	589.90	299.20	419.30	349.60	740.20	570.00	489.50

R 1.2* 7.9

Figure 9-17A. Computational results of Fishburn's relative value operations by evaluator (row) for each design alternative (column).

```
order fishb row grt

R  0.1*   8.1

show fisho
```

	A	B	C	D	E	F	G	H	I	J
* ZOL	3	10	4	1	7	9	6	5	2	8
* FOU	6	10	4	1	2	8	5	7	3	9
* BRO	3	8	1	4	5	7	9	2	6	10
* FAR	1	10	2	5	9	4	8	6	3	7
* DAY	1	7	3	5	9	8	6	4	2	10
* BAR	5	10	3	8	7	4	9	2	6	1
* RIC	9	10	2	7	6	3	5	8	4	1
* MAR	1	8	8	6	7	2	5	3	4	10
* BER	3	10	4	6	9	5	7	2	1	8
* KIR	3	10	2	4	9	7	8	1	5	6

```
R  1.1*   9.2
```

Figure 9-17B. Rank ordering from greater to less of Fishburn's relative value by evaluator (row) for each design (column).

9.9 Choice Rankings by Evaluators

In contrast to displaying different rankings for each evaluator by rules (Figure 9-1B for prior, Figures 9-15, 16, 17B for total, weighted total and Fishburn's criterion) the following shows the different rankings for each rule by evaluators. One can see the correspondence in choice for each evaluator if he had used one of the four schemes computed.

Figures 9-18 through 9-27 indicate different preference rankings for different rules displayed by evaluator.

Operations included the following:

(1.) Create a new set of summary accounts as order matrices zolo, fouo, etc.

(2.) Using correspondence sign =, transfer ordinal information from accounts in Figures 9-15, 16, 17B.

(3.) Show

show zolo

*	A *	B *	C *	D *	E *	F *	G *	H *	I *	J
*PRIOR	1	9	5	1	7	7	4	5	1	9
* TOT	3	10	4	1	7	9	6	5	2	8
*WTTOT	2	8	3	1	4	10	9	7	6	5
*FISHB	3	10	4	1	7	9	6	5	2	8

R 0.4* 7.5

Figure 9-18. Preference ranking of alternative designs (columns) with respect to different choice rules (rows) by evaluator Zolon.

```
show fouo

         *     A    *     B    *     C    *     D    *     E    *     F    *     G    *     H    *     I    *     J

*PRIOR         6          9          2          1          4          8          6          5          2          9
*   TOT        6         10          4          1          2          8          5          7          3          9
*WTTOT         7         10          4          1          2          8          5          6          3          9
*FISHB         6         10          4          1          2          8          5          7          3          9

R   0.4*    8.2
```

Figure 9-19. Preference ranking of alternative designs (columns) with respect to different choice rules (rows) by evaluator Fournier.

show broo

*	A	* B	* C	* D	* E	* F	* G	* H	* I	* J
*PRIOR	1	10	1	4	6	4	8	6	1	8
* TOT	2	8	1	4	5	5	9	3	7	10
*WTTOT	2	8	1	4	7	5	9	2	6	10
*FISHB	3	8	1	4	5	7	9	2	6	10

R 0.4* 8.9

Figure 9-20. Preference ranking of alternative designs (columns) with respect to different choice rules (rows) by evaluator Brown.

show faro

	A	B	C	D	E	F	G	H	I	J
*PRIOR	1	10	2	6	8	4	8	7	3	5
* TOT	1	10	2	5	9	4	8	6	3	7
*WTTOT	1	10	2	5	9	4	7	6	3	8
*FISHB	1	10	2	5	9	4	8	6	3	7

R 0.4* 9.6

Figure 9-21. Preference ranking of alternative designs (columns) with respect to different choice rules (rows) by evaluator Farrell.

show dayo

	A	B	C	D	E	F	G	H	I	J
*PRIOR	1	1	1	1	1	1	1	1	1	1
* TOT	2	10	2	5	9	8	6	4	1	7
*WTTOT	2	9	3	5	10	7	6	4	1	8
*FISHB	1	7	3	5	9	8	6	4	2	10

R 0.4* 10.3

Figure 9-22. Preference ranking of alternative designs (columns) with respect to different choice rules (rows) by evaluator Day.

show baro

	A	B	C	D	E	F	G	H	I	J
*PRIOR	3	10	7	5	2	7	3	1	5	7
* TOT	4	9	3	8	6	2	7	1	5	10
*WTTOT	4	5	3	9	6	1	8	2	7	10
*FISHB	5	10	3	8	7	4	9	2	6	1

R 0.4* 10.9

Figure 9-23. Preference ranking of alternative designs (columns) with respect to different choice rules (rows) by evaluator Barlow.

show rico

*	A	*	B	*	C	*	D	*	E	*	F	*	G	*	H	*	I	*	J
*PRIOR	5		9		1		2		5		9		5		5		2		2
* TOT	8		10		2		8		6		3		5		6		4		1
*WTTOT	6		10		2		8		9		3		5		7		4		1
*FISHB	9		10		2		7		6		3		5		8		4		1

R 0.4* 11.6

Figure 9-24. Preference ranking of alternative designs (columns) with respect to different choice rules (rows) by evaluator Rich.

show maro

	* A	* B	* C	* D	* E	* F	* G	* H	* I	* J
*PRIOR	2	9	9	3	6	3	6	3	1	6
* TOT	2	8	9	5	7	1	5	3	4	9
*WTTOT	1	9	10	6	8	4	7	2	3	5
*FISHB	1	8	8	6	7	2	5	3	4	10

R 0.4* 12.2

Figure 9-25. Preference ranking of alternative designs (columns) with respect to different choice rules (rows) by evaluator Martell.

```
show bero
```

	A	B	C	D	E	F	G	H	I	J
*PRIOR	9	1	8	7	2	4	4	4	9	2
* TOT	2	10	4	6	9	4	7	2	1	8
*WTTOT	2	10	3	6	9	5	7	4	1	8
*FISHB	3	10	4	6	9	5	7	2	1	8

R 0.4* 13.0

Figure 9-26. Preference ranking of alternative designs (columns) with respect to different choice rules (rows) by evaluator Bertman.

show kiro

	* A	* B	* C	* D	* E	* F	* G	* H	* I	* J
*PRIOR	1	8	1	1	8	5	8	1	5	5
* TOT	2	9	3	5	10	7	8	1	4	6
*WTTOT	2	10	4	3	9	6	8	1	5	7
*FISHB	3	10	2	4	9	7	8	1	5	6

R 0.4* 13.7

Figure 9-27. Preference ranking of alternative designs (columns) with respect to different choice rules (rows) by evaluator Kirwin.

9.10 Comparison of Disagreement among Evaluators and Choice Rules

Having arrayed the results of different rules by different evaluators, one may be interested in the correspondence between evaluator and rule. Using standard deviation as a measure of disagreement or dispersion of rankings, two summaries are provided to relate evaluator and rule.

Figure 9-28 shows the standard deviation of rank orders over the range of choices produced by all evaluators for each rule and alternative.

Figure 9-29 displays the standard deviation of rankings over the range of choices produced by using all rules for each evaluator and alternative.

Calculations were based on the following:

(1.) Create summary accounts csdev to represent the standard deviation of criteria used, and esdev to represent the standard deviation of evaluator considered.

(2.) Compute entries to each summary by use of CHOICE sdev. For csdev, calculations were made on rankings based on different rules of choice (columns of Figures 9-15, 16, 17B as well as 9-1B for prior orderings). This operation measures the variation of choices due to a range of different evaluators.

Entries for esdev were computed by using sdev on the choices for each evaluator using a range of different rules (columns of Figures 9-18 through 27).

(3.) Show cdev and edev.

show csdev

	A	B	C	D	E	F	G	H	I	J
PRIOR	1.93	2.97	2.96	1.95	2.56	2.66	2.54	2.36	1.69	2.91
TOT	2.09	.80	2.11	2.27	2.28	2.62	1.36	2.04	1.74	2.50
WTTOT	1.97	1.51	2.33	2.52	2.45	2.45	1.37	2.17	1.97	2.62
FISHB	2.42	1.10	1.85	2.19	2.14	2.28	1.54	2.28	1.62	3.26

R 0.4* 10.2

Figure 9-28. Standard deviation of rank orders for each rule over range of all evaluators.

show esdev

	A	B	C	D	E	F	G	H	I	J
ZOL	.83	.83	.71	0.	1.30	1.09	1.79	.87	1.92	1.50
FOU	.43	.43	.87	0.	.87	0.	.43	.83	.43	0.
BRO	.71	.87	0.	0.	.83	1.09	.43	1.64	2.35	.87
FAR	0.	0.	0.	.43	.43	0.	.43	.43	0.	1.09
DAY	.47	1.25	.47	0.	.47	.47	0.	0.	.47	1.25
BAR	.71	2.06	1.73	1.50	1.92	2.29	2.28	.50	.83	3.67
RIC	1.58	.43	.43	2.49	1.50	2.60	0.	1.12	.87	.43
MAR	.50	.50	.71	1.22	.71	1.12	.83	.43	1.22	2.06
BER	2.92	3.90	1.92	.43	3.03	.50	1.30	1.00	3.46	2.60
KIR	.71	.83	1.12	1.48	.71	.83	0.	0.	.43	.71

R 1.1* 19.4

Figure 9-29. Standard deviation of rank orders for each evaluator over range of all rules.

9.11 Results

Experimenting with different evaluators and evaluation schemes validates two important assumptions on which CHOICE is based. The first conclusion is that the wide variation of different judgments rendered by different evaluators requires a system in which many points of view can be represented. Secondly, the comparison of different evaluation schemes indicates more variation over choices rendered by different evaluators than variation due to use of different rules. At least for the four rules tested, an evaluator displays less variation in his ranking of alternative designs when using different rules than different evaluators display by using the same rule. It is more important to determine the chooser than the rule by which he chooses. This makes a case for allowing a designer to suggest his own evaluation scheme, rather than prescribing a single set of rules.

CHAPTER 10. CONCLUSIONS AND EXTENSIONS

10.1 CHOICE

The development of CHOICE has demonstrated the feasibility of identifying a set of operations and a data structure with which evaluation schemes can be performed. Such schemes represent manipulations of values on a set of measurement scales which the designer uses to derive his preferences. The use of a time-sharing capability allows the designer to "design" evaluation strategies rather than deterministically apply a given scheme. Alternative evaluation schemes or changes in the weightings, account definitions, and measurement functions of a particular scheme generates consequences of choice. The system used as a model of evaluation can describe the change in choice of alternatives due to a change in specification of the evaluation scheme. One can search for the set of evaluation schemes which produce the same choice. A choice is not produced by a unique set of evaluation assumptions; the same choice can be derived by using any one of a set of evaluation schemes. Such is the argument for constructing a system which can accommodate many schemes, rather than prescribing a single type of evaluation.

10.2 Extensions of CHOICE

The present configuration of CHOICE can be thought of as a set of micro operations. The designer must specify the sequence of derivations, account creations, and other operations. Although no effort should be made to predetermine or limit the designer's sequencing of these steps, a capability for defining and saving a complete strategy should be implemented. The first step in a more comprehensive system would be the development of computations for repeating the same operation on all alternatives and/or all accounts. One basic reason for having a matrix format is to display alternatives available for choice. Most schemes would perform the same derivations on each of the available alternatives. Presently, this repetitive cycle over all alternatives or accounts must be introduced by the designer step by step.

A second extension to the system could be the use of a graphical terminal to describe transformations from a performance parameter to a measurement of how well objectives for that parameter have been accomplished. This would allow the designer to visually describe different performance transformations as discussed by Rittel.

A third area of extension lies in the scope of the system's use. One can easily see a richer set of derivation functions which could be included. In addition to basic arithmetic operators, simple statistics, and discounting, decision rules such as a Bayesian operator can be imagined.

10.3 Conflict and Resolution of Goals

Operations available on the CHOICE system include comparisons of account with account and account with a goal file. A third operation would permit the comparison of goal file with goal file. Such goal comparisons would identify regions of conflict among different evaluators. Conflicts of preference can be identified by checking relative goal statements which are logically opposite. For instance, "more taxes" to an account representing a government conflicts with "less taxes" as a preference of the household. Regions of conflict or agreement can also be identified from absolute goals by checking performance requirements such as "greater than 50" on a particular dimension with "less than 70" on the same parameter. Such statements can be satisfied by results falling within 51 and 69. In summary, there is a set of operations of interest which can be performed on goal files which can assist in identifying regions of conflict and possible resolution.

10.4 Management of Design and Development: A Second Level of Choice

CHOICE is a general structure for manipulating alternative consequences. In design, choices are made among alternative environments and alternative design processes to specify the alternative environments. CHOICE as an accounting structure can be used to represent expenditures of different types of manhours to perform different tasks for each unit of design time. An account can also be used to represent different programs (alternatives) and expenditures of different types of resources (parameters) for each point in time. Such a scheme may be useful for program budgeting management. The flexibility of the system suggests that evaluative accounting in which goals or constraints must be checked, new measurements derived, and definitions changed as new information is gathered are possible applications for CHOICE.

BIBLIOGRAPHY

1. Ackoff, Russell L., Scientific Method: Optimizing Applied Research Decisions, John Wiley and Sons, Inc., New York, 1962, p. 24.

2. Braybrooke, D. and C. W. Lindblom, A Strategy for Decision, Free Press, New York, 1963.

3. Bross, Irwin D., Design for Decision, Free Press, New York, 1953, p. vii.

4. Davidoff, Paul and Thomas A. Reiner, "A Choice Theory of Planning," Journal of the American Institute of Planners, Vol. XXVII, No. 1, February, 1962, pp. 103-115.

5. Debreu, Gerard, Theory of Value: An Axiomatic Analysis of Economic Equilibrium, Monograph #17, Cowles Foundation, John Wiley and Sons, Inc., New York, 1959.

6. Division of International Affairs, Department of Housing and Urban Development, Proposed Minimum Standards for Permanent Low-Cost Housing, Washington, D.C., May, 1966, p. 12.

7. Dorfman, Robert, "Basic Economic and Technological Concepts: A General Statement," Design of Water-Resource Systems, Arthur Maass, et al, Harvard University Press, 1966, pp. 88-158.

8. Dryer, F. S., "Note on Fishburn's Independence in Utility Theory with Whole Product Sets," Operations Research, Vol. 13, No. 3, May-June, 1965, pp. 494-499.

9. Dyckman, John W., "Planning and Decision Theory," Journal of the American Institute of Planners, Vol. XXVI, No. 4, November, 1961, pp. 333-345.

10. Fishburn, Peter C., Decision and Value Theory, John Wiley and Sons, New York, 1964, Chapter 4.

11. ________________, "Independence in Utility Theory with Whole Product Sets," Operations Research, Vol. 13, No. 1, January-February, 1965, pp. 28-45.

12. ________________, "Utility Theory," Management Science, Vol. 14, No. 5, January, 1968, pp. 335-378.

13. Hall, Fred L., "A Method for Dealing with Complex Goals and Indefinite Utilities in Decision Problems," Master's Thesis, Sloan School of Management, M.I.T., 1967.

14. Henderson, James M. and R. E. Quandt, Microeconomic Theory, McGraw-Hill, New York, 1958, Chapters 1 and 2.

15. Hill, Morris, "A Goal-Achievement Matrix for Evaluating Alternative Plans," Journal of the American Institute of Planners, January, 1968, pp. 19-29.

16. ____________, "A Method for Evaluating Alternative Plans: The Goal Achievement Matrix Applied to Transportation Plans," Ph.D. dissertation, University of Pennsylvania, 1966.

17. Hodge, Gerald, "Use and Mis-Use of Measurement Scales in City Planning," Journal of the American Institute of Planners, Vol. XXVIII, No. 2, pp. 112-121.

18. Leven, Charles L., "Regional Income and Product Accounts: Construction and Applications," Design of Regional Accounts, W. Hochwald, ed., Resources for the Future, Inc., Johns Hopkins Press, Baltimore, 1961, p. 148.

19. Lewis, Roger K., "Community-Scale Design Variables," Master's Thesis in Architecture, M.I.T., July, 1967.

20. Litchfield, Nathaniel, "Spatial Externalities in Urban Public Expenditures: A Case Study," The Public Economy of Urban Communities, Julius Margolis, ed., Resources for the Future, Washington, 1965, pp. 207-250.

21. Luce, R. Duncan, and Howard Raiffa, Games and Decisions, John Wiley and Sons, New York, 1957, p. 13.

22. Lynch, Kevin A., Site Planning, M.I.T. Press, 1962, pp. 11-13.

23. Manheim, Marvin L., Highway Route Location as a Hierarchically-Structured Sequential Decision Process, Department of Civil Engineering, M.I.T., May, 1964, pp. 39-47. (Also published as Hierarchical Structure: A Model of Design and Planning Processes, M.I.T. Report 7, M.I.T. Press, 1966.)

24. ________________, "Problem-solving Processes in Planning and Design," Technical Paper P-67-3, Department of Civil Engineering, M.I.T., January, 1967.

25. Marglin, Stephen A., Design of Water-Resource Systems, Arthur Maass, et al, Harvard University Press, 1966, Chapters 2 and 4.

26. Maryland-National Capital Park and Planning Commission, The, General Plan for the Maryland-Washington Regional District, 1962, pp. 16-19.

27. Musso, Arne, and Horst Rittel, Measuring the Performance of Buildings, Washington University, St. Louis, Missouri, September, 1967.

28. Page, Alfred N., ed., Utility Theory: A Book of Readings, John Wiley and Sons, Inc., New York, 1968.

29. Porter, William, "DISCOURSE - Between Computer and City Designer," presented at first international Design Methods Group Conference, M.I.T., June, 1968, and in forthcoming doctoral dissertation by Mr. Porter.

30. Prest, A. R., and R. Turvey, "Cost-Benefit Analysis: A Survey," The Economic Journal, Vol. 75, No. 300, December, 1965, p. 683.

31. Ramstrom, D., and E. Rhenman, "A Method of Describing the Development of an Engineering Project," IEEE Transactions on Engineering Management, Vol. EM-12, No. 3, September, 1965.

32. Rothenberg, Jerome, The Measurement of Social Welfare, Prentice-Hall, Englewood Cliffs, New Jersey, 1961, pp. 6-7.

33. Schlaifer, Robert, Probability and Statistics for Business Decisions, McGraw-Hill, 1959, p. 3.

34. Simon, Herbert A., Models of Man, John Wiley and Sons, New York, 1957, pp. 241-260.

35. Smith, N. M., "A Calculus for Ethics: A Theory of the Structure of Value - Part I," Behavioral Science, April, 1956, pp. 111-142.

36. Stevens, S. S., "Measurement, Psychophysics, and Utility," Measurement: Definitions and Theories, C. W. Churchman and P. Ratoosh, eds., John Wiley and Sons, New York, 1959, p. 19.

37. Torgerson, Warren S., Theory and Methods of Scaling, John Wiley and Sons, Inc., New York, 1958, Chapters 1, 2, and 3.

38. White, D. R. J., D. L. Scott, and R. N. Schulz, "POED - A Method of Evaluating System Performance," IEEE Transactions on Engineering Management, December, 1963, pp. 177-182.

39. Wohl, M., and B. V. Martin, _Evaluation of Mutually Exclusive Design Projects_, Special Report 92, Highway Research Board, 1967.

40. Young, Robert C., "Goals and Goal-Setting," _Journal of the American Institute of Planners_, Vol. XXXII, Number 2, March, 1966, pp. 76-85.

BIOGRAPHICAL NOTE

John Pearce Boorn was born in Englewood, New Jersey, on April 19, 1939. Prior to his doctoral program, he attended Princeton University where he majored in architecture and graduated cum laude in 1961. He has also received a Bachelor in Architecture degree from Massachusetts Institute of Technology in 1964, and a Master of City Planning degree from the University of California in 1966.

Mr. Boorn's professional experience includes architectural practice with O'Connor and Kilham in New York City and Claude Oakland Associates in San Francisco. His planning experience includes work with the Boston Redevelopment Authority and Warren Jones/Francis Violich Associates in Berkeley, California. Research projects include a state-wide poverty study at the Center for Planning and Development Research at Berkeley, work on the application of systems analysis to building design at M.I.T.'s Center for Building Research, and the application of decision theory to transportation systems design for M.I.T.'s Department of Civil Engineering.