THE FUNCTION AND APPLICATION OF ANALYTICAL AIDS FOR DECISION MAKING IN URBAN PLANNING

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ABSTRACT

THE FUNCTION AND APPLICATION OF ANALYTICAL AIDS
FOR DECISION MAKING IN URBAN PLANNING

by Donn Leonard Anderson

In urban planning, as in most human activity, there is usually more than one way to solve a problem. Rarely does a planning problem permit one solution; ordinarily there are many possible alternatives. Not all approaches to a problem, however, are equally good. In making a decision, therefore, a decision maker must both define each of the possible courses of action which appear to be feasible solutions for his problem and, then, he must choose from among these the one which is the "best" solution. This need for selecting one course of action from among a number of possible alternatives is the most distinctive characteristic of decision making.

Decision making in urban planning usually also has the characteristic of requiring the decision maker to project himself into the future and this process involves the element of uncertainty. The selection of the "best" solution requires that the decision maker know, with insightful sureness, the outcome of each of his possible courses of action. The outcome depends upon circumstances as they will be when the course of action is implemented, and therefore the orientation is toward the future.

The principal job of a decision maker then is to make choices between alternative courses of action by determining a future about which he is uncertain. In this situation, experience and intuition must be used and the decision maker must make guesses. Guesses may constitute the entire basis for a decision or they may only fill in where information

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is inadequate or unavailable. The question a decision maker must answer is the extent to which he is willing to base his decisions on speculations.

This thesis explores the use of analytical aids to reduce the decision maker's reliance on intuitive vision in making decisions. The function of a systematic and rational approach to decision making is proposed to define a problem and the factors relevant to its solution consciously and explicitly, to specify the objectives and conditions which a solution must satisfy, to make an effort to mobilize information about resources and the environment and to define possible solutions. In this approach an effort is made to estimate and compare the costs, benefits and risks of each solution and to select the solution which can be regarded as the best balance of cost, benefit and risk. Inspiration and judgment are not refuted as being important in this process, but the aim is to make them the plus ingredient in decision making instead of its sole basis.

The function and application of analytical aids are discussed in reference to dealing with complexity, variability and lack of information in the decision making process. Applications, where specific tools of analysis were used in analyzing problems, point to the usefulness or potential usefulness of the techniques or methods for analyzing decision situations in urban planning. The techniques and methods of analysis which are considered and for which applications are rendered include model building, cost-benefit analysis, simulation, operational gaming and decision theory.

The tools of analysis which were considered reveal that the

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systematic approach to decision making enhances the ability to isolate critical variables in some situations and to relate events to them in a simple and effective manner. Through analysis with the available tools, many problems can be converted to ordered patterns from situations which seem too complex, too random or too uncertain for treatment with anything other than intuition, experience and judgment.

While systematic decision techniques are useful tools within the areas considered, they do not make good decision by themselves. The decision techniques do not themselves determine the scope of the decision, formulate the alternatives, set goals, determine the worth of costs or values, or determine which decision technique to use. Systematic decision techniques can assist decision makers, but they do not supersede them.

THE FUNCT

FOR

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By

Donn Leonard Anderson

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Donn Leonard Anderson

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INTRODUCTION

In the process of planning activity there arise many problems which consist of multiple variables. Rarely does a planning problem permit one exclusive solution. Generally, there are many possible solutions, but all solutions are not equally good. In decision making, two things must be done. Each of the possible courses of action which appear to be feasible solutions for the problem must be defined. Then, a choice must be made from among the solutions, selecting the one which is the "best" solution. The need for selecting one course of action from a number of possible alternatives is the most outstanding characteristic of decision making.

Decision making has two other important characteristics. A projection into the future is required and uncertainty is involved. If the "best" solution is to be chosen it must, obviously, be recognized. "Best" must be defined. Such a solution is one which embodies achievement of the objectives of the organization. Defining "best", therefore, means defining the goals which will be achieved through solving the problem. In terms of these goals, the outcomes of several alternative courses of action must be predicted and compared. After these comparisons, the "best" solution can be chosen. The selection of the "best" solution therefore requires that the outcome of each possible course of action be known. Outcomes depend on circumstances not as they were, or are, but as they will be when the course of action is implemented. In making a choice, therefore, concern is with the future. The orientation toward the future is another major characteristic of decision making in planning.

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the element of uncertainty. Consequently, decision making involves also the element of risk.

The principal job of a decision maker is then to make choices between alternative courses of action by interpreting a future about which he is uncertain. In facing this difficult task, experience, rules of thumb, and intuition must be called upon. The decision maker must make guesses and rely on hunches. Guesses may be "wild" or informed and they may constitute the entire basis for a decision or they may fill in where information is inadequate or unavailable. The question which the decision maker in planning must answer is not whether he is willing to base his decisions on guesses or hunches, because he cannot avoid this condition. It is the question of the extent to which he is willing to do so.

Decision makers in many organizations have concluded that complete reliance on vague operating rules or on sizing up the situation or on intuition is inadequate and often dangerous. Growth in the size and complexity of enterprise and the accelerated change of pace in the environment have made the decision maker's problems vastly more complicated. The structure and operations of many organizations have become so complex that only rarely can decision makers see directly to the heart of a problem. More commonly, they cannot even readily define a problem, much less the many critical factors involved, the inter-relationships between these factors, the possible courses of action and their outcomes, and the probability of occurence of each outcome. Under these circumstances, decision making based on guess work has become risky.

In this situation, many decision makers have endeavored to reduce their reliance on intuitive vision in making decisions. They have tried to substitute a systematic and rational approach to problem solving.

These decision makers seek, consciously and explicitly, to define a problem and the factors relevant to its solution. They specify the objectives and conditions which a solution must satisfy. They make an effort to mobilize information about resources and the environment and to define possible solutions. They try to estimate and compare the costs, benefits and risks of each possible solution. And finally, they select the solution which they regard as the best balance of cost, benefit, and risk. Throughout this process, inspiration and judgment remain important, but the aim is to make them the plus ingredient in decision making rather than its entire foundation.

This systematic approach need not be linked to solely economic or efficiency ends as is often proposed. In fact, this procedure of comparing costs, benefits and risks may be used to bring out other social and cultural values which might not be considered without a systematic approach to the subject matter. In our society, where economic ends are often the only goals considered, it is the systematic approach that will bring to light other aspects of the situation in which other than economic goals will manifest the desired relationship of costs, benefits and risks. Decision making which utilizes a systematic consideration of variables and relationships provides an opportunity for shifts in cultural and social values to be incorporated into the fabric of the evolving and changing environment. A blind reliance on past experience and the major deterministic factors, such as efficiency and economy, slow up the incorporation of changes of the social and cultural environment.

Decision making utilizing a systematic and rational procedure has not necessarily made decision making easier. It has often, in fact, become more difficult. Improvement in the quality of decisions has made "get

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the facts" a byword for decision makers and many organizations have consequently become voracious collectors and processors of information. The volume and diversity of information moving across the desks of executives has attained immense proportions. The effect frequently has been that problems have been obscured rather than illuminated. Effects may have been reported but not their causes. Symptoms may have been described but not their reasons. Sifting of the information to separate out the significant and relevant has become enormously time-consuming. The precise definition of a problem and the methodical evaluation of alternative solutions in a complex situation has come to require more time and greater capabilities than many decision makers have to offer. Uncertainty and risk involved in alternative solutions have remained in some instances, despite the analytical data, crude estimates based on opinion and generalities. Although the systematic approach to problem solving has been of some help in most situations and of great help in some situations, experience and inspiration have continued to be the principal sources of decisions.

The utilization of operations research and other analytical aids gives promise of altering this situation in business and other endeavors where decision making is a major function. The theory building and testing approach to problem solving based on advanced techniques of quantitative analysis greatly enhances the ability to isolate critical variables in a situation and to relate events to them in a simple cogent manner. It often makes inference possible from experience and from the volume of available data of meanings and relationships that are not at all apparent or common sense. In disputes concerning which of two alternative qualitative views is better, this approach can often resolve the dispute by proposing a qualifying comparison of outcomes. Even when this app

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when this approach results in the conclusion that the common sense view held by decision makers is correct, it will usually be able to buttress the view with numerical proof and so give added confidence to the decisions based on it.

Specifically, the method and technique of quantitative analytical aids can ease the executive's difficulties in making decisions by contributing the following:

1. a better and more logical description of his objectives and of the assumptions on which they are based.
2. a more precise and illuminating definition of his problem and of the critical factors involved, the relative importance of each, and the relationships among them.
3. a clear indication of the information required in order to determine the "best" solution.
4. the ability to take into account, in determining the "best" solution, a larger number of relevant factors.
5. a precise description of many more of the possible solutions for the problem, the assumptions underlying each, and the costs, benefits, and risks involved in each.
6. the ability to compare many more possible solutions and to locate the "best" among them, rapidly, efficiently, and with considerable confidence.
7. a basis for predicting the consequences of change in the organization's procedures or in the environment.

The general field of operations research promises to provide executives with a more precise description of the assumptions, cause-and-effect relationships, and risks at the base of operation. It promises to convert many prob

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[1] Shuch
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[2] Perlo
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[3] *Ibid.*

convert many problems which now seem too complex, too chaotic, or too uncertain for treatment other than intuition, experience, and judgment, to ordered patterns which can be analyzed with tools already known and widely used in other disciplines. It promises to provide an understanding of the underlying characteristics and fundamental nature of many complex problems, an understanding which may give managers new insights, and the capability to determine better solutions with greater speed and assurance. The use of operations research may mean that managerial decision making is to become less of an art and more of a science.[1]

The term systems approach has been used widely to describe the higher level of coordination required in complex groupings of many inter-dependent parts. These systems may involve, for example,[2] weapons, communications, automatic controls or groups of people -- separately or in combination. They may comprise a geographic, social, economic, political organization, or institutional entity -- such as a metropolitan city, space exploration, the federal government, or a business corporation.

Melville Branch,[3] who has been associated with a number of different forms or applications of planning, makes an appeal for comprehensive planning, characterized by a concern with coordination and with projection into the future. Comprehensive planning is set apart from specialized physical planning and functional planning (the application of many of the functional fields to planning).

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[1] Shuchman, A., Scientific Decision Making in Business (New York: Rinehart & Winston, Inc., 1963), p. 9.

[2] Perloff, H.S., (Editor), Planning and the Urban Community (University of Pittsburgh Press: Carnegie Institute of Technology, 1961), p. 198.

[3] Ibid., p. 206.

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In its practical application, coordination in planning not only presents problems of mechanical or material interconnection, but also requires the correlation of highly disparate elements, the tangible and the intangible.

Projection is also an objective common to most areas of endeavor. A major concern of intellectual fields in general is to develop knowledge which can be applied today to be of benefit at some future time. For example, a measurement of success in science is the capacity to predict. The word planning in itself connotes this primary characteristic. Some extrapolations are made with high reliability by established analytical methods. Others can be made only within a range of variation. A third category of projections must be based on subjective judgment, intuition, or guess.

In comprehensive planning, long-range reliable prediction is not essential to success. Of greater significance is the regular reporting of recent history, the current situation, and the present trend extrapolated a short time into the future. With these regularly-revised, shorter-range projections, the lead-time for advance planning and action is reduced but the reliability of the forecast is increased. If the comprehensive planning program is organized for rapid revision, and the short-range adjustment of operations is possible and worthwhile, the basic function and benefits of the process are realized. Of course, the longer range, more reliable, and comprehensive the projections, the more definite planning can be. Herein, projection is a universal and complex activity, involving past experience, mathematical and statistical probability, other forms of analytical extrapolation, subjective judgment, and pre-conscious intuition or reasoning.

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Beside coordination and projection, there are other general characteristics of comprehensive planning. Some of these characteristics are: flexibility, time and degree of commitment, plans, considerations of alternatives, safety factor, foci of single or multiple-function emphasis, psychological factors, and optimum allocation of available resources over time.

Trends in the direction of a comprehensive approach are apparent in the systems approach developing within a number of fields, in information and decision theory, game theory, symbolic logic, the psychology of groups, operations research techniques, data processing, quality control, and dynamic financial accounting. There is also experimentation with certain specific mechanisms closely related to comprehensive planning or management science: planning control rooms, data-processing centers, computer simulation, or more inclusive analogues facilitating and extending architectural-engineering design in physical planning. Comprehensive planning can help to synthesize and crystallize these developments because it is the common-denominator field representing and encompassing many crucial areas of practical need and application.[4]

Urban planning is now a professional and educational interest of engineering, architecture, geography, sociology, and economics -- as well as the principal concern of physical planning. The expanding scope of urban planning makes it subject to the more comprehensive viewpoint expressed by Branch. Because of the wide range of interest expressed by other functional areas in the enlarged scope of urban planning, applications of the systems approach should be apparent.

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[4] *Ibid.*, p. 207.

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The systems approach as developed in the field of business has been utilized by the business decision maker in many of his functions. The profit incentive has encouraged a wide utilization of systematic decision making procedures. Under the incentive of better integration of inputs from the fields of interest mentioned above, urban planning has been subjected to a limited exposure to the systems approach. Applications for the utilization of systems techniques are more difficult to devise than in the more specialized business applications. However, as the knowledge within the realm of business applications broadens, the range or applications which can be linked to other areas of concern also broadens.

Although the systems approach has found limited direct use in urban planning, the structuring of planning problems in the systems concept can help in the understanding of problems in a more comprehensive manner. There are some techniques among the analytical aids used in business which are applicable to urban planning problems. These techniques within the subject matter of complexity, variability, and lack of information will be investigated in this study.

Before the techniques are investigated, the structuring of the problem situation and the use and scope of available analytical aids will be discussed.

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CHAPTER I

THE STRUCTURE OF A PROBLEM

A. The Nature of Problems

The minimal necessary and sufficient conditions for the existence of a problem are as follows:[1]

(1) An individual who has the problem: the decision maker.

(2) An outcome that is desired by the decision maker: an objective. Without the desire to obtain an as-yet-unattained outcome there can be no problem. An objective, then is an outcome which has positive value for the decision maker.

(3) At least two unequally efficient courses of action which have some chance of yielding the desired objective. There must be a "real" difference between the choices available to the decision maker. If he has a choice between equally efficient or completely inefficient alternatives, he may think he has a problem, but the problem has only subjective reality.

(4) A state of doubt in the decision maker as to which choice is "best." There must be a question in the mind of the decision maker as to which choice to make.

(5) An environment or context of the problem. The environment consists of all factors which can effect the outcome and which are not under the decision maker's control.

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[1] Ackoff, R. L., and S.K. Gupta and J.S. Minas, Scientific Method-Optimizing Applied Research Decisions (New York: John Wiley & Sons, Inc, 1962), p. 30.

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Problems may be considerably more complex than the minimal one described. Complications may result from such conditions as the following:

(1) The decision makers make the decision but others carry it out. Such is the case when managers make policies or plans which others must follow.

(2) A group of individuals, rather than one, must make the decision.

(3) The decision may have an effect on others who may react to it in such a way as to affect its efficiency. Reactions which decrease the efficiency of the original action are called counteractions. Those in conflict or competition tend to counteract each other's actions.

(4) More than one objective may be involved in a problem, and the objectives may not be consistent. Furthermore, the objectives may change with time.

(5) The number of possible courses of action may be very large.

To solve a problem, whether simple or complex, is to make the best choice from among the available courses of action. In order to maximize our chances of attaining or approximating the best or optimal solution to a problem, it is apparent that we must understand what the "best" or "optimal" solution to a problem is. In determining what such a solution is we are concerned with the choices a decision maker should make, not necessarily with those he normally makes. To the urban planner the task of interpreting the best or optimal solution is a crucial issue in firming plans for future societal forms and values. Underlying motivations and guides should extend beyond the present interpretations which society displays toward best or optimal solutions. Effective planning for the future entails the projection of value systems, to the degree that such projections

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The analysis of criteria of "best" choice is divided into three parts that are based on the distinctions described as follows:[2]

The field of decision making is commonly partitioned according to whether it is effected under conditions of (a) certainty, (b) risk, or (c) uncertainty.

(a) Certainty, if each action is known to lead invariably to a specific outcome.

(b) Risk, if each action leads to one of a set of possible outcomes, each outcome occurring with a known probability. These probabilities are assumed to be known by the decision maker.

(c) Uncertainty, if either action or both has as its consequence a set of possible specific outcomes, but where the probabilities of those outcomes are completely unknown or are not meaningful.

A course of action, in the above context, is not to be taken as a mechanistically-specified pattern of behavior. Variations in the action with respect to specific characteristics may not change the course of action. A course of action may be specified with varying degrees of rigidity, depending on the purpose of the study.

There are situations in which a decision maker does not directly select a course of action. Instead he selects a procedure or rule which permits the selection of a course of action in a specific context. This procedure or rule specifies how the course of action to be taken should be derived from information available at the time action must be taken, though this information is not available at the time at which the decision rule is selected. Such a procedure or rule is called a strategy

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[2] Luce, R.D. and H. Raiffa, Games and Decisions (New York: John Wiley & Sons, Inc., 1957) , p. 13.

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and is itself a type of course of action.[3]

For each course of action there are several types of measures of efficiency, the definition of which require the concepts on input and output.[4] Input refers to the resources which are consumed or expended in taking a course of action. Thus, input refers to the cost of a course of action, where cost is used in a general sense.

Output may be measured in terms of either the resources which result from taking the course of action or the psychological or sociological characteristics of the resulting state. We may talk about the money earned, the material produced, the time saved, or the amount of enjoyment which results from a course of action. Thus, output refers to the return or payoff resulting from a course of action.

Outcomes, which can be classified as objectives, may be defined in terms of either inputs or outputs or both. The type of measure of efficiency required depends on whether the amounts of input and/or output are specified in the definition of the relevant outcome. The relevant outcome in turn is expressed in variables which can be assigned varying degrees of certainty, risk, or uncertainty.

Frequently, the most difficult part of the entire planning process deals with the determination of the degree of certainty to be assigned to significant variables. The problem of uncertainty exists because most plans are formulated in the present on the basis of future expectations, and knowledge of the future is incomplete. In attempting to

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[3]Ackoff, _op_. _cit_., p. 34.

[4]_Ibid_., p. 35.

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determine the degree of certainty to be assigned to each significant variable, the planner is guided by such consideration as the nature of variables, existing policies and procedures, organizational records and experience, the experience of others, the relative cost of measurement in effort and money, the time period covered, and the qualifications of the planner.

These concepts dealing with the nature of a problem can be generally considered as elements of most problem situations. However, decision theory systematically considers problems of certainty, risk, and uncertainty and will be discussed separately in Chapter IV.

B. Formulating the Problem

In the formulation of a problem, in the context described in the preceding section, it is necessary to translate the decision maker's problem into a framework suitable for analysis. This requires an identification of the components of the decision maker's problem. Ackoff[5] identifies the components as follows:

(1) The decision maker(s).

(2) The relevant objectives.

(3) The possible courses of action.

(4) The context: those aspects of the problem environment which, though not subject to the decision maker's control, may affect the outcome of his choice of action. These may be (a) acts of nature, or (b) acts of other decision makers: reactions or counteractions.

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[5] Ibid., pp. 67-73.

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Identifications required for any problem may be simple or complex, depending primarily on the problem context. If the decision maker controls an organization within which, or to which, others may react and which may be sensitive to general social or economic conditions, the mere formulation of the decision maker's problem may consume a significant portion of the total available time.

Ackoff elaborates upon the problem components and a general discussion of the elaboration follows.

1. The Context of the Problem

Most problem contexts consist of a set of needs or desires, and interrelated activities connected by the flow of information which leads to decisions bringing about actions designed to yield some outcome that will satisfy the needs or desires.

The triggering need or desire which it is the purpose of the system to fulfill must be identified. The question of how information concerning the triggering need or desire is conveyed to the organization which can do something about it should be answered. The forms and paths of the communications should be identified. Information may go through many processes, it may be abstracted, or it may be combined with other information.

At each place where information is received a determination should be made as to what is done with it. At some points simple operations such as routing and compiling may be performed. At others, information may be collected, tabulated, and analyzed. All the relevant informational inputs and outputs at each node should be identified. At some points along the information paths decisions are made. The location and nature of the decision should

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decision should be identified. In the planning process, locating the decision inputs relative to a specific problem is important because such decisions form the framework about which a problem context can be built. These decisions which help to form the context of a problem can be classified as sub-decisions in the system which evolves into a problem suitable for analysis.

The information in the system and the sub-decisions based on it eventually make contact with the operations of the system -- that is, they lead to action. To deal with the flow of information in an orderly and efficient way, a procedure should be established for handling the information. The information on decision making and operations is usually best recorded and displayed in flow charts with explanatory notes indicating precisely what has occurred.

In light of what has been learned about decisions and operations in the system, a determination should be made as to which messages have no effect on the activities of interest. These can be eliminated from further consideration.

The activities which are performed between control points -- points at which sub-decisions affect the operation -- can be combined into one composite operation.

The resultant information-process-flow chart will show how the system operates, where and how sub-decisions are made, and what they affect and how. Such an analysis may frequently reveal problems of which the decision maker was unaware, or even show that the problem which he thinks exists is quite different from the one which actually exists.

The complexity of an analysis, such as has been described, depends directly on the complexity of the problem context. However, in all problems an analy

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problems an analysis of the problem context is of primary importance. Such an analysis establishes the framework upon which the various stages of the solution can be evolved.

2. The Decision Maker

It might appear as though the decision maker identifies himself when a problem situation is stated, but this is not necessarily the case. In reference to the sub-decisions identified in the problem context, a heirarchy of decision makers may exist. Possibly those who would appear to be the decision makers may in effect be unrelated to the program. In many large organizations, particularly public ones, the organization at times appears to be designed to conceal the identity of the decision makers and to confuse him who tries to make the identification.

Where the decision maker acts on behalf of an organization, nothing less than the type of analysis described, relative to the problem context, may be required to locate the sources of decisions. Organization charts seldom provide reliable information in this regard; they may show who is responsible for control but not who exercises it. Identifying those who make what have been called sub-decisions (sub-decisions in relation to the decision evolved from the overall analysis and objectives of the problem statement) is necessary because these individuals provide the inputs that form a complete problem context. If these inputs cannot be validated, in respect to source and content of information, the context will be incomplete and further analysis will be unsure.

3. The Relevant Objectives

What is the decision maker trying to attain by solving the problem? And what is he trying to retain? Objectives may involve either getting something one does

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something one does not have or giving up none or as little as possible of something one does have. The decision maker's desire to retain things he already has is usually formulated as restrictions on possible solutions to the problem which limit the courses of action that are acceptable to him.

Objectives are seldom fully elaborated at the time when the problem is formulated. Objectives are likely to be stated in the form of platitudes which have no operational significance. Consequently, objectives usually have to be extracted by the problem researcher. In so doing, the researcher may be performing his most helpful service to the outcome of the problem analysis.

No matter what end or goal the problem is oriented toward, the set of decision objectives which serve as guide lines must be enumerated as clearly as possible. There are few if any selective procedures available. Each problem must be measured against the boundaries which emerge as the analysis of the problem progresses. In fact, the researcher may be relatively unaware of the dimensions of any specific decision objectives until reactions to direct action concerning the problem can be measured.

4. Alternative Courses of Action

Various alternatives may be revealed by analysis of the system and organizations involved. Essentially the task of identifying the possible courses of action consists of (a) identifying the variables that significantly affect the outcome of the problem, and (b) determining which of these can be controlled directly or indirectly by the decision maker.

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Determination of which variables affect the relevant outcome may require the use of analytical procedures. Such analyses should be carried out with the realization that variables may increase or decrease in importance as the problem approaches the final goal.

In development problems, none of the available alternative courses of action is considered to be good enough -- a better one is sought. Such problems can be of two types: design or search. In a design problem a new instrument or process is sought which is more efficient than any of those available. The alternative designs must be compared with each other and the available courses of action.

In a search problem the instruments necessary for a better course of action are believed to exist, and they must be identified and/or located. A development problem, then, consists of formulating a course of action, whereas a search problem consists of finding one. Once new possibilities are developed or found, they must be evaluated relative to each other and previously available courses of action. In either developmental or search problems it may not be possible to specify all the possible courses of action in advance, since the information gained in testing one possibility may be used in formulating the next alternative to be examined.

This phase of the study program is extremely important to the maximization of established goals. It sets the initial course of pursuit and it identifies the difficulties which should be realized as work progresses. If this phase is subjected to a direct detailed study, many of the otherwise unforseen difficulties will be confronted before a final program is initiated.

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A further step in formulating a problem may be to distinguish the main elements in the problem framework. This will in effect bring together the components elaborated upon above into a specific common structure. All decision situations have certain elements in common, and these elements stand out especially clearly when complex decision situations and problems are considered. These common elements are:[6]

(1) Sets of variables and parameters. These include (a) a set of decision variables, which are assumed to be at the disposal of the free choice of the decision maker, (b) a set of outside or exogenous variables, whose values are determined outside the particular theory supporting the given analysis and must be taken as noncontrollable by the decision makers, (c) a set of parameters whose values are also assumed to be noncontrollable and to be accepted as completely determined by the given "state of nature."

(2) A model, or set of relationships among the various parameters and variables.

(3) An objective function, the value of which depends on the values assumed by the variables and parameters. This function allows the decision maker to rank, in the order of desirability, the results which follow from different decisions about the variables under his control.

This element brings together the components identified earlier in the program and converts them into a specific set of variables and parameters together with a value ordering of the functions.

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[6] Carr, C.R. and C.W. Howe, Quantitative Decision Procedures in Management and Economics (New York: McGraw Hill, 1964) p. 9.

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(4) Computational methods by which the decision maker may systematically evaluate the ranking or results which would follow from various decisions. These are procedures for finding those values of the decision variables which optimize the objective function.

If some particular decision-situation is considered where an organization is to make a complex decision, the decision maker may feel overwhelmed in the face of the huge number of variables, the complexity of their interrelationships, the difficulty of predicting the outcomes related to different sets of decisions which might be made, and even by the task of comparing different outcomes as to their desirability. Yet these decisions do in fact get made, and it is apparent that the persons responsible must and do simplify the actual situation by considering only the important variables, the major interrelationships and the important features of the predicted results.

It is one of the major objectives of the quantitative analyst to force these so-called simplifications into the open by requiring that all variables considered, and their interrelationships, be expressed as completely as possible in an explicit model. The process of attempting to formalize decision problems in this manner forces us to:

(a) Consider what data we ideally need to make a good decision, and define what we mean by a good decision.

(b) Efficiently organize and analyze these data.

The quantitative analyst wants to go farther than this, however. He wants to determine the best, or optimal decision when the situation permits. A decision may consist merely of a number, or it may consist of a policy to be followed over a long span of time. In order to optimize,

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the quantitative analyst formalizes the entire problem and attempts to apply mathematical procedures to get an answer.

Problems in business have stimulated research in this type of analysis, and many situations have been structured to conform to such analysis. In production, problems in the areas of lot size, inventory control, assignment of resources, transportation, and allocation of facilities have been modeled and formulated into decision conditions. In marketing, decision problems have been modeled for pricing, competitive bidding, competition strategies, media effectiveness, and brand selection. In administration, financial problems, size of work force, absenteeism, reservations, and maintenance scheduling are some of the decision problems that conform to this type of analysis.

An indication that this systematic type of analysis is being adopted in a number of separate areas of concern is evident from the program of the Second International Conference on Operational Research. The program in 1960 included addresses and discussion on the application of operational research methods to the steel industry, the oil industry, local government, atomic & electric power, national decisions, military applications, mining and transport.

R.T. Eddison from the United Kingdom began the discussion on local government problems by saying:[7]

> "If it be accepted that the objective of public service is to maximize the public good, how is that good to be defined? How can it be measured? And hence how can it be ensured that positive or restrictive activities or public servants and authorities are conducive to that end?

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[7]Eddison, R.T., The Scope for Operational Research in Local Government. In J. Banbury and J. Maitland (Editors), Proceedings of the Second International Conference on Operational Research (New York: John Wiley & Sons, Inc., 1961) p. 393.

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> In a letter to The Times, November 20, 1958, on "Planners at a Disadvantage," Sir William Halford wrote regarding proposals in the Town and Country Planning Bill then before Parliament, 'Development schemes will again have to be maneuvered to suit existing and potential values.'
>
> The industrialist might laugh at the thought that he could buy a piece of equipment simply because it was a beautiful engineering design. His first thought is to decide what he requires done; his second is whether the equipment will do it effectively; to him this is neither novelty nor disadvantage; engineering design will be considered only in deciding between equipment all capable of carrying out the required function. Operational research helps the industrialist to define his requirements and to forecast the effects of introducing new equipment or methods in the complex situations of today. The industrialist's problem is no different from that of the town planner, the school planner, or the hospital planner, although it may be easier in that he can usually measure his satisfaction in terms of money. How far does, or can operational research help the public servant to establish criteria of effectiveness for his plans and suit his designs to functional requirements?"

In one reply, J. P. Coyle[8] from the Massachusetts Institute of Technology, developed some thoughts on the cybernetic principles of planning and the position of the operations research analyst or other technical staff in the process of decision making. A concept is developed describing the evolution of the city as an intricate teleological mechanism which generates its objectives intrinsically.

In the essentially political environment in which broader policy decisions are made it is observed that the appreciation of quantitative analysis tends to be less responsible than in an executive organization. Of equal importance, therefore, to the competence of the quantitative basis offered for decisions is the organization of large and fateful

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[8] Coyle, J.P., The Contribution of Public Policy and Long-Range Plans to Urban Evolution. In J. Banbury and J. Maitland (Editors), Proceedings of the Second International Conference on Operational Research (New York: John Wiley & Sons, Inc., 1961) p. 422.

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The interdependence of all elements of the city with all others is such that no simple outcome can be achieved that does not in fact involve every element in some degree. People and enterprises competing, cooperating, and adapting, interact as an intricate teleological or homeostatic system that hunts for and evaluates its own intrinsic goals. The outcome, and perforce the goal, of such a process must be balance, comprimise, continuity, rather than completion. Where urban planning has been least effective it is through confusion as to these functions. The error is made when planners choose to address the problem "what to evolve" rather than "how to evolve best."

The analyst should concern himself seriously with the decision process involved, in addition to the routine cautions about the validity of his analysis. If measures can be found that make the effectiveness of future actions less vulnerable to present misconceptions or ignorance of unknowables, the analyst is obligated as much to advocate these measures as to contribute to the refinement of the concepts and forecasts.

The difficulty of working with unknowables remains a major deterent in the decision process. However, there has been progress made in the handling of large numbers of variables, and for dealing with complex and variable inputs. The use of analytical aids for decision making is the topic of the next section.

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CHAPTER II

ANALYTICAL AIDS FOR DECISION MAKING

In working with problems of choice, people have always found it advantageous to consider the consequences of alternative policies rather than to choose among them by simply flipping coins. To assist in predicting consequences, models of the real situation are used. These models may be small-scale representations, such as a pilot industrial plant. They may be mathematical models developed from experiment, observation, and reasoning. Or these models may be simple sets of relationships that are sketched out in the mind.

In no case are these models photographic reproduction of reality. If they were, they would be so complicated that they would be of no use to us. In reality, they abstract from the real world. Such abstraction does not mean that they are either bad or good models. Whether or not one is better than another depends upon its usefulness in predicting the future. This comparison may be difficult to determine because of the range of variables involved. The concept of models precludes the utilization of systematic thought about any problem of choice. The alternative is to rely on conjecture or chance.

Some of the most fundamental analytical aids have long been available. Although refinements have occurred, as in the handling of uncertainty, the main elements of the theory of choice have existed in economic theory, mathematics, and some branches of philosophy. This sort of aid indicates at least what questions should be asked in comparing alternative courses of action. Raising the right questions can often generate sim

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generate simple models that are powerful problem solvers.

The spectacular advances over recent years, however, have pertained to the development of other tools. One contributing occurrence has been the rapid development of all the sciences so that it has become possible to say much more about the relationship of one event to another. As missing links in the chain of relationships were filled in, it became possible to predict more accurately the consequences of various actions. Higher-level development has sometimes necessitated the collaboration of teams of scientists and analysts in order to utilize the knowledge of specialists.

Along with the better understanding of scientific relationships has evolved more and better data. Perhaps the data might be described as one facet of better understanding. Also there have been refinements in the methods of statistical inference such as the use of small samples, sequential sampling, and experimental designs. The techniques of computation and model building have become more sophisticated and the computer has been developed to make it practicable to utilize all the other refinements. With the computer, more complex models can be employed, often yielding more useful predictions; more numerous calculations to show results in a wider range of situations have become feasible.

At the same time that these tools were being developed, new applications, or types of analysis, were emerging, and new terminology was being used to describe them. Originally, thoughtful analysis was called merely "problem solving." Under the new analytical stimulus the terms economic analysis, scientific management, efficiency engineering, financial analysis, consumers research, and market research became widely used.

During World War II, modern statistical techniques and knowledge

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from different sciences were used in the comparison of military tactics. Because these studies were used to assist in operational decisions, they became known as "operations research." Since the war, this general approach has been applied to military development and procurement problems, which has meant peering further into the future, including a greatly expanded number of variables, examining a wider range of possible actions, and taking higher-level alternatives into account. The comparison of such enlarged systems of interrelated elements has been called "systems analysis." For analysis to help business firms increase their profits, a variety of names, from operations research to capital budgeting, have been used.

Generally, these various titles do reflect somewhat different types of analysis, the differences stemming largely from the character of the problems attacked. Yet at the same time these types exhibit a marked similarity; they are all attempts to trace systematically at least part of the effects of alternative courses of action. Consequently, many of the methodological difficulties encountered in any one of these types are common to all. Conversely, the breakthroughs in ways or means of analysis are often helpful in the solution of many different types of problems.

Aside from the encouraging developments of analytical tools and of new application, it is clear that the role of such analysis must be that of an aid to the decision maker, not that of a substitute for him. In the face of uncertainty of outcomes, operations research and kindred activities can assist, but not supplant, the exercise of judgment as to which policy is best.[1]

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[1] McKean, R.N., Efficiency in Government Through Systems Analysis (New York: John Wiley & Sons, Inc., 1958) pp. 4-8.

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A. The Need

The need which analytic aids attempt to satisfy arises out of conditions of:

1. The complexity of decision-making operations --

This results from organizational growth, diversity of interests, technological developments, the lengthening futurity of organizational decisions, the impact of new and complex laws and governmental regulations, competitive pressures, and from other social pressures. These conditions point to a need for a higher degree of precision in decision making and implementation than now exists.

There is increasingly needed a growing body of analytical, logical and conceptual skills to establish realistic alternative solutions, to express key factors in such solutions, and to develop measures of their effectiveness. Such skills would help in allowing the risks inherent in a course of action to be judged rationally, prudently and, to the greatest feasible degree, in advance of the time when fundamental decisions must be taken. Also, these skills would provide the information

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[2] Hurni, M.L., "Operations Research and Synthesis in General Electric," Management Consultation Services of the General Electric Company, 1954, p. 28.

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2. The need for operational data --

There is required, increasingly, a properly organized body of facts out of which quantitative relations have been distilled and evaluated to the point where a manageable body of common knowledge is available so that common purposes and common interests may be discerned and heeded.

The tendency toward increasing the automatic equipment in offices and facilities calls for an increasingly higher order of quantitative integration of both primary functional as well as sub-functional classifications of work. The assumption that the manager, from his knowledge, experience and perception alone and the understanding of the need to work with others, can integrate his activities and those of all applicable functions to the common good may progressively become invalid under such conditions. A higher order of relationship responsibilities become as vital as purely functional responsibilities, and teamwork becomes as essential as work by the individual alone.

3. Decision making as a flow process --

The understanding that any business or public service activity, viewed in proper perspective, is a flow process, if not in physical things, then in terms of information is an increasingly acceptable concept. This poses a problem of integration and indicates that the need for integration comes not only from within but also from without the organizational entity. This flow is in fact not broken by institutional organization or ownership division but actually extends from the end product to the

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B. The Opportunity

The opportunities to meet these needs is founded in a growing awareness that many decision-oriented situations have a marked similarity to those in the natural sciences that have been resolved and utilized in various applications in recent years. In particular, the following major problems facing the decision-oriented organization, parallel closely basic problems of the scientist.

1. Time as part of the decision process --

In the decision process, time is not just a dimension in which phenomena happen. It is in itself a part of the process.

Changes in decision situations are apt to be imperceptible but cumulative. They are likely to build up by a relatively slow process from the familiar and established patterns on which past experience and current policies and procedures have been based. They are apt, therefore, to result, in apparent suddenness at some moment in time, in a complete change in the basic situation. Conventional methods, such as the normal methods of analyzing and reporting current operating information, cannot predict when this moment will occur. On the basis of the conventional approach, these changes appear to be unpredictable while at the same time the peiod between such changes appears to be unchanging. Analytical aids in the area of operations

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research and synthesis should make possible the determination of the nature of such changes and the anticipation or prediction of the time at which the cumulative effect will bring about a basic regrouping, and with it a new situation.

2. Measurements and their interrelations --

The decision maker faces a problem of measurement in that measurements are relative to each other rather than absolute. The decision maker therefore has to decide what measurements are applicable and relevant and how to relate the readings of different measurements to each other. This function closely parallels the measuring tasks for which the scientists developed some of the specific approaches and methods used in operations research and synthesis.

3. The multi-dimensional nature of decision problems --

A majority of problems are commonly multidimensional rather than single dimensioned. Therefore, they require for their analysis some kind of quantitative model which relates the data to other known information. By using such a model, the decision maker can predict outcomes, starting with known or assumed conditions. The methods of operations research and synthesis are basically methods of building logical models presenting multi-dimensional situation, preferably in quantifiable form.

4. The probabilistic nature of decision problems --

Typically in a decision situation the decision maker cannot say that a given event will always follow another. The best he can do is to say that there is a greater expectancy that this event, rather than another, will follow. He therefore needs a quantitative measure of the likelihood of various events occurring. Until this is done, data by themsel

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5. Risk-taking --

Similarly, the decision maker is faced with alternative courses of action. Most decisions involve risk-taking which necessitates choosing between alternatives rather than finding one complete and exclusive answer. The professional decision maker, therefore, requires an approach that will identify the existing alternatives, will enable him to assess the risk ratio, and will help him to select at the time his decision is required, that alternative which maximizes the desired outcome.

6. Continuity and Discontinuity --

The data with which the professional decision maker deals are likely to be aggregates of functions, quite frequently containing discontinuous elements as well as continuous ones. In many instances, it is not possible to discern by inspection any degree of continuity whatsoever. In addition, this situation is likely to contain not just a few but many variables that affect the end results. In such a situation neither intuitive methods nor conventional records of past events will necessarily lead to effective or valid results. This problem is similar to problems in biological research from which some of the specialized analytical methods were specifically developed.

From these observations it is apparent that the <u>need</u> for the systematic and organized method available through the use of analytical aids is particularly great in view of the nature of many private and public operations, their size, their technological complexity, the time span for whi

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span for which decisions have to be made and the goals the organizations have set for themselves. It is equally apparent that the opportunities are great.

Beyond the business sphere of influence, other decision-making organizations have shown interest in the use of analytical aids for assistance in decision making. As mentioned earlier in this text, the Second International Conference on Operational Research included, aside from business, discussion of applications in local government, national decisions, military operations, and methods of transport. In the discussion above, considering the need and opportunity for the use of analytical aids, many of the need and opportunity situations can be linked to decision functions in any large-scale decision-making organization. Applications have in the past been limited primarily to business decisions because of the direct incentive to attempt to minimize the expected loss while maximizing the expected gain. In business, the measurement of outcome in profit and loss, measured in dollars, presents a relatively simple and direct measurement media. The incentive for business men to embrace decision-making tools which would enable them to achieve a higher profit ratio has been great. With this incentive, advancement in the sophistication of these tools has been steadily increasing. The advancement has broadened the field of knowledge, and in so doing, has broadened the field of applications open to the use of analytic aids.

Melville Branch, writing in the Journal of the American Institute of Planners, says,[3] many professional fields are now involved directly in different applications of planning: architecture, economics, engineering,

[3]Branch, M.C., "Comprehensive Planning: A New Field of Study," Journal of the American Institute of Planners, Vol. XXV, No. 3, August, 1959.

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geography, business and government management, mathematics, and operations research, military and physical planning, sociology. Such recent intellectual advances as information and decision theory, symbolic logic, mathematical and other simulation, queueing theory, linear programming, or the psychology of groups are being applied successfully to planning problems.

In an earlier article, Dr. Branch[4] developed a comparative discussion of planning and operations research from which the above observations have been amplified.

In 1960, D.T. Cross[5] from England's Ministry of Housing stated that there is evidence that valid empirical generalizations can be made about the size, distribution, and structure of urban areas. Multiple regression and co-variance analysis may prove useful in developing better theories of urban growth. He suggested that at present, criteria by which planning policies may be judged are not adequately formulated and that an improved type of cost-benefit analysis capable of dealing with large-scale planning problems is required. He continues by saying that operational research may be valuable in developing such an analysis and is improving prediction techniques.

L.S. Jay,[6] another planner from England, advocates the application of statistical procedures to land-use studies. He says:

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[4]Branch, M.C., "Planning and Operations Research," Journal of the American Institute of Planners, Vol. XXIII, No. 8, 1957, pp. 168-169.

[5]Cross, D.T., Some Prediction Problems in Town Planning. In J. Banbury and J. Maitland (Editors), Proceedings of the Second International Conference on Operational Research. (New York: John Wiley & Sons, Inc., 1961) p. 396.

[6]Jay, L.S. Characteristics of the Settlement Pattern in South-East England, In J. Banbury and J. Maitland (Editors), Proceedings of the Second International Conference on Operational Research. (New York: John Wiley & Sons, Inc., 1961) p. 414.

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Jay's aim has been to find systematic procedures that will enable the planner:[7]

(a) to identify and measure the factors most closely related to the structure, character, and function of settlements.

(b) to ascertain whether any given characteristic or behavior is or is not typical of some, most or all settlements.

(c) to discover areal patterns, if they exist, and the factors that determine them.

It is suggested that these aims may be achieved by a comparative method based on such techniques as the study of frequency distributions, multi-variate statistical analysis of theoretically related factors, and the construction of matrices.

The above examples of the involvement of planning problems with analytical aids indicate that as applications become more profound, decision making in urban planning problems will be based on a substantive body of knowledge synthesized from intellectual advances in analytical activities.

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[7] Ibid., p. 404.

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[7] Ibid., p. 404.

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In the following sections attention will be directed to the methodology of some specific analytical aids which have relevance in dealing with complexity, dealing with variability, and for dealing with the lack of information in situations related to urban planning.

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CHAPTER III

TOOLS FOR DEALING WITH COMPLEXITY

A. A Framework for Complexity

One of the readily recognized dimensions of a plan is the degree of simplicity or complexity found within and between its components. The simplicity or complexity is conditioned by many factors. The more important ones are:[1]

(1) The number of parts within the plan and the interdependence of these parts.

The number of parts or subparts which appear in a final plan is not the measure to be used here. Frequently a complex plan becomes more simple by the mere act of breaking the total plan into more manageable subunits. The basic unit here is what might best be called components which are logically distinct and identifiable within themselves, but which need to be coordinated into a final total plan.

(2) The number of variables to be considered in arriving at a decision about each component.

The second factor which complicates a plan is the number of alternatives one may choose from in deciding upon a given course of action. This is not to be confused with the number of components previously referred to, but rather the number of choices within each agreed upon component of the plan. The larger the number of alternatives found within components, the more complex the overall planning process becomes.

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[1] LeBreton, P.P. and D.A. Henning, Planning Theory (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1961) pp. 23-28.

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In attempting to decide the superiority of one alternative over another, the planner will be guided by certain variables pertinent to the problem under consideration. To the extent that fewer or more variables are considered, the complexity will change. The degree of change is seldom proportional to the number of variables considered. Usually, however, a plan becomes more complex as additional variables are considered.

(3) The precise guides available to help decision makers in choosing alternatives.

In formulating a plan, the planner must consider the stated objectives of the organization to which the plan applies. He may next consider the written and implied policies at all levels which pertain to the areas of his planning problem. To the extent that all necessary objectives are expressed in unequivocal terms and policy statements cover most components within the plan, the area of judgment to be exercised by the planner is reduced and the planning process becomes less complex than it would be without the guides available to him. Policy statements by government agencies and other planning bodies can serve as general, and at times specific, guides.

(4) The technical nature of the subject matter being considered.

A distinction can be made between a plan which is complex because of the nature of the subject matter as such and the same plan which is more or less complex depending upon the planner and other factors within the organization. In other words, is the complexity of a plan chiefly a function of the technical components of the plan? There

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are a number of ways in which a planner might approach the preparation of his plan. He could decide to do the entire planning job himself in which case it would have maximum complexity for him. If he has a staff of specialists, he could delegate components of the plan to them, in which case his role in the planning procedure would be less complex. Or he could seek advice from outside consultants, which would result in the reduction in complexity of the planning process for him. In all cases the technical nature of the components of the plan remained the same but the role of the planner was changed significantly to the extent that specialized assistance was available. The final decisions on the plan must still be made by the planner regardless of the assistance he may have received. At this crucial stage the full impact of the complexity of the plan will be felt.

The technical nature of the subject matter or the analytical devices to be used in formulating the plan have a significant impact upon the complexity of the plan. The greatest impact is felt when the knowledge required for analysis is limited to specialists in a specific discipline. The specialist's phase of the planning process may be highly complex even to him because he is frequently asked to push forward the science of his field.

(5) The ease with which master plans and components can be subdivided into more manageable units.

Some plans by their very nature are easily separated into logical components. The fact that a plan can be divided into logical parts does not mean that it will be so divided. It may remain an integrated unit because the planner is not able to visualize it as made up of logical units.

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The complexity of a plan, and thus the planning process, is a function of the number of major components within a plan, the number of alternatives one would logically consider in evaluating each component, the various guides and assistance available in the form of stated objectives and policies and staff specialists and outside consultants, the technical nature of the subject being considered, and the divisibility of the plan and its components.

The more complex plans become, the greater likelihood that the planner could gain significant benefit from the use of sophisticated tools for collecting and processing data for use in the decision processes. Evaluating the complexity of a plan, as stated above, establishes the basis of the need for analytical tools to assist in the decision process.

If a problem is stated in terms of the logically-distinct and identifiable components, the alternatives found within each component, the objectives and policies pertaining to the problem, and the available abilities to deal with the technical nature of the problem, there is a greater possibility that the problem can be divided into logical and more manageable parts. The parts, after they are developed, can then be introduced into the plan framework and be integrated as a part of the plan evolved from the problem.

During the development of the problem components, it may be profitable to subject various phases to some type of analytical or methodological evaluation. The applicability of such a procedure would most likely become evident during the consideration of step number 4 discussed above. Whether a problem is complex because of its content or whether it is complex because of the way in which the problem is formulated, there should be an investigation to see if an analytical aid could be used to implement the problem solution. An analytical aid may help to formulate the framework of a problem in a way which gives the decision maker a new insight into obscure facets and details of the problem. Such a framework may also give the decision maker more direct control over variables which, because of the complexity of the problem, may not receive adequate consideration without a more detailed analysis.

Increasing attention has been paid both to the use of symbols in the process of thinking and to the problems that arise when symbols are combined into larger configurations or models -- particularly when these models are then used as an aid in investigating or forecasting events that occur in a real world situation. The notion of a system involves the idea of input variables, operating environment, and output results. Be defining the input variables, the operating environment and the figure of merit of the measure of performance that will be used to compare the results of actual or hypothetical changes in the input variables, the researcher has, in effect, defined the system and has limited the changes that can be made in it. The definition can be as narrow or as broad as the problem requires. The virtue of this approach lies not in the size of the problem it can handle -- it can be used for the smallest and the largest -- but in the direction it supplies for the gathering and analysis of data, for establishing criteria of relevance for observations, and for constructing and using a model or series of models. The largest single advantage of a model to the decision maker is the insight it yields into the dynamics of the modeled system.

The idea of a model to describe a system is a method of analysis that is used in many branches of science and has often been used more informally in many problem-solving situations. The methodology embodied

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in the use of models is an important tool for the urban planning decision maker. The use of planning and control models is discussed in detail in Section B.

Despite the existence of a model and the accompanying rules, a logical decision is a complex thing. The complexity does not necessarily lie in the rules or model, but in the details of implementation. Viewed as a logical, rational process, even simple decisions have many dimensions and interrelations. Cost-benefit analysis gives a useful framework for analyzing complex planning problems.

The cost-benefit approach considers the major dimensions of quality, quantity, time and probability, plus a dimension concerned with the scope of the decision. These dimensions are expressed in terms dependent upon the type and complexity of the problem. These dimensions affect both costs and values. The net or total effect of all dimensions depends on interrelating them in some way. The general problems of cost-benefit analysis, and an application interrelating the dimensions of a problem, is discussed in section C.

Other methods of dealing with complexity have been developed for specific applications in various areas of business and industry. Factor analysis, symbolic logic, mathematical programming, and dynamic programming are some of the tools used by business analysts. In applications related to urban planning, mathematical programming has been utilized for traffic analysis, projecting land uses, some forms of transportation problems and an associated problem of maximal flows in networks, and in the efficient operation of a system of dams.[2] Specifically, these

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[2] Gass, S.I., Linear Programming - Methods and Applications. (New York: McGraw-Hill Book Co., 1964) p. 17.

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applications use linear programming technicues. A linear programming problem differs from other programming problems in that a mathematical model or description of the problem can be stated which uses relationships that are straight-line or linear.

Programming problems are concerned with the efficient use or allocation of limited resources to meet desired objectives. These problems are characterized by a large number of solutions that satisfy the basic conditions of each problem. The selection of a particular solution as the best solution to a problem depends on some aim or overall objectives that are implied in the statement of the problem. A solution that satisfies both the conditions of the problem and the given objectives is termed an optimum solution.[3]

Mathematical programming refers to techniques for solving a general class of optimization problems dealing with the interaction of many variables subject to a set of restraining conditions. Such problems are allocation problems and arise when:[4]

(a) There are a number of activities to be performed and there are alternative ways of doing them.

(b) Resources or facilities are not available for performing each activity in the most effective way.

The allocation problem, then, is to combine activities and resources in such a way as to maximize overall effectiveness.

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[3] Ibid., p. 3

[4] Ackoff, R.L. (Editor), Progress in Operations Research, Vol. 1 (New York: John Wiley & Sons, Inc., 1961) p. 109.

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The method of mathematical programming translates information into mathematical form from which the answer is calculated. In most cases the method of computation is an iterative procedure. The answer to a programming problem will ordinarily not be arrived at directly. Instead, the solution is found by advancing in steps to a final answer.

Although current applications of mathematical programming to urban planning problems are exceedingly limited, the allocation problem as described above fits the framework of some planning activities. The major drawback in the use of this tool is the problem of translating planning information into mathematical form. As the use of systems analysis and model formulation become more a part of the planning method, relationships will undoubtedly be increasingly expressed in terms of mathematical units. This occurrence will open the way for the use of mathematical programming as well as other analytical tools.

B. Planning and Control Models

Scientific models are utilized to accumulate and relate the knowledge concerning different aspects of reality. They are used to reveal reality and to serve as instruments for explaining the past and present, and for predicting and controlling the future. The application of models can help in achieving control over reality as well as providing descriptions and explanations of reality. A scientific model is, in effect, one or a set of statements about reality.[5]

A model of a problem situation has two essential characteristics. At least one of the input variables is subject to control by the decision maker confronted by the problem -- that is, it must model his possible

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[5] Ackoff, R.L. and S.K. Gupta and J.S. Minas, Scientific Method - Optimizing Applied Research Decisions (New York: John Wiley & Sons, Inc., 1962), p. 109.

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choice of action. Also, the output variable must be a measure or index of the value of the alternative choices to the decision maker. Models which satisfy these two conditions may be called decision models.[6] Decision models may be applicable to the decision maker's problem, or to decisions which must be made in trying to find a solution to the decision maker's problem or in answering a question.

In the construction and use of decision models many other models may be required. In some cases other models are incorporated in a decision model, and in other cases specific models are used as preliminary steps in the construction of a decision model.

Planning models incorporate a series of decision models related to specific aspects of the design of a system. This system, relating the various aspects of the planning model, is characterized as a long-term process. Control models are short-term in function and apply to the design and operation of control systems within the enlarged system encompassed by the planning model.

1. Planning Models --

In previous sections it has been stated that judgment, intuition, and experience are means utilized to manage various types and sizes of systems. Methodology is another means that is utilized. Each organizational unit uses a combination of these means, the combination varying depending upon the stage of development and the availability of relevant methodology.

When considering long-term planning, it is apparent that as the planning interval decreases the achievement of meaningful predictions and

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[6] Ibid., p. 111.

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useful problem solutions is greatly improved. Decision-making methods can be used for long-term situations, but it is generally recognized that only through systems planning can acceptable long-range synthesis be achieved.

There are several functions in which methodology can assist in meaningful long-range planning:[7]

(a) It can categorize and summarize a mass of information so that it is most useful to the decision maker.

(b) It can organize the problem area, making all relevant variables explicit so that administrators can communicate with each other about the problem.

(c) It can be used to produce long-term predictions.

(d) It can be used to structure projects, so that details will not be forgotten; so that actions will be taken in appropriate sequence; intelligent allocations of resources will be made; and control over the development of the project will be insured.

(e) Alternative strategies can be tested by various methods to determine how sensitive a particular strategy is to the things that other organizations might do as well as to the relative accuracy of predictions and estimates.

In regard to organizing the problem area (point b. above), long-term decisions are frequently based upon opinion. If differences of opinion exist concerning a problem situation, the reasons for the differences form the background upon which intelligent discussion of the variables can be carried out. Such reasons for disagreement are difficult to uncover

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[7]Starr, M.K., Production Management Systems and Synthesis (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1964) p. 103.

when complex problems are encountered. Generally, systematic explicitness in dealing with varying opinions is a necessary function.

The use of long-term predictions (point c. above), can be applicable to the following considerations even though the degree of belief in predictions is low. There is a preference for decisions which promise greater flexibility. Other things being equal, decisions that permit corrective actions to be taken at a future date are preferred to decisions that cannot be compromised once they are made. A strategy that can produce a catastrophic outcome -- although with very small likelihood -- will be avoided, even though it has a higher expected value. This is because the disutility of irreversibility or ruin is likely to outweigh any usual outcome measures.

Also, there is a preference for decision that promise a reasonably good expected outcome, across a broad spectrum of likely conditions. This is desirable compared to decisions that produce an exceptionally good expected outcome across a narrow band of likely estimates, where the remaining possibilities are relatively undesirable.

These are some of the functions which influence the long-term planning of an organization. Throughout the realm of organizational activities, project planning is a most critical factor. A great deal of effort has been expended by both theoretical and practical analysts to define and develop methods that can adequately deal with the handling of flows of information. The methodology which has evolved found initial acceptance in military and business programs. However, since introduction in about 1957, applications have been widespread, with one of the areas being urban planning. Network analysis has as yet been utilized in a limited number of specific long-term planning projects. Where they have been us

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been used the functions listed above have been more completely and efficiently served.

The area of network analysis permits optimal or near-optimal sequencing and utilization of resources. A number of different approaches to this problem were developed for different reasons. In spite of a variety of names that emerged for each different method, they all are fundamentally alike. In the area of long-term planning, some of the names of the methods which have been developed are:

CPM -- Critical Path Method

PERT -- Program Evaluation and Review Technique

PEP -- Program Evaluation Procedure

IMPACT -- Integrated Management Planning and Control Technique

PRISM -- Program Reliability Information System for Management.

CPM was developed by DuPont and Remington Rand to plan the construction of a plant. PERT was developed by the U.S. Navy Special Projects Office for use on the Polaris Missile project. These two initial methods plus the other approaches share in common the notion of a critical path.

Three steps are required to utilize these network analytic tools.[8]

(a) All the elements, jobs, steps, tasks, and activities that are required to bring the project to fruition must be detailed.

(b) A sequencing order must be determined which is based on technological and administrative dependencies. In other words, all

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[8]Battersby, A., Network Analysis for Planning and Scheduling (New York: Saint Martin's Press Inc., 1964) p. 9.

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(c) The time (and cost) to perform each task and activity must be estimated. When all of this information has been assembled, a network can be constructed. Detail is essential for the success of network analysis. Activities cannot be overlooked without adversely affecting the results. Various estimates are required for each activity, with the result that for normally complex projects, an immense amount of information is generated. Computer programs has been developed to handle information for most of the network systems.

In planning a long-term project, some activities go through a cycle of steps and then repeat themselves at increasing levels of detail. Some activities and subsequent events are arranged in series so that the first activity must be finished before the succeeding one can begin. In other cases activities can parallel each other. Thus the relevant network of activities and events can be laid out to conform to the desired information and decision flow.

Time is an important element in a network analysis, and in the PERT system, three estimates of the time that will be required to complete an activity are required. The three estimates include an optimistic estimate, a pessimistic estimate, and an estimate of the most likely amount of time required for completion of the activity. The three estimates are combined with derived weightings to give an expected elapsed time. The combination gives a reasonably good estimate of the expected elapsed time required for the completion of an activity.

The established time sequences for the various specified activities form the basis for establishing a critical path of the system. The last node of the network--which is job completion-- is given the time value required to perform the longest time-sequence of activities in the network. This longest time-sequence then becomes the critical path of the system. Working backward from the final node, expected elapsed activity times are subtracted from each previously accepted time value that immediately precedes it in the network. In some cases, two or more activities converge on a node such that the time values are not equal. In this case the longest required time interval is used for establishing the event node, and the other activities are assigned slack time, which is the amount of time the specified estimates can slip and still allow the total job to be completed on time. This entire time sequencing of activities and events with an established critical time path forms a complete network of a system.

A useful trait of the critical path method is the possibility that a better arrangement of resource utilization might be found which would reduce the length of the critical path and thereby decrease the amount of slack in other branches of the network. Action that would produce this result would be to employ added resources to the critical path, or to shift resources from the activities having the largest amount of slack to the critical path.

The critical path method is directly applicable to dealing with the complexity of urban planning activity. The network approach can be used as a means of unifying the complex totality of activities, problems, decisions, and operations that constitute a specific plan over a span of time. The methodology of network analysis can be applied to a system as a planning tool which is operational from the inception of a planning activity to the completion of a given program.

Specific applications of network analysis are becoming increasingly more sophisticated. The scale of utilization ranges from the structuring of segments of a plan over a limited time span to the structuring of an entire plan over the life of the program.

The critical path methods has been extended to utilize other than the time objective. In the area of project planning the objectives of minimizing cost, of maximizing the quality of work, or maximizing the performance characteristics of a system have been developed. The PERT/COST system formalizes the planning cycle in the following steps:[9]

Establish project and breakdown structure.

Define tasks.

Prepare an account code structure.

Construct networks.

Estimate activity times.

Schedule.

Prepare resource and cost estimates.

Review and revise the plan.

The PERT/COST system can be modified to meet the particular requirements of a given project. It is not an optimizing technique but is a logical attempt to utilize reasonable trade-offs between cost and time in order to obtain an approximation to an optimal result.

The critical path methods that have been discussed above do not allow a choice to be made with respect to which of two branches at a junction node might be utilized. Every network activity was one to which the project was constrained. Decision alternatives were embodied in the

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[9] Ibid., p. 118.

definition of the activity. Development of generalized networks incorporating events with alternative outcomes would utilize probability statements to describe the relative likelihoods that alternative branches of a network would be utilized. Such network methods are being developed which will permit the consideration of alternative paths when laying out the plan of the project. Long-term nonrepetitive planning projects require that many important decisions be made as the project evolves. Thus, inherent in the planning network are these decision points and the subsequent alternative paths that choice implies.[10] This method of analysis, now in the development phase, will add useful dimensions to any long-term systems problem.

Network analysis facilitates the management of a planning project, both in the planning and control phases. It also focuses attention on problems of allocating responsibility, defining the work to be done, measuring performance, and arranging a proper flow of information.

2. Control Models --

Control systems are needed because disturbances arise which cause shifts in a system. If disturbances did not occur, a system could be designed and coordinated to a standard level of performance from which it would not deviate. Control systems operate by adjusting to a disturbance by a readjustment of strategy. Control is exercised over strategies and thereby over outputs. The function of control in the planning process actually becomes a part or addition to the planning model. In separating out the control model, the distinct characteristics of the various types of control can be examined relative to the action of exercising control.

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[10] Starr, op. cit., p. 129.

These types of control are:[11]

(a) Control over Strategies.

To the extent that we can create powerful strategies that yield promising outcomes under all conceivable, relevant circumstances, control can be exercised through design. This is the culmination of technological knowledge and methodological analysis. We must not overlook the fact that strategies utilize instruments. These instruments are not always totally under control. The variability of instrument performance is what makes golf an interesting game. Similarly, the control over strategic resources is not always precise. This is a characteristic of financial control. It is even more apparent that instruments are variable when we consider human resource control. We say that leadership is an important attribute, but we cannot measure it and we can count upon neither its presence not its affects. There is usually an area of tactical uncertainty that is characteristically called a control problem.

(b) Control over States of Nature.

By means of technological advances, man has gradually obtained more control over his environment. In production systems, statistical quality control is utilized to hunt down states of nature that are causing disturbances in the quality of output materials. These states of nature, called assignable causes of variation, are removed when discovered, so that the production quality can be stabilized. The system's analysis approach is used to discover the disturbing states of nature and

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[11] Ibid., p. 189.

to find ways to remove these disturbances or to isolate the system from them. Control here is applied to the ability to regulate the environment and to remove the unwanted states of nature.

(c) Control over Outcomes.

If the system is stable, we can utilize decision theory to select an appropriate strategy. The choice represents control over outcomes. The most extreme example of control over outcomes in a stable system is when certainty exists. Then, the task is one of searching for an optimal outcome with no inclusion of risk considerations.

A control system provides the means of achieving a plan and, if necessary, adjusting it to correct for unexpected disturbances. In order for control to develop, it is apparent that the disturbances must be recognized and interpreted. Certain consequences flow from performing any response. The model of control most generally incorporates a feedback control circuit. The problem of identifying the feedback stimulus is basically the same as that of identifying the original stimulus, involving interpretation of strategies, states of nature, and expected or desired outcomes.

When disturbances arise in the planning model, the intervening control model consists of varying degrees of analysis leading to feedbacks within the planning model. The strategies which the control model feeds back to the planning or decision model reflects actions or counter-actions aimed at overcoming the disturbance which resulted in an interruption or an inappropriate or uneconomical outcome in the planning model. The successful use of control models depends upon the ability of the researcher or decision maker to reorient the problem in terms of new or re-evaluated data. When costs and several resources are being considered collectively, the problem of balancing them becomes extremely difficult, and up to now no satisfactory substitute for human judgment has been devised. Methods of priority weighting are available in computer routines; they assume that weights can be allocated to the several resources, but they give no help in determining the weights, other than trial and error.

C. Cost-Benefit Analysis

As a starting point, a rule which has been called the General Rule of Decision will be stated.[12] "Starting from any given point, total satisfaction will be increased if a decision is made in favor of any alternative whose value exceeds its cost, when both value and cost are measured forward from the moment the decision is effective."

That satisfaction will be increased by a decision in favor of any alternative whose value exceeds its cost is axiomatic, being logically inescapable once we have defined satisfaction, value, and cost. Despite such a straightforward rule, a logical decision is a complex thing. The complexity does not lie in the rules, but in the details of implementation. Viewed as a logical, rational process, even apparently simple decisions have many dimensions, and often almost infinitely complex interrelations.

Cost-benefit analysis is intended to help us choose among alternative means to our ends. The alternatives may be similar or quite dissimilar. Whatever the particular problem in choosing among alternative means to our ends, we need to investigate the ends themselves

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[12] Kuhn, Alfred, The Study of Society: A Unified Approach (Homewood, Illinois: Richard Irwin, Inc., 1963) p. 275.

with a critical view. This phase of investigating the ends is particularly critical in urban planning, where social-cultural values often provide the vehicle of motivation toward specific ends. Scientific developments may be extremely efficient in achieving certain ends but these ends may be the wrong ones.

To say that we should scrutinize our ultimate ends carefully in deciding upon the best course of action is much too vague. Merely to name the things we ultimately value is not very helpful in solving a problem. It is wise to think about such a list of values, for it may prevent us from choosing some project that does not incorporate any of the stated values, but in most situations the list of ultimate values provides little counsel. A major reason for this is the tremendous gap between the direct consequences of a project and the ultimate aims that might be listed. This gap must be at least partially bridged in order for policy implications to emerge. Another reason is the necessity of trading part of the ultimate aim for some of the desired direct consequences.

These comments, hopefully, point out that the enumeration of the ultimate values or aims, while it may be pertinent, does not serve as a guide to specific action. In cost-benefit analysis several general parts of the analysis can be developed to provide a base for action.

1. <u>General Problems of Cost-Benefit Analysis</u>.

a. <u>The Correct Criterion</u>.

In choosing among alternatives, we do more than enumerate things which it would be desirable to have. Explicitly or implicitly, we adopt criteria or tests of preferredness. The process of choosing includes the elements of: predicting the consequences of alternative actions -- a step which involves the use of sets of relationships or models, and distinguishing preferred combinations of consequences from less desirable consequences -- a step which entails the use of criteria.

A distinction between the problems of prediction or measurement and those of criteria is difficult to draw. Changing the manner of measuring some consequences could be regarded as changing the criterion, at least the real content and meaning of the criterion. The criterion problems in this way could consume practically all aspects of the comparison of alternative courses of action. At the other extreme, the criterion could be taken as maximum satisfaction, and from this viewpoint the whole difficulty would be the measurement of satisfaction. The measurement problem could then embrace nearly everything. Criterion in some comparisons is limited because only some of the consequences of alternative actions can be determined. In this situations, a comparison in terms of selected consequences, or a partial criterion, may be used. There is then no problem of devising a definitive test, but there is the closely related problem of deciding what consequences face the decision maker. In other situations, the analyst may be able to trace all of the significant effects and know enough about the decision requirements to evaluate those effects. In these instances, quantitative analysis may be used to pick out preferred courses of action. A definitive test of preferredness is necessary in this case and the criterion problem is the devising of that test.[13]

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[13]McKean, R.N., Efficiency in Government Through Systems Analysis (New York: John Wiley & Sons, Inc., 1958) p. 28.

There is clearly no all-purpose criterion, for the appropriate test depends upon what alternatives are open to the decision maker, upon what aspects of the situation must be taken as given, and upon what kind of measurements are feasible. If gains and costs can be measured in the same units, to maximize gains minus costs is certainly an acceptable criterion. In some analyses, a constraint exists wherein a particular gain or cost is fixed. In these situations it is impossible to maximize gains minus costs, and an acceptable procedure may be to set either gains or costs, seeking to get the most for a given cost, or to achieve a specified objective at least cost. Other aspects of criteria which should be considered include the situation where costs and gains which occur in different time periods have unequal values, the aspect of uncertainty, and the intangible considerations -- those which cannot be translated into the same units in terms of which the other gains or costs are expressed.

b. The Appropriate Alternatives.

The appropriate concepts of cost and gain depend upon the level of optimization and alternative policies that are allowable. The appropriate level of optimization and the alternatives that should be compared depend in part upon the search for a suitable criterion. However, no matter what the criterion, it will not reveal the best course of action if that course has not been considered among the possible alternative policies.

Generalizations cannot be made about the potential aid that analysis can provide or about the formulation of analyses in connection with particular problems of choice. There are no clear-cut rules for determining

the list of actions that should be considered or the scope of the systems into which the actions should be fitted. However, in defining alternatives there are some general precautions which can be formulated.[14]

First, the system into which the possible actions should be fitted, and hence the level of optimization, must be decided upon hand-in-hand with the devising of criteria. The advantages and disadvantages of including additional parts of the system in a particular decision situation should be consciously weighed. Second, ingenuity in the designing and redesigning of alternative courses of action is of great importance in operations research; the devising of the alternative policies to be compared cannot be undertaken prefunctorily. Third, in designing alternative policies, different scales of each project and different combinations of measures should not be neglected. The addition or removal of extra features or increments in size creates alternative courses of action that are highly relevant. Fourth, special regard must be given to interrelationships between the alternative courses of action if more than one of the actions may be taken or if those actions are to be ranked for future reference. Finally, the results must be interpreted and used critically, with awareness of the limitations that are attached to the particular scale of analysis.

The limitations of the particular scale of analysis as well as the nature of the criterion may influence the content of conclusions or the confidence with which they are held. A particular course of action may seem to be best on the average, but because it entails an appreciable chance of complete failure, it is probably the worst alternative. The

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[14] _Ibid_., p. 56.

limitations of the criterion, where intangibles and uncertainty are a vital consideration, must be explicitly taken into account in interpreting the appropriate alternative.

2. Application of Cost-Benefit Analysis.

An important example of the application of cost-benefit analysis is its use in shaping of water-resource programs. Cost-benefit analysis is important in the water-resource program for several reasons. Expenditures in the nation wide water-resource development programs are extensive and the control function is dependent upon adequate analysis. Second, there is a great deal of controversy about the efficiency with which outlays have been spent or are scheduled to be spent. Cost-benefit analysis provides comparisons which help to answer questions such as: will the gain from the proposed project exceed its cost? How will the project affect other elements of the systems of which it will become a part? How much importance should be attached to the intangible effects of the new project? Third, cost-benefit analysis is pertinent to the systematic scrutiny of component measures that are not now subjected to analysis, marshland drainage, subsurface storage, reclaiming of water from sewage, or direct use of sea water. Utilization of cost-benefit analysis is pertinent to special studies that may be called for from time to time to provide for a comparison of alternative ways to achieve control over persistent problems such as flooding.

The Santa Maria project[15] is an example of the use of a cost-benefit analysis. The project would provide water for irrigation and protection from floods in the Santa Maria Valley of California. The Valley is part of

[15] Santa Maria Project, California, Printed as House Document No. 217, 83rd Congress, Ist Session, U.S. Government Printing Office, Washington, 1953.

the Santa Maria Basin located 130 miles north of Los Angeles. The locality presents the problem of a rainy season which often brings floods, and a dry season which keeps unirrigated land from being productive.

The proposals in this project include a dam and reservoir, designed to provide water for irrigation and some flood protection, and a system of levees and channel improvements intended to provide additional protection against floods.

a. Project's Benefit Model --

The people of the Santa Maria Valley faced the problem of a rapidly lowering water table. Municipalities, industrial plants, and farms use deep wells to get their water, and due to increasing demand an overdraft of 14,000 acre feet per year existed. The overdraft if continued would cause an estimated 8,000 acres of presently irrigated land to be returned to dry farms.

The proposed dam would make it possible to recharge the underground supply and would also contain storage space to be reserved for flood control. The project would capture approximately 50 percent of the losses to the ocean.

With an increased supply of water, the increase in irrigated acreage is translated into increased income. With the project, the anticipated crop patterns, yields, prices, operating expenses and net income per irrigated acre are used to weight the benefits in the analysis.

Another item in the benefit model is the effect of reservoir and channel levee works on flood damage. From a discharge-frequency curve and a discharge-damage curve a damage-frequency relationship was obtained.

In gauging the physical consequences of various peak discharges, the analysts considered probable depth and duration of inundation, velocity of flow and the anticipated location and physical characteristics of various assets. They reviewed the behavior of past floods to determine the areas covered by floods of different sizes. To estimate the economic consequences, the analysts attached values to both direct damage, the physical destruction due to overflow and erosion, and indirect damage which includes losses from interruptions of traffic, communications, and industry -- expenditures for the care of flood victims -- and losses from the disruption of community activity.

The effect of the reservoir on water supply, the effect of the reservoir on farm incomes, and the effect of reservoir and channel levee works on flood damage made up the benefit model of the project.

b. Project's Cost Model --

The construction cost was spread over the period of installation. The cost estimates allowed for the dam and appurtenant works -- land, easements, and rights of way -- camp construction -- clearing of the reservoir area -- levee and channel construction -- relocation of transportation and utility routes -- engineering work, overhead, and contingencies. In each of these estimates, local circumstances were considered.

A fifty-year time horizon was adopted for the entire project. A salvage value, based on an estimated life of 140 years, was deducted from investment costs to allow for the remainder of the reservoir's life after fifty years.

The benefit-cost time streams were reduced to annual equivalents by calculating the present worth of the time streams and then amortizing them over the fifty-year period. The results were the amounts which, if received or paid out each year, would be equivalent to the present worth of the benefit stream and the cost stream respectively. A discount rate was applied to all calculations.[16]

The ultimate result of devising these models and making the calculations pertaining to the project was a benefit-cost ratio of 1.87 to 1. The project was considered economically justified since benefits were in excess of costs.

As another instance of how a cost-benefit analysis might be utilized, several examples related to roads and highways will be listed. Useful analysis might compare:[17]

(1) Additional construction of freeways in metropolitan areas vs. interstate highways vs. intrastate roads. Specific proposals would have to be examined.

(2) Extra highways in one region vs. addition to the networks in other regions.

(3) Additional routes vs. extra-lane superhighways.

(4) The cost of highway construction by government construction crews vs. that of highway construction by private contractors.

(5) The cost of using alternative materials, equipment and methods in highway construction to meet certain specific actions.

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[16] McKean, R.N., op. cit., p. 232.

[17] Ibid., p. 290.

(6) The quantitative effects of alternative sets of gasoline taxes, vehicle taxes, and tolls that would reflect costs more accurately, helping to adjust economically the rate of growth of automobile usage.

In each of these examples, as is true in water resource analysis, cost-benefit analysis provides a tool which relates the complex relationships of a project and gives a useful and meaningful comparison of the complex relationships. By subjecting such a planning problem to cost-benefit analysis, a greater probability exists that all pertinent variables will be considered. Also, the parameters of a problem must be explicitly stated in measurable terms. The necessity of assigning measurable values to functions requires a study program which in effect establishes a problem framework that reduces complexity into distinct, manageable units.

Considering complexity in terms of planning and control models and cost-benefit analysis reduces the complex and often unmanageable situation to a form which allows more systematic consideration. These forms of systems analysis do not relieve the planner from responsible action and decision making, but they do give him an analytical aid for a more systematic and perhaps a more thorough consideration of problem variables and parameters and with complex interrelationships.

CHAPTER IV

TOOLS FOR DEALING WITH VARIABILITY AND LACK OF INFORMATION

A. The Nature of Variability and Lack of Information

The difficulties encountered by decision makers in making decisions have two principal sources -- complexity and uncertainty. Often the decision maker's problem involves an enormous number of variables interrelated in many different ways so that many possible solutions exist. Faced with such a problem, the decision maker usually finds that he cannot even define, much less evaluate all of the possible solutions. He cannot spend the time that this requires and also he cannot take into account so many variables and so many relationships, simultaneously, in his mental calculations. As a result, there is always the danger that he has overlooked or failed to properly evaluate some solution for his problem.

In addition, the decision maker's problem may involve random or chance variables. The values which such variables assume cannot be predicted exactly. They can be predicted only in probabilistic terms. When random variables are important in a problem, the decision maker usually finds that he is unable to predict the consequences of any solution with satisfying confidence. He is frequently so uncertain about the outcomes of each of his possible solutions that he is unable to determine which of them should be adopted.

There is another factor, in addition to chance variables, which makes prediction of the consequences of possible solutions extremely difficult. This is the existence of other decision-makers. The outcome of any contemplated solution to many planning problems depends upon the actions of other associated public or private planners. Yet it is usually impossible to forecast precisely what these individuals or groups will do. The result is that the decision maker is unable to evaluate his alternative solutions. Again, he cannot estimate their outcomes with desirable confidence.

Like the actions of other individuals or groups, other events over which decision makers have no control produce uncertainty. Whether there will be favorable or unfavorable legislation, whether there will be necessary financial support, and whether a particular social or cultural trend will continue are examples of such events. From the point of view of the individual decision maker, these events are uncontrollable variables. Nevertheless, for many planning problems the "state of nature" has a considerable bearing on the effectiveness of each solution that may be considered. Since the decision maker cannot know which state of nature will characterize the relevant future, he often cannot determine the best course of action.

Also, uncertainty about the consequences of action alternatives may originate from an entirely different source. It may arise because records of past experience with similar or analogous problems are inadequate or simple not available. This may be because adequate records have never been kept or because the situation being faced is different enough from any in the past to make it truly unique. Where either of these conditions prevail, and there are no records which could provide information on which the decision maker could base his predictions, he is again faced with an uncertainty condition.

Thus complexity, discussed in the previous section, variability arising from the presence of chance factors, variability in the actions of other decision makers, variability in states of nature, and lack of information are the chief obstacles to decision making of high quality in planning. The tools used by analysts in the planning field or in other fields can be looked upon as means for coping with one or more of these obstacles. The decision maker dealing with these or similar obstacles must either ignore the obstacles or deal with them in direct or indirect ways. A direct confrontation with them through the application of available analytical aids is an alternative which is receiving increased exposure in the planning field. There are a greater number of examples of the use of analytical aids in business or corporate planning. Urban planning analysts have also applied analytical tools to some areas of urban planning.

Again it should be stated that where these analytical tools have been used to attempt to obtain a more complete understanding about a specific aspect of a problem situation, the analytical tools do not make decisions by themselves. The techniques for dealing with variability and lack of information do not themselves set goals, determine the scope of the decision, formulate a prescribed set of alternatives, determine which decision technique to use, or determine whether information is worth its cost. Systematic decision techniques have been developed as an aid to the decision maker; they have not been developed to supplant him. The aim of discussing these tools for dealing with complexity, variability and lack of information is to suggest or reinforce the opinion that the tools developed for use in business and other areas of interest can be of assistance to the urban planning decision maker.

There is a growing list of applications which indicate that planners in many areas are utilizing analytical aids to assist in planning and decision making. Probability theory, game theory, queuing theory, decision theory, sampling, statistical inference, simulation, and monte carlo simulation are some of the tools used for dealing with variability and lack of information. Three tools which will be discussed here as being applicable to problems in urban planning are simulation, game theory, and decision theory.

Simulation has been referred to as nothing but the systematic use of the classical idea of a hypothetical experiment; it is applied when true experimentation is too costly or physically or morally impossible or when the real-world situation is too complex to permit the intrinsic use of experts. The application of simulation techniques is particularly useful when it is desirable to employ intrinsically several experts with varying specialities in a context in which their forecasts cannot be entered independently but where they are likely to interact with one another. Here a model furnishes the experts with an artificial, simulated environment, within which they can jointly and simultaneously experiment, responding to the changes in the environment induced by their actions, and acquiring through feedback the insights necessary to make successful predictions within the model and thus indirectly about the real world. This technique lends itself particularly to predictions regarding the behavior of human organizations inasmuch as the latter can be simulated most effectively by having the experts play the roles of certain members of such organizations and act out what in their judgment would be the actions, in the situations simulated, of their real-life counterparts.[1]

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[1]Helmer, O., and N. Rescher, "On the Epistemology of the Inexact Sciences," Management Science, Vol. 6, No. 1, October 1959, p. 49.

A particular case of simulation involving role-playing by the intrinsic experts is known as operational gaming. A simulation model may properly be said to be gaming a real-life situation if the latter concerns decision makers in a context involving conflicting interests. In operational gaming, the simulated environment is particularly effective in reminding the expert, in his role as a player, to take all the factors into account in making his predictions that are potentially relevant. If he does not, and chooses a tactic or strategy which overlooks an essential factor, an astute "oponent" will soon enough teach him not to make such an omission again.[2]

Operational gaming is not be confused with the theory of games. The theory of games is a well-defined mathematical discipline in which each side may be assumed to know the payoff values in the payoff matrix corresponding to the various strategies it and the opposition may make. Mathematical techniques exist for obtaining optimal strategies for each opponent. In operational gaming many plays of the game must occur before any pattern can be expected to emerge regarding which strategies are rewarding and which unrewarding. Even then, the presence of humans in the opposition makes it difficult to know whether the apparently good plays were not just the result of opponent carelessness. Operational gaming may put people into realistic situations in order to derive what assumptions to make about human behavior, while game theory proceeds from simplified assumptions concerning the behavior of human beings in conflicting situations to a guide on how to win at least a definable game value.[3]

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[2] Ibid., p. 49.

[3] Morgenthaler, G.W., "The Theory and Application of Simulation in Operations Research," in R.L. Ackoff (Editor), Progress in Operations Research, Vol. 1, (New York: John Wiley & Sons, Inc., 1961) p. 371.

Game theory is a method for the study of decision making in situations of varying opinion or conflict. It deals with problems in which the individual decision maker is not in control of the factors influencing the outcome. The essence of a game problem is that it involves individuals with different goals or objectives whose fates are interlocked.[4] There are many examples of decision making where this is not so. An architect who has been allotted a specified sum of money in order to carry out a given building program or an engineer engaged in redesigning a process in order to cut costs is not involved in a game situation. The engineer and architect face direct minimization or maximization problems in which they are in control of the relevant variables and do not have to contend with anti-engineers or anti-architects who try to destroy their work. The architect may try to maximize certain features of the quality and quantity of building that he can get done from the amount of money at his disposal. There may be forces which he does not control, such as the weather; but in most cases some physical law of prediction can be found for estimating the effect of outside influences.

The problem of game theory is more difficult than that of simple maximization. The individual has to work out how to achieve as much as possible, taking into account that there are others whose goals are different and whose actions have an effect on all. A decision maker in a game faces a cross-purposes maximization problem. He must plan for an optimal return, taking into account the possible actions of his opponents.

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[4] Shubik, M., "The Uses of Game Theory in Management Science," Management Science, Vol. 2, No. 1, October 1955, p. 40.

The development of decision theory has been of interest to analysts involved in the basic structure of decisions. The major features of the typical decision structure[5] start with the fact that a decision situation does not exist unless the decision maker has various alternative courses of action. The various alternative courses of action in any decision problem are referred to as the strategies of the decision maker. The selection of a strategy is taken to be under the control of the decision maker and it is often convenient to use mathematical terminology and say that the strategies are based on the variables which are controllable.

The second feature is that it is an equally obvious fact that reality is rarely so tractable as to make the result or outcome of a selection of strategy depend solely on the strategy selected. The outside world will usually play a crucial role in determining what happens as a result of the selection of strategy. In some ways, the outcome which results will depend both on the selection of strategy and on what happens in the outside world. In mathematical terminology this is to say that there are usually some uncontrollable variables which also have an effect on the results of any specific selection of strategy.

A third key component of the decision structure is that the decision maker has objectives, ends, goals, or purposes which he wishes to achieve and which are his motivation for making the decision.

Decision theory undertakes to consider the structure of quantitative decisions in themselves, abstracted from any specific problem which may have

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[5]Miller, D.W., "The Logic of Quantitative Decisions," in A. Shuchman, Scientific Decision Making in Business (New York: Holt, Rinehart & Winston, Inc., 1963) p. 313-314.

occasioned the decision problem and abstracted from any specific involvement in particular quantities.[6] In short, decision theory is concerned with the basic structure of the quantitative decision process. In considering this basic structure the methodology of decision theory utilizes an outcome matrix, relating various strategies with various possible states of nature, and a payoff matrix which is the basis of the decision theory analysis of quantitative decision problems. Quantitative here refers precisely to the fact that the worth of the outcome is measurable. The numerical measure of this worth is called the payoff. In some cases where numerical measures cannot be achieved, it is possible to rank the outcomes in order of worth and this is sufficient for some kinds of analysis.

Details and applications of simulation, operational gaming, and decision theory, as they relate to aiding the decision maker, will be discussed in the following sections.

B. Simulation

Figuratively speaking, a characteristic of simulation is captured by the observation that a model represents a phenomenon, but that simulation imitates it. Simulation is a way of using a model. It is, in effect, experimentation on a model rather than on the phenomenon itself. In principle, everything that can be accomplished by simulation can be accomplished by experimenting directly on the phenomena involved in the problem. In practice, however, it may be impossible or impractical to experiment on the phenomena themselves. The environment related to the

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[6] Ibid., p. 313.

phenomenon may be such that observations are not possible.[7]

The scientific method is the principal tool used for prediction and estimation. The steps usually identified are: close observation of the physical phenomenon, creation of a theory or model which explains the observations, predictions of observables from the theory by using mathematical or logical deduction, and performance of experiments to test the validity of the model.

Sometimes it is not possible to follow this procedure for a given problem or system. It may not be possible to observe the phenomenon in its desired environment. The phenomenon or system may be too complex to summarize in a compressed mathematical formulation. It has not been possible thus far, for example, to reduce the operation of a large business activity to a few simple equations. Analytical techniques may not exist for solving the mathematical formulation once it has been achieved. Even when analysts have the confidence and ability to arrive at a theoretical prediction of the behavior of a large system, it may not be possible to perform validating experiments. When any of these difficulties occur, some form of simulation is the tool to be tried. Simulation then means to duplicate the essence of the system or activity without actually attaining reality itself.[8]

1. The Principle Uses of Simulation

Simulation is useful in the study of a class of problems wherein the operating rules, policies, procedures, and other elements

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[7]Ackoff, R. L. and S.K. Gupta, and J.S. Minas, Scientific Method - Optimizing Applied Research Decisions, (New York: John Wiley & Sons, Inc., 1962) p. 346.

[8]Morgenthaler, W.S., op. cit., p. 367.

that control production, inventory etc., are under question and in which the number of variables involved, the uncertain nature of inputs, among other things, makes these problems, which are referred to generally as a system, difficult to analyze.

Stated somewhat differently: mathematical analysis is not powerful enough to yield general analytical solutions to situations as complex as are encountered in many disciplines. The alternative is the experimental approach.

The mathematical model of the system is constructed. Such a mathematical model is a detailed description that tells how conditions at one point in time lead to subsequent conditions at later points in time. The behavior of the model is observed and experiments are conducted to answer specific questions about the system that is represented by the model.[9]

Therefore, simulation, as described above, is the process of conducting experiments on a model instead of attempting the experiments with their real system. The process of simulation is characterized by the following:[10]

a. It is a problem solving technique.

b. It is an experimental method.

c. Application of simulation is indicated in the solution of problems of system design and system analysis.

d. Simulation is resorted to when the system under consideration cannot be analyzed using direct or formal analytical methods.

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[9]McMillan C., and R.F. Gonzalez, Systems Analysis - A Computer Approach to Decision Models (Homewood, Illinois: Richard D. Irwin, Inc., 1965) p. 15.

[10]*Ibid.*, p. 16.

Simulation has applications from very small day-to-day problems to complex management problems requiring the use of computers. In the broad range of problems, simulation has the advantage of being easily understood, of being expressed in relatively simple mathematics, and of often being quite superior to mathematical methods which may be too complex to apply or even not available. Another distinct advantage is that simulation generally eliminates the need for costly trial and error methods of trying out a new concept in the real situation.

The principal uses of simulation in deriving or testing solutions from decision models are as follows:[11]

(a) To determine the optimizing values of controlled variables.

The complexity or distribution of some variables makes it possible to perform analysis on only certain variables in the total range of the variables encountered. By simulation, outcomes with these difficult variables can be estimated, and by this estimation, solutions to problems can be approximated.

(b) To study transitional processes.

In many cases where a model can be solved analytically, the solution specifies only the terminal or steady state that results from changing the values of the variables, and not the intermediate states, the states of transition. Simulation exposes the transition to as careful a study as the researcher may care to make.

(c) To estimate values of model parameters of the model's functional form.

In some cases we may be able to construct a model but not to evaluate all its parameters because of the lack of data. We may, however

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[11]Ackoff, Gupta and Minas, _op_. _cit_., pp. 348-349.

have good and plentiful data on past outcomes and values of the controlled variables. In such cases we can by simulation try out a large number of possible values of the parameters, together with known past values of the controllable variables, until we obtain one or more sets of values which yield outcomes that correspond well with the known past outcomes. The same kind of procedure can be used to explore alternative functional forms of the model.

(d) To treat courses of action which cannot be formulated into the model.

In some problems the performance of an entity under a set of specified conditions may be one of the important variables, but we may not be able to characterize them by a set of quantitative variables. Such a problem is quite common when such an entity is a decision maker and when the conditions involve other (cooperating or competing) decision makers. When such an entity's performance cannot be modeled, the entity itself may be put into a modeled situation to determine the effects of its behavior, as well as that of other variables, on outcomes. When this entity is human, such simulation is called gaming.

The principal uses of simulation enumerated above take on increased significance when the indirect benefits of simulation are considered. Some of the more or less indirect consequences of carrying out a simulation are:[12]

(a) The task of laying out and operating a simulation of a process is a good way to systematically gather the pertinent data about the process. It makes necessary a broad education in the process or operation being simulated, on the part of all who participate seriously in the simulation.

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[12] Morgenthaler, G.W., op. cit., pp. 372-375.

(b) Simulation of a complex operation may provide an indication of which variables are important and how they relate. This may lead to later successful analytic formulations.

(c) A physical simulation device can sometimes play a useful training or briefing role. Simulations are valuable in conveying the meaning and implication of proposed policy changes.

(d) Simulations are sometimes valuable in that they afford a convenient way of breaking down a complicated system into subsystems, each of which may then be modeled by an analyst which is expert in that area. It affords a vehicle for orderly incorporation of many skills and for pooling of expert opinion and information.

(e) Some simulations have led to the evaluation of new policies and new ideas, or to the realization of simple but hidden truths concerning the nature of the operation.

(f) Understanding gained through simulation may enable human judgment to intuit a good solution.

(g) Simulation gives a control over time. It is a way of incorporating time into an analysis of an essential dynamic situation. In simulation of some operations, one can compress real time and observe the results of a given policy for a ten-year period in just a few minutes' running time. Or, one can expand time. Another time advantage is the ability to handle objects which move at different time rates.

(h) Simulation makes generalists out of specialists. Analysts are forced into an appreciation and understanding of all facets of the system, with the result that final conclusions are less apt to be biased by particular inclinations and less apt to be unworkable within the system framework.

The principal applications of simulation can be divided into three main categories -- large-scale military simulation, industrial applications, and classical Monte Carlo application. Military applications were among the first of the large-scale digital simulations. Almost all military study groups and weapons system manufacturers have employed this technique in some form. Industrial applications are continually becoming more numerous and more sophisticated. As more of industry and management comes under the scope of systems analysis, simulation is looked to as a useful tool of analysis. The Monte Carlo technique has application in other simulation beside the more classical engineering type of application. The engineering type of application has been used to obtain results in basic research which involves a stochastic element. The stochastic nature of many real life situations has been opened for analysis by the use of this same kind of Monte Carlo simulation. A bried description of the theory of Monte Carlo will indicate the range of possible applications.

Monte Carlo applies to those simulations or to those portions of larger simulations in which random sampling is used. An activity is simulated which in real life may have one of several (or a continuum) of outcomes. Repeated samples are drawn according to the probability laws which describe the activity, and by collecting the resulting data, con clusions may be drawn concerning the activity and the parameters associated with the outcome population.

Since the decision process is primarily concerned with choosing among several outcomes, Monte Carlo simulation supplies a useful tool for decision analysis. Methods devised for random number generation in computers give the most elegant techniques for using the Monte Carlo form of analysis. The major drawback, then, in being able to utilize this technique, is the inability to formulate models and systems which can be programmed into computers.

Considering again the full range of simulation techniques and applications, the ability to isolate variables and parameters measures the usefulness of this tool just as it measures the usefulness of most of the analytical aids. However, to put the use of simulation in the correct perspective, some remarks on simulation theory should be cited to convey the ultimate philosophy and spirit of the technique.

2. On Simulation Theory

Consideration of the atomistic characteristic of simulation reveals much about its properties. First, it suggests a condition for feasibility of simulation; a system, however complex, can be simulated if it can be broken down into a set of elements for which operating rules can be given. If the smallest elements into which we can divide a system are themselves unpredictable (even in a probabilistic sense) digital simulation is not feasible. Second, it is a mathematical model that is "run", rather than one that is "solved". It is not inherently optimizing; rather it is descriptive of the performance of a given configuration of the system. Optimization must be superimposed upon this model by varying the configuration in search of a maximum of performance. Third, the simulation does more than yield a numerical measure of the performance of the system. It provides a display of the manner in which the system operates. Finally, this discussion of the description of individual elements, the recording of individual events, and the frequent necessity of replication is rather suggestive of the reason why this form of system simulation was not widely used before the advent of the modern high speed stored-program digital computer. There is certainly nothing in the process that could not be executed manually and, in fact, there have been instances of manually-executed simulations. It is simply the tremendous volume of logical, numerical and bookkeeping operations that must be performed that makes this procedure a very natural application for the digital computer.[13]

Two basic viewpoints in simulating have been distinguished.[14] When the submodels of a process are understood and known to be valid, but their interaction as a complete system is not known, the simulation is used as a synthesis. The synthetic use of simulation is an example of deductive logic. The operating characteristics of the individual components are essentially the postulates of a formal deductive system, the programmed interactions of the components with each other are the rules of inference, and the over-all patterns of behavior traced out by the complete system are the derived theorems. If we agree with the postulates and rules of inference, we necessarily agree with the theorems (simulation results) as being empirically true.

When the over-all behavior of the system is known and observable, but the characteristics of the components and their relationships are not, simulation may be used to theorize and then test to see if the theory, when mobilized and run in simulations, leads to the observed results. This is the analytic use of simulation. The analytic use of simulation is an

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[13] Conway, R.W., and B.M. Johnson and W.L. Maxwell, "Some Problems of Digital Systems Simulation," Management Science, Vol. 6, 1959, pp. 94-95.

[14] Morgenthaler, G.W., op. cit., p. 382.

example of inductive logic, that is, of empirical inference. Although the underlying operating characteristics of the microunits of the system are formally treated as postulates, the fundamental interactions of the individual units as rules of inference, and the over-all system behavior as theorems of a formal deductive system, empirical testing is carried out at the level of the theorems, that is, with regard to the behavior of the complete system. If the over-all system behavior is in fact found to be in serious disagreement with the theorems derived from the model, we then must infer that the microlevel model is in some way an inadequate representation of the world. If agreement is observed, the microlevel model is accepted in the sense of not being refuted by the facts.

Morgenthaler continues the above viewpoint by saying that a simulator will not inherently optimize. It is essentially an "if-then" computer. Simulation itself will not make decisions. It is merely a tool for generating pertinent information and data for the decision maker.

From this generalized philosophy of simulation, attention will be focused upon simulation of social systems, an area of prime interest to urban planning, and upon application of simulation to a water resource system design, and to management control systems.

3. Application of Simulation

a. Simulation of a Social System.

Simulation of a social system involves building and operating a model designed to represent those features of the system which are held to be significant in view of the stated objectives behind the simulation.

The more obvious objectives of simulation of social systems include:[15]

(1) Forecasting of macro-behavior.

(2) Predicting macro-consequences of alternative governmental actions.

(3) Conducting of control and stabilization studies.

(4) Provision of aids to teaching, training, or achievement of understanding.

(5) Conducting of sensitivity studies as a source of research guidance.

(6) Facilitating testing and estimation.

In addition to other virtues of simulation mentioned previously, it is possible to organize simulations on a computer in such a way as to make it relatively easy to investigate the effects of altering specific operating characteristics, parameters, or initial conditions in the light of new knowledge or needs. It permits experimenting in a relatively direct way with models to find out how their behavior is affected by alternative policy selections or by the incorporation of control and stabilization schemes.

However, the major reason for the ascendancy of simulation methods in the study and use of models of social systems is the fact that an increasing percentage of models of the types that research workers wish to build cannot now be solved by known purely deductive approaches. Subsequent development of mathematical methods may again tip the balance in the other direction, but the present rapid development of computers

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[15] Orcutt, G.H. "Views on Simulation and Models of Social Systems," in A.C. Hoggatt and F.E. Balderston (Editors), Symposium on Simulation Models: Methodology and Applications to the Behavioral Sciences, Cincinnati, Ohio: South-Western Publishing Co., 1963, p. 221.

powerfully favors increasing the use of simulation as an approach by means of which such models can be studied and used.[16]

A major tenet underlying the objectives of simulation proposed by Orcutt, and listed above, is that the proper study of socio-economic systems must have its foundations in research on the micro-components out of which such systems are formed. To illustrate how such micro-analytic models might be conceived and developed, the characteristics of such models will be outlined from Orcutt's application.[17]

A distinctive characteristic of a micro-analytic model is that it contains components corresponding to micro-components of real economies. These components primarily fall into three broad categories: decision units, markets, and goods.

In an economy it is possible to identify several types of decision units -- individuals, families, firms, banks, labor unions, local governments, etc. A micro-analytic model of the economy would contain a population which is composed of a relatively small numer of these types of decision units and a relatively large number of units of each type.

In the economy it is possible to identify many different markets. A micro-analytic model of the economy would also contain many different markets, and these components would provide linkages between the decision unit in the model just as real markets serve to link potential buyers and sellers, or borrowers and lenders, in the real economic system.

In the economy it is possible to identify many different types of goods, services, credit instruments, and other things which are used or

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[16] Ibid., p. 222.

[17] Ibid., pp. 225-236.

held or enter into transactions. A micro-analytic model, like the economy, may contain a constantly evolving population of these things which are used or held or produced by decision units and which pass through markets in their way between decision units.

Variables in a model relate in one way or another to the components of the model. It is convenient to classify variables used in reference to components of micro-analytic models into three broad categories: output, variables, status variables, and input variables.

The decision units have various possible behavior outputs. Individuals may go to school, enter the labor force, earn wages, get married; firms may purchase raw material, hire labor, establish new plants, produce goods, etc. Any behavior of a component which is regarded as acting upon or influencing other components is considered to be an output of the first component and an input into the component it affects.

The outputs of a decision unit during a given time period are taken to depend directly or indirectly on inputs to the component and on the values of the component's status variables at the beginning of the period.

Anything external to a decision unit which acts on it or influences its behavior may be considered an input to the component. Inputs thus include the seasons, the weather, time, and the prior outputs of other components.

A component's status variables are internal variables which at any given time describe the state of the component. Status variables are characteristics of the units themselves -- initially assigned in the proportions with which these characteristics appear in the real system. For example, status variables of individuals might include age, sex, marital status, education, income; status variables of firms might include inventories, sales in the last quarter, back orders, balance sheet variables, and anticipated sales. Status variables may be generated and updated by the components they describe or they may be based on surveys and introduced at appropriate times.

In addition to components and the variables relating to the components, a model of an economy must also contain relationships if it is to generate any predictions. Relationships specify how the values of different variables in the model are related to each other or how they are otherwise generated. In general, each relationship in a model of an economy is used to determine the value of one variables given the values of other variables.

An operating characteristic is a relationship specific to a given component which specifies either an hypothesis or an assumption about the manner in which behavior of the component is related to the status variables and input variables of the component and/or to the outputs of other operating characteristics of the component. Operating characteristics, by specifying how they generate outputs even in the absence of external stimuli, embody much of the real knowledge brought to bear, and it is primarily upon them and upon the initial distribution of status variables that any predictive use of the model must ultimately depend.

The implications of the micro-analytic model are worked out by simulation on a computer. As a first step, the initial values of status variables are assigned in the proportions in which the corresponding characteristics appear in the components of the real economy. The simulation proceeds one period at a time. In each period, each individual unit is considered in turn. For each possible output of the unit, a probability of occurrence is specified by the relevant operating characteristics which are used in connection with the appropriate status variables and inputs to the unit. Whether the output occurs or not is determined by a random drawing from this probability distribution.

When each possible output for each unit has been considered in this way, the first pass or month is complete. We enter the second month with a population of units which is slightly different, both in size and composition, from the initial one. The whole procedure is then repeated for the second month and for as many more as desired. To find out what has happened to the system at the end of a desired period of time, we take a census and actually count the number of units with various characteristics, or combinations of characteristics.

At the present time, this type of analysis is unavailable to all but the largest urban research organizations. However, in summarizing the simulation of a social-economic model, it becomes apparent that such an analysis would supply the urban planner with a predictive device which would enable him to plan for the future with much more clarity. Achievement of significantly improved ability to predict the behavior of socio-economic systems requires the construction and utilization of realistic and detailed working models. The construction of micro-analytic models of sufficient realism requires intensive and fundamental research on households, firms, governmental units, markets, and other basic components of real socio-economic systems. An improved knowledge of how these units behave, what stimuli they respond to, and how they respond is required. To carry out the needed research requires many skills and kinds of knowledge as well as access to and ability to use very large or complicated tools like sample surveys, large-scale electronic computers, and modern multi-variate statistical techniques.

As was stated in the prior section on complexity, the urban planner can anticipate the usage of useful simulation models by equipping himself with the knowledge and skills necessary to work with such problems, by surrounding himself with specialists skilled in the necessary disciplines, or by committing the work to consultants who would present him with completed analyses. It seems probable that a combination of these alternatives might produce the most useful results. The urban planner, if he is to function as a decision maker, must have a basic understanding of the analytical tools and procedures to guide and lead the given projects to a decisive conclusion. He must, however, because of the complexity involved, rely upon specialists for support and assistance in much of the actual detail of the analysis. In his duties of predicting and planning for the future, the urban planner will find that simulation is a tool which should be used for analysis when the necessary skills and facilities and information can be assembled.

b. Simulation of a Water-Resource System

One aspect of research carried on under the Harvard Water Program was concerned with the optimal design of a multi-unit, multi-purpose water resource system. For purposes of experimentation, a model river basin system consisting of four reservoirs, two hydro-power plants, an irrigation distribution system, and a flood damage center was developed, and the behavior of this system for different designs was simulated on a computer with the objective of finding the optimal design.[18]

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[18] Hufschmidt, M.M., "Simulating the Behavior of a Multi-Unit, Multi-Purpose Water-Resource System," in A.C. Hoggatt and F.E. Balderston (Editors) Symposium on Simulation Models: Methodology and Applications to the Behavioral Sciences, Cincinnati, Ohio: South-Western Publishing Co., 1963, pp. 203-220.

The model considered the following decision variables:

Total storage capacity at reservoirs A, C, and D.

Active capacity and dead storage capacity at reservoir B.

Flood storage capacity at reservoirs B, C, and D.

Installed capacity at power plants B and G.

Annual target outputs for irrigation water and electric energy.

The objective of considering the decision variables was the maximization of the present value of the 50-year stream of gross annual irrigation, energy and flood control benefits less annual operation and replacement costs, discounted at a selected interest rate, less capital costs.

The task was to select values for the design variables so as to maximize the values of the objective subject to the applicable constraints. For each combination of the variables sampled, a simulation run was made to determine the corresponding value of the objective function.

From model simulation, the research found the optimal design for the particular trace of hydrology considered. Based on these experiments, it was concluded that the use of synthetic hydrology seemed to be a promising means of dealing with hydrologic uncertainty.

c. Simulation of Management - Control Systems.

Another area where simulation can support the decision maker is in management control systems. Every organization is a control system. Each has direction and objectives both explicit and implied. Each has policies and procedures whereby it reaches decision and takes actions to attain its goals more closely.

The organization as a whole or any one of its component subsystems can be represented by the feedback process shown below.[19]

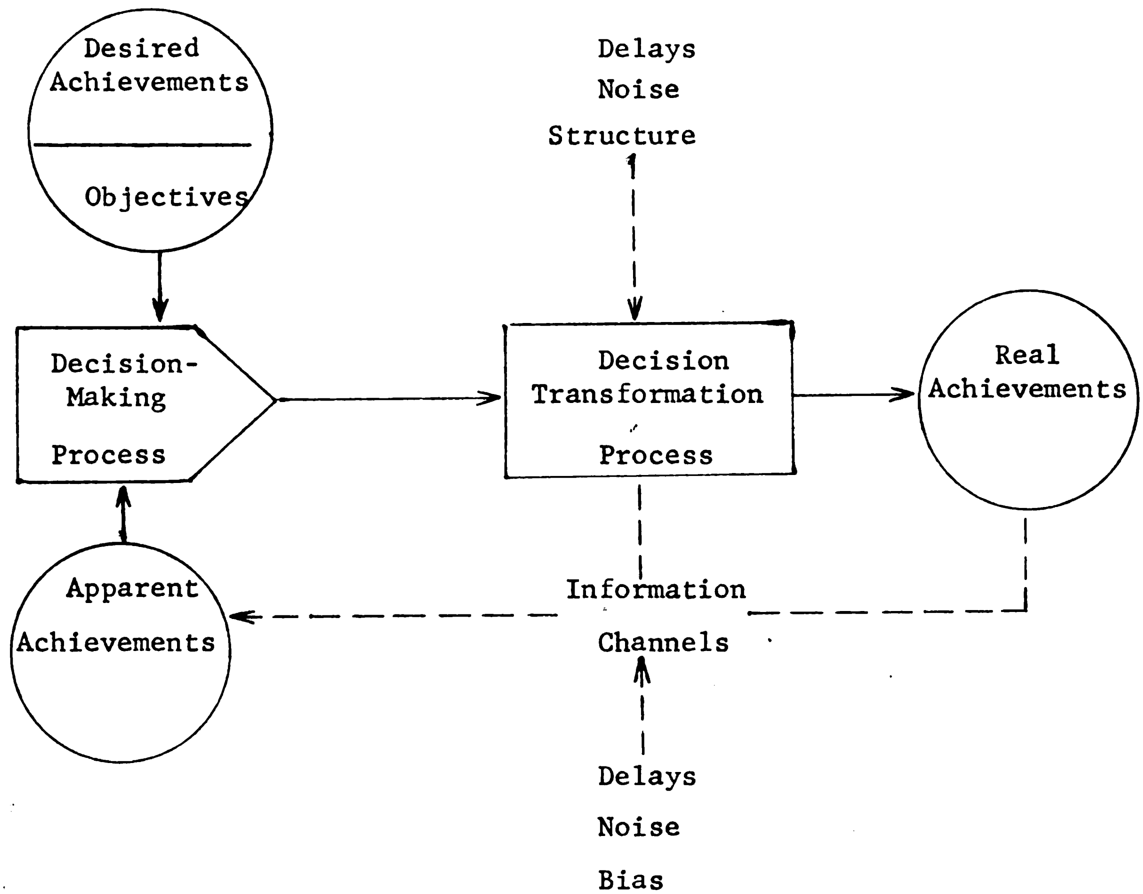

Figure 1. Transformation of the Decision Process

Four characteristics of this diagram are noted by Roberts, a researcher from the Massachusetts Institute of Technology. First the transformation of decisions into results takes place through a complex process which includes a basic structure of organizational, human, and

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[19] Robert, E.B., "Industrial Dynamics and the Design of Management Control Systems," in C.P. Bonini, R.K. Jaedicke, and H.M. Wagner (Editors) <u>Management Controls - New Directions in Basic Research</u>, (New York: McGraw-Hill Book Company, 1964) pp. 102-103.

other relationships; this structure is sometimes not apparent because of its numerous sources of noise or random behavior and due to its often lengthy time delays between cause and effect.

The second aspect to be noted is the distinction between the achievements that are apparent in the organization and those which are real. The real situation is translated into the apparent through information and communication channels which contain delays, noise and bias. The bases of actual decisions in an organization may be assumptions which bear little relation to fact.

The third feature is that the decision-making process is viewed as a response to the gap between objectives of the organization and its apparent progress toward those objectives. Although both the objectives and achievements may be difficult to define precisely and measure accurately, such goal-seeking behavior is nonetheless present in all organizations.

The fourth characteristic is the continuous feedback path of decision-results-measurement-evaluation-decision. It is vital to effective system design that each element of this feedback path be properly treated and that its continuous nature be recognized. Whether the decision in the system is made by the irrational actions or logical deductions of a manager or by the programmed response of a computer, the system consequences will eventually have further effects on the decision itself.

Some of the results of simulation studies on models like this are of particular interest to designers of management control system. They demonstrate the importance of taking cognizance of the complete system structure in attempting to create and implement methods of system control.

For the manager of an urban planning organization, such control system analysis can provide valuable insight into problems of organizational control. Simulation models do not necessarily need to be constructed and run for his particular organization. Such analysis for most organizations would be unwarranted at the present stage of development of this particular tool. However, by studying models of other organizations and by going through the process of laying out a basic organizational control model, valuable insights can be gained into the decision making process.

The key to effective control often lies outside the boundaries of conventional operational control systems; in fact, it is sometimes outside the formal boundaries of the planning organization. The proper design of management control systems often requires inclusion of the effects of intangibles; in particular, the role of decision makers who are part of the total system of control must be treated carefully. A true understanding of total system basis and system behavior can permit effective design of both operational control systems and top management policy, without differences in philosophy or methodology of approach.[20]

Principles of management control system design, such as those stated above, have been arrived at from many applications of model simulation to organizational systems. An awareness of this tool of analysis can aid the planning manager in understanding and controlling the decision-making structure of his own organization and of the larger

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[20] Ibid., pp. 123-125.

system of which his organization is a part.

C. Operational Gaming

1. The Purpose and Results of Gaming.

In the introductory remarks in section A, a differentiation between operational gaming and game theory was stated. Operational gaming, because of its real world orientation, is a method of analysis which can be used in planning operations. The scope and detail of this method, and the expense of building, operating, and analyzing the models, have limited application of this technique primarily to the study of large and complex real world situations.

When gaming is employed to study the broad structure of an interacting system or when it is employed in situations where the observer desires to study the interplay of competing forces, where the strategies and goals of these forces come into conflict or competition with one another, it can be a comparatively inexpensive method of research. In gaming aimed at the examination and identification of broad strategies and the general outcome of a given situation, the greatest expense is in the intensive use of people. However, this expense is usually justifiable because of the valuable learning experience received during the set-up and operation of the game. It affords opportunity for those who are unfamiliar with given situations to obtain experience through the process of participating in the game.

The game roles in this situation are essentially matters of convenience for observation of game play. The players are usually the research people themselves and there is no particular interest in studying roles or organizations. Players are as concerned with the structure and activity of the game as with its outcome. Emphasis is typically on the strategies and their consequences. There is not usually strict structuring of players to organizations and the analysis of results relates to the purpose and design of the experiment. The ease of setting up such a gaming situation, the facility with which changes can be injected into the assumptions, the rules, the strategies used, means that the games can be played many time -- usually with rapidity so that broad exploration can be undertaken freely.[21]

Operational gaming becomes much more complex when the purpose is to study decision rules in the context of a given organization and environment. The decisions evolved through the gaming concern alternatives that confront a specific organization as it operates and plans for an explicit time period. Consequences of specific strategic decisions are examined and are used to implement strategies and to provide useful experience for modifying strategies.

Unlike the more generalized gaming situation described, the participants in this form of gaming are usually selected because they come from real world organizations or functions like those being studied. They occupy specific slots in the simulated organization and are instructed to deal with their functions much as they would in the real world. Players receive instructions to be part of the model, and to provide decisions consistent with policy and experience. They are asked to provide assessments of the realism of the model, and to evaluate the feasibility of carrying

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[21] Geisler, M.A., W.W. Haythorn and W.A. Steger, Simulation and the Logistics Systems Laboratory (The Rand Corporation, RM-3281-PR, September, 1962) pp. 23-24.

out the decisions and functions in the real world. So participants are essential parts of the simulation, and their contribution helps insure greater realism of the gaming problem.[22]

In this type of rigid analysis, the results of the gaming are expected to have meaning relative to the defined inputs. For some of the questions investigated, results can be directly linked to feasibility and payoff of an action or plan. Where this type of rigid analysis is required, dependence on detail adds to the cost and reduces the flexibility of the gaming when compared to the more loosely-designed game. The degree of rigidity in the analysis should be derived from the purpose a gaming analysis is to serve. The application of gaming to this purpose determines the size, scope and detail of the analysis.

If urban problems are to be investigated through gaming techniques, the model would be extremely complex and operating conditions would be rigid. The range of required investigation would include questions of how consequences of current decisions on future patterns of development can be accurately predicted and how alternative decisions affect the future environment. As new methods of handling and employing data are devised, the complexity of the urban environment and knowledge about corresponding relationships will become more susceptible to operational gaming.

Looking at the purposes of gaming generally as an aid in problem solving, three classes of uses can be stated:[23]

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[22] Ibid., p. 22.

[23] Ackoff, R.L. and Gupta and Minas, op. cit., pp. 263-264.

(1) to help develop a decision model.

(2) to help find the solution to such a model.

(3) to help evaluate proposed solutions to problems modeled by the game.

Gaming can aid in constructing a model by providing a basis for testing the relevance of variables or the functional form of the model (the relationships between the variables). It can also be used both to help uncover possible courses of action and decision strategies, and to compare the alternatives. In cases where a completely specified course of action or decision procedure cannot be derived analytically from a model, but a partially specified action or procedure can, the effect of the action or procedure may be determined by gaming.

The potential usefulness of gaming in the development of an operational urban model is indicated by these uses of gaming. Until techniques of handling and employing data for complex urban analysis are developed, the utility of gaming for urban planning problems will be found in more general forms of analysis.

Applications of operational gaming in business situations have become an effective tool of analysis in recent years. Some applications in fields allied to planning have direct implications for considering urban decision making. Because the urban planner is directly concerned with the functioning of the community, both as a totality and as a composition of the various components, the research concerning the community as an ecology of games is of interest. Some implications of management games also are of interest for directing an urban planning organization. One primary application is in the use of gaming as a teaching aid for understanding decision processes. These applications of gaming will be the subject of the remainder of this section.

2. Application of Gaming.

a. Considering the Local Community

The local community can be usefully conceptualized as an ecology of games. In a particular territorial system a variety of games goes on. The games give structure, goals, strategies, tactics, and publics to the players. Players in each game make use of players in the others for their particular purposes. The interaction of the games produces unintended but systematically functional results for the ecology. By subjecting this conceptualized interacting game situation to analysis, insights into actual functional relationships develop. When relationships between the "community actors" are better understood, situations can be manipulated to bring about increased understanding.

Through the research he has done, Norton Long[24] contends that the structured group activities that exist in a particular territorial system can be looked at as games. These games provide the players with a set of successes or failures. They provide them deterministic roles and calculable strategies and tactics. In addition, they provide the players with an elite and a general public that is in varying degrees able to tell the score. Long's position is that man is both a game-playing and a game-creating animal, that his capacity to create and play games and take them deadly seriously is of the essence, and that it is through games or activities analogous to game-playing that he achieves a satisfactory sense of significance and a meaningful role.

In the territorial system there is a political game, a banking game,

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[24] Long, N.E., "The Local Community as an Ecology of Games," American Journal of Sociology, Vol. 64, Nov. 1958, pp. 252-254.

a contracting game, a newspaper game, a civic organization game, an ecclesiastical game, and many others.

Within each game there is a well established set of goals whose achievement indicates success or failure for the participants, a set of socialized roles making participant behavior highly predictable, a set of strategies and tactics handed down through experience and occasionally subject to improvement and change, an elite public whose approbation is appreciated, and a general public which has some appreciation for the standing of the players. Within the game the players can be rational in the varying degrees that the structure permits.

Long proposes that a particular highway game structure may be the result of a bureacratic department of public works in which are combined a professional highway engineer game with its purposes and critical elite onlookers; a departmental bureaucracy; a set of contending politicians seeking to use the highways for political capital; a banking game concerned with bonds, taxes and the effect of the highway on real estate; newspaper men interested in headlines; contractors eager to make money by building roads; ecclesiastics concerned with the effect of highways on their parishes and on the fortunes of the contractors who support their churchly ambition; labor leaders interested in union contracts and their status as community influentials; and civic leaders who must justify the contributions of their bureaus of municipal research or Chambers of Commerce to the social activity. Each game is in play in the complicated pulling and hauling of siting and constructing the highway grid. A wide variety of purposes is subserved by the activity, and no single overall directive authority controls it. However, the interrelation of the groups in constructing a highway has been developed over time, and there are general expectations as to the interaction.

The ecology of games in the local territorial system accomplishes unplanned but largely functional results. The games and their players mesh in their particular pursuits to bring about over-all results. Its inhabitants are rational within limited areas and, pursuing the ends of these areas, accomplish socially functional ends.

Acknowledgement of a game structure such as that described above, enables the urban planner to better understand how a particular project is accomplished. Because of the planner's contact and relationships with many of the community groups and leaders, he can more adequately promote fulfillment of planning projects linked to established goals and objectives if he at least in part understands the game structure for a particular project.

Designing a formal game to be played by a research staff, for a project such as a highway system, would be impractical for most planning groups and probably impossible because of the complexity involved. However, the planner working in a community is in a good position to know many factors and relationships involved in an urban project. If he considers the project as a game situation, his success in promoting understanding and cooperation may be increased. An indirect use of an analytical aid, such as this way of considering a project, provides an analytical tool, admittedly often crude and incomplete without the expense and the need for know-how of the formal use of the tool. It may be that the indirect use of the tool will provide the necessary insights for effectively facilitating the planner's role in a community project. The consideration of a project as a game situation may help him to predict formal and informal relationships involved with a project, and may help the planner identify the range of decision makers involved. In doing this type of analytical thinking the planner may through time and experience develop a model of interaction which he can use in a general analysis of local community interaction.

b. Management Games

There have been a large number of management games developed for use both in research and in actual problem situations. The Carnegie Institute of Technology Management Game, developed through a period of play with students, collected data that bear both upon problems of education for management and on questions of social research.

In the Carnegie game, conclusions supported the hypothesis that management games can also be used as research devices, either contemporaneously with their educational use or as an independent mechanism. Experience with an extended run of the Carnegie game demonstrated that it is quite possible (1) to evaluate certain educational aspects of the game; and (2) to gather data from the play of the game about some questions of organizational and group behavior. They were able to investigate relationships between game performance and (1) individual ability; (2) personality variables; (3) dispersion of power within teams; and (4) consonance of perceptions of influence within teams. They were able also to show positive relationships between predictions about influence made before the game and actual influence measured just after the game.[25]

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[25] Dill, W.R. and W. Hoffman and J.H. Leavitt and T. O'Mara, "Experiences with a Complex Management Game," California Management Review, Vol. 3, No. 3, 1961, p. 50.

Although the number of management games is already large and increasing steadily, and although the differences among them are con siderable, it is possible to abstract some general features found in most of the games that have been designed.[26]

The simulation of the environment to make possible feedback of the results of their actions to the players is the fundamental game idea, and this feature is found in all of the management games. The characteristics of the environment have always been expressed in logical and mathematical relations. Some of these relations -- the rules of the game -- are always completely made known to the players, while the remaining relations - which describe the detailed intrinsic characteris tics of the environment -- are usually made known to the players in only a vague qualitative manner. The representation of the environmental characteristics by a set of formal relations makes it necessary for the environment to be represented in the game by a computer. Whether the computer used is electronic or human is fundamentally of little importance, since its role is the same in all cases: passive interpretation of the environment's response to the players' actions as dictated by the logical and mathematical formulas describing the environment.

The interaction between the players and the environment is thus the core of all management games. In games where players compete against each other, the interaction between players is another essential idea. In

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[26] Cohen, K.J. and E. Rhenman, "The Role of Management Games in Education and Research," Management Science, Vol. 7, Jan. 1961, p. 143.

the Carnegie game mentioned above, another interaction that has been of prime interest in the design of the game is the interaction between functional groups within the organization. This functional group interaction is of interest because such a game design broadens considerably the possibility of studying the complex interaction at a level above the individual sphere of influence.

In an application of gaming simulation as a teaching aid, Richard Duke has developed a game designed to familiarize the student with some of the more significant community decision-making roles as they relate to community growth patterns, in the context of public capital improvement expenditures.[27]

The game's potential value includes its ability to:

(1) clarify and illuminate the decision-making processes involved.

(2) enable a player to view the consequences of a previous decision while the circumstances are still fresh in his mind, through compression of time span.

(3) force the players to view the decision from the various roles portrayed, creating a larger basic perspective for his future actions.

(4) familiarize the player with the relative quantities which are involved in the decision.

(5) introduce various decision-assisting tools.

(6) force the student to evaluate the goals, objectives and value structure inherent in his decision.

The gaming-simulation technique creates the environment of a hypothetical community in abstracted form in which players are placed in a dynamic setting and forced to choose a course of action from various

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[27] Duke, R.D., Gaming Simulation in Urban Research (Institute for Community Development and Services, Continuing Education Service, Michigan State University, East Lansing, Michigan, 1964) p. 6.

alternatives. Simultaneous decisions are required on a two-level basis at each "cycle". The first level of decision is private and involves personal gain. The second involves some public use, generally a capital improvement. Resources are limited for each level of decision, and each decision results in deterministic consequences at a later date.

The implications of the usefulness of this game as well as that of management games such as the Carnegie game have already been established. As development of techniques continue, other factors, such as functional group interaction, will become a subject of more complete analysis. The gaming technique, used as a teaching aid and as a research device, is a tool which can enable the urban planner to transmit as well as more fully understand the intricacies of the urban community.

The major expected future developments of management gaming, as outlined by Feeney[28] may help to establish the broad purposes established for this technique of analysis. The expected future developments include:

(1) Large scale exercises involving long decision intervals and detailed representations of complex situations.

(2) The use of a game as a laboratory in which to develop and test new methodology and train personnel in the use of new methods.

(3) The use of games which simulate a particular actual situation as a basis for predicting the effect of policy changes in competitive contexts.

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[28] Feeney G. J., "The Future of Management Games," in C.W. Churchman and M. Verhulst, (Editors), Management Science - Models and Techniques, (Oxford: Pergamon Press, 1960), p. 263.

Each of these developments hold interest for urban planning situations and applications of such newly developing methodology should be investigated in light of the usefulness achieved in other disciplines and the practicality of use in the urban environment.

3. Another Look at the Value of Gaming.

Anatol Rapaport has written concerning the value of game theory, and his ideas have implications for operational gaming as well.[29]

He states that the value of game theory is not in the specific solution it offers in highly simplified and idealized situations, which may occur in formalized games but hardly ever do in real life. Rather, the prime value of the theory is that it lays bare the different kinds of reasoning that apply in different kinds of conflict. Whether game theory leads to clear-cut solutions, to vague solutions, or to impasses, it does achieve one thing. In bringing techniques of logical and mathematical analysis to bear on problems involving conflicts of interest, game theory gives men an opportunity to bring conflicts up from the level of fights, where the intellect is beclouded by passions, to the level of games, where the intellect has a chance to operate. This is in itself no mean achievement, but it is not the more important one. The most important achievement of game theory, in Rapaport's opinion, is that game theory analysis reveals its own limitations. Game theory teaches us what we must be able to do in order to bring the intellect to bear on a science of human conflict.

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[29] Rapaport, A., "The Use and Misuse of Game Theory," Scientific American, Dec. 1962, pp. 114 & 118.

To analyze a conflict scientifically, we must be able to agree on relative values (to assign utilities). We must learn to be perceptive (evaluate the other's assignment of utilities). Furthermore, in order to engage in a conflict thus formalized, we must be able to communicate (give a credible indication to the other of how we assign utilities to outcomes). At times we must be able to convince the other that he ought to play according to certain rules or even that he ought to play a different game. To convince the other we must get him to listen to us, and this cannot usually be done if we ourselves do not listen. Therefore we must learn to listen in the broadest sense of listening, in the sense of assuming for a while the other's world outlook, because only in this way will we make sense of what he is saying.

All of these skills are related not to know-how but to wisdom. It may be that if we acquire the necessary wisdom, many of the conflicts that the strategy experts in their professional zeal insist on formulating as battles of wits or wills, will be resolved of their own accord.

This insight into the alignment and use of intellect for resolving situations of conflict, deserves careful consideration in light of the problems of misunderstanding encountered in the urban environment. The use of gaming as a teaching aid and as a research device has proved to be effective in promoting an understanding of different kinds of reasoning that apply in conflict situations. With continued development and sophistications of gaming techniques, more of the underlying values suggested by Rapaport may become operational within conflict situations.

D. Decision Theory

The type of analysis which is used in a decision situation is dependent upon the nature of the problem (the number of variables and the parameters), and upon the resources allotted for the given analysis. Shlaifer has stated that decision theory might be used to advantage in two general types of problems:[30]

(1) Those where the problems are complex and the stakes very high so that analysis which promises to be of real help is worth virtually whatever it costs in the way of effort on the part of the decision maker.

(2) Those where the problems are complex but formal analysis costs the decision maker relatively little effort because most of the factors involved in the problem can be dealt with by technicians and only a few factors require the attention of the responsible decision maker himself.

To explore the usefulness of decision theory for planning problems, the individual elements of a decision situation will be investigated. It is through the elements of a decision situation that decision theory analysis is evolved. Decision theory applies to all types of decision situations and the elements of a decision situation can generally be categorized as follows:[31]

(1) Strategies or plans constructed of controllable variables.

(2) States of Nature composed of noncontrollable variables.

(3) Outcomes which are observations of results that occur when a specific strategy is employed and a particular state of nature exists.

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[30]Schlaifer, R., "Decision Theory and Management Theory" in H. Koontz (Editor), Toward a Unified Theory of Management, (New York: McGraw-Hill Book Company, 1964) p. 70.

[31]Starr, M.K., Production Management Systems and Synthesis, (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1964) p. 67.

(4) Predictions of the likelihood that each state of nature will occur.

(5) The decision criterion which dictates the way in which the information above will be used to select a single plan to follow.

The element of chance enters the decision system through the uncontrollable variables that characterize states of nature. It is the element of prediction, which gives us a kind of control over outcomes, that gives decision theory its most unique attribute. Prediction, of course, is used to some extent in all forms of analysis, but in decision theory an effort is made to systematically formulate predictions concerning specific states of nature which exist in a decision situation.

Decision making under certainty occurs when in a decision problem we know with certainty which state of nature will occur. There is no difficulty, in theory, in determining the decision criterion under certainty. In theory, there is a single need of finding the strategy which has the largest payoff and that is the strategy which should be selected. There is no reason for doing otherwise. Each strategy has only a single payoff representing the degree of achievement of the objective. The largest payoff in a series of strategies is the best that can be done in terms of the objective.

The second kind of decision problem occurs where there are a number of states of nature but where the decision maker knows the probability of occurrence of each of the states of nature. This kind of situation is decision making under risk. Under risk there is no longer just one payoff for each strategy. There are a number of payoffs, one for each possible state of nature. So a decision criterion will either have to be based on all the possible payoffs for each strategy, or on one or more payoffs selected according to some rule.[32]

The simplest type of problem situation is one involving only two possible outcomes, but qualitatively defined, and two courses of action.[33] Which of the two courses of action is the better? It is clear that this question cannot be answered unless it is known which of the outcomes is desired. It is necessary to know the relative values of these outcomes to the decision maker. For the urban planner, the problem of relative values is one which comes under discussion from many viewpoints. Each distinct element of society has unique values and these separate values must be brought into a common focus if an outcome is to be chosen.

Intuitively, the problem of conflict of interest is a problem of individual decision making under a mixture of risk and uncertainty, the uncertainty arising from the decision maker's ignorance as to what others in his interested sphere of society will do. In game theory this type of problem situation is idealized in such a way as to transform it into a decision under certainty or risk.[34] This is not accomplished directly by assuming that the opponent has certain information and that he is motivated in certain ways; that is, that he behaves rationally. Put another way, the central problem of game theory does not turn out to be what choice to make given certain or probabilistic knowledge of the opponent's

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[32]Miller, D.W. and M.K. Starr, Executive Decisions and Operations Research (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1960) p. 80.

[33]Ackoff, R.L. and Gupta and Minas, *op. cit.*, p. 37.

[34]*Ibid.*, p. 46.

choices, but rather what choices can the opponent be assumed to make, given certain assumptions about his state of knowledge and motivation.

In most real conflict decision situations the choices available to the players seldom completely determine the outcome. The choices and the environment cannot be defined so as to be sufficient for any specified outcome. Consequently, even if all the choices are known, the outcome is known only probabilistically at best. Furthermore, even if the outcomes were known with certainty, the values placed on them by the opposing players are seldom, if ever, known with certainty. For one or both of these reasons the pay-offs in real situations are almost always known with less than certainty. However, if in the concept of a game the assumption of perfect knowledge is dropped, it is then a suitable model of decision under uncertainty.

In decision making under uncertainty the probabilities of occurrence of the various states of nature are not known. Such problems arise wherever there is no basis in past experience for estimating the proabilities of occurrence of the relevant states of nature.

If the assumption of perfect knowledge in game theory is replaced with an assumption of complete ignorance, the result is a model of an uncertainty problem situation.[35] The argument in the condition of certainty that to assume perfect knowledge of the plays is to assume too much, is here replaced by the argument that to assume complete ignorance is to assume too little. The argument is based on the observation that in order to formulate a pay-off matrix for a problem situation some know-

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[35] Ibid., p. 50.

ledge of the opposition (decision maker or nature) is necessary and that this knowledge can and should be used in the decision process.

In the uncertainty game it is assumed that neither player can assign probabilities to the possible plays of his opponent. If a player could assign such probabilities and could construct a pay-off matrix, he could try to maximize expected value, or he is justified on the basis of his ignorance in assuming that his opponent is equally likely to select each possibility. Otherwise he must employ some other criterion such as that of optimism, pessimism, regret or rationality as outlined by Miller and Starr.[36]

An interesting result of decision theory has been the discovery that there is no one best criterion for selecting a strategy. Instead, there are a number of different criteria each of which has a good rationale to justify it. The choice among these criteria is determined by policy and/or the attitude of the decision maker.

Before further consideration of the elements of prediction and decision criterion, the other elements of a decision situation will be discussed in the order outlined previously.

1. Strategies.

The various available alternative courses of action in any decision problem are the strategies of the decision maker. It is assumed that the decision maker can select any one of the available strategies at his option. Since the selection of a strategy is under the control of the decision maker, strategies are based on the variables which are controllable.

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[36] Miller, D.W. and M.K. Starr, op. cit., pp. 85-94.

The element of strategy takes form as plans are formulated. The process by which plans are formulated includes some measure of the effectiveness of each strategy included as part of a proposed plan. Decision making in this context is the process by which a selection is made from among courses of action, not the process through which plans are formulated. The measure of the effectiveness of each strategy is dependent upon the objectives associated with the planning program. Here again is pointed out the importance of having clear and explicit objectives which can be tested in accordance with the strategies generated for a given plan.

The focus of strategy should operate on the broad structure of planning linked to the overall objectives and goals. In addition to considerations of internal strategies, the planner should be cognizant of the global strategies which affect a given internal strategy. An evolving plan will not be adopted into an environment devoid of external strategies. These global strategies must be considered in relation to the measure of effectiveness of each strategy considered.

Within the element of strategy, tactics should be considered. Tactics are a method or procedure for accomplishing or carrying out a strategy. In this function tactics refer to more definite procedures than does strategy.

Starr[37] gives reference to four considerations of tactics. These are:

(1) Tactical considerations resemble short-term planning whereas

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[37]Miller, D.W. and M.K. Starr, Executive Decisions and Operations Research,(Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1960) p. 58.

strategies can be applied to long-term plans.

(2) A number of tactical possibilities will follow from a single strategy. Thus, detail is multiplied as we move down this ladder. Seldom will there be only one configuration of instruments that can be used to achieve a specified strategy.

(3) Strategic evaluation implies that a tactical choice has been made. Generally, when comparing strategies, some hypothetical tactic is assumed for each, and an estimated cost is employed. The effectiveness of this procedure depends upon the degree of sensitivity involved. When the tactical costs for each strategy considered are large or when an overlapping of tactics among the various strategies occurs, it is impossible to compare strategies with any degree of confidence without detailing the various tactical alternatives. This process usually involves a direct consideration of the entire system.

(4) Tactical considerations involve the degree of control that can be exercised over the instruments. When the degree of control and the consequent variation of results is an issue, this consideration must be included in the evaluation and appraisal of the strategies.

The innovation of strategies and the imitation of strategies both serve useful functions for the decision maker. For some phases of planning, an organization can benefit by imitating some of its previous behaviors. Because of convenience, effectiveness, and costs involved, the imitation of previous actions may be the correct strategy to employ. However, opportunities for innovation always exist. Because of a combination of organizational and environmental characteristics, a brilliant strategy might be formulated. In this situation, the organizational decision system should be able to recognize the existence of this occurrence. It should also be able to select from a number of possibilities the best strategic possibility. Only when these conditions exist within the decision framework can creativity be usefully employed in the innovation of strategies.

2. States of Nature.

States of nature include the factors in a situation that affect the expected results of a plan but which are not completely under the planner's control. Rarely is reality so maneuverable as to make the result or outcome of a selection of strategy depend solely on the strategy selected. The outside world will usually play a crucial role in determining what happens as a result of the selection of strategy. In some way, the outcome which results will depend both on the selection of strategy and on what happens in the outside world.[38]

The element of uncontrollable variables forms a formidable obstacle in the urban environment. A thorough enumeration and evaluation of this factor is a necessary part of decision theory analysis. Therefore, the planner must be insightful both to the existence of the uncontrollable variables and to the interrelation which these variables form in their relations to the strategy of concern. Until the relevant states of nature are recognized, the analysis involved in the planning process cannot logically proceed.

A survey of the problem situation may reveal that the states of nature can be ignored without adversely affecting the decision problem. This type of decision problem, as mentioned above, is called decision making under certainty. For problems where risk or uncertainty exist,

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[38]Miller, D.W., "The Logic of Quantitative Decisions," in A. Shuchman, Scientific Decision Making in Business (New York: Holt, Rinehart & Winston, Inc., 1963) p. 313.

the planner must consider the uncontrollable features of the problem because these features may be vital to the success of the plan. Under risk or uncertainty conditions, an enumeration of the uncontrollable variables gives opportunity for a thoughtful analysis either by the decision maker himself or by an expert or a group of experts. Such analysis can help prevent an invalidating of a plan of action because of some unforseen occurrence.

According to Starr,[39] states of nature are intended to describe everything that might happen within a specific time period that can affect the relative value of the decisions that we make. Thus, depending on the type of problem, varying amounts or degrees of the various uncontrollable variables can play significant roles in the evaluation of a set of plans. It should be noted that as the problem moves into the realm of tactical decisions the breadth and diversity of states of nature tends to decrease. The states become more predictable, but never entirely so.

3. Outcomes.

The decision problem so far has various strategies, any one of which the decision maker can select, and various alternative states of nature which may occur in the world. The selection of any specific strategy and the occurrence of any specific state of nature will result in some outcome. A convenient way to portray this structure is with a decision matrix with the rows being the various strategies and the columns being the various possible states of nature. The outcomes are

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[39] Starr, M.K., op. cit., p. 79.

given at the intersection of the corresponding columns and rows.

State of Nature	N
Strategy 1	
Strategy 2	
Strategy 3	

FIGURE 2. Outcome Matrix-Decision Making Under Certainty.

State of Nature	N_1	N_2	N_3
Probability	P_1	P_2	P_3
Strategy 1			
Strategy 2			
Strategy 3			

FIGURE 3. Outcome Matrix-Decision Making Under Risk.

State of Nature	N_1	N_2	N_3
Probability	?	?	?
Strategy 1			
Strategy 2			
Strategy 3			

FIGURE 4. Outcome Matrix-Decision Making Under Uncertainty.

The decision matrix is therefore constructed so that for each intersection an outcome measure must be obtained that would adequately describe the objectives of the planning operation. Outcomes are obtained in at least three basically different ways:[40]

(1) By means of estimates and guesses.

(2) By observation and experimental results.

(3) By a knowledge of relationships that have previously been hypothesized.

In order to by-pass the estimation stage and supplement these with experimental evidence, an initial investment is required. This investment may be small in comparison to the eventual requirements of the plan, but the decision to study the problem on an experimental level represents a commitment of funds. When test conditions are almost as costly as the full commitment, or when only a full commitment to a specific strategy would provide meaningful observations, the decision maker may be compelled to reach a decision on the basis of estimates. Experimentation is more easily associated with short-term than with long-term systems.

The use of hypothesis and theory in the form of mathematical equations or a set of logical postulates is the third way in which outcomes can be derived. Under this condition, a type of situation has been isolated for which a pattern has been found that can explain all the variations that pertain to this situation. When this is true the conditions must be rendered in explicit form, usually in mathematical symbolism. The usefulness of this way of deriving outcomes for urban planning problems is certainly limited at the present stage of analytical development.

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[40] _Ibid._, pp. 80 & 82.

Deriving outcomes, it should be pointed out, does not constitute the means by which a choice is to be made between two or more plans. The decision criterion plays no part in the development of meaningful outcome measures. Outcomes relate only to what will happen when a particular strategy is used and a specific state of nature has occurred.

Returning again to ways of deriving outcomes, the use of estimates and guesses is most prevalent in the long-range planning situation. There is always room for error when estimates are used to describe outcomes. Starr continues this thought by saying that with estimates mental gymnastics are required which defy description simply because they are totally internalized and part of the process of cerebral behavior -- about which science knows almost nothing. The phrase "mental gymnastics" is used because it would appear that a mental image must be constructed from prior experiences to be as close a representation of the situation that is being analyzed as can be developed from prior experiences. Then, somehow, the estimates must be able to modify the complex parallel that he has built in his mind to obtain an exact fit with the situation that concerns him. That is why the range of experience of such an individual is important. Unless his library of experience is sufficiently great, he cannot be expected to call up from memory sufficiently good analogs.

A particular characteristic of long-range decision is that the situations that must be examined are likely to be quite unique. Therefore the ability to adapt, alter, interpolate, and extrapolate supposes that some basic pattern of association can be determined. The use of decision theory is therefore not a mechanistic endeavor, but it is an exercise requiring great imagination and a full use of knowledge and experience.

Outcomes then are intersection values obtained by problem-solving models. The models can use mathematics, logic, experimentation, observation, and intuition. The outcomes are formulated to represent degrees of attainment of the decision maker's objectives. The matrix of outcomes maps out the range of possible achievement of the objectives.[41]

4. Predictions.

In decision theory, the element of chance enters in the decision system through the uncontrollable variables that characterize states of nature. Even though control over these variables is non-existent or at least very limited, there are ways of dealing with the variables. Many actions can be predicted according to the methods of probability theory.

Probability theory deals with events of a special kind, called random events.[42] These are events for which the outcome is determined by chance. Frequently this situation occurs when a large number of possible actions contribute to produce the final outcome which is the event in question. Probability theory deals with the conclusions that can be drawn in reasoning about such events. The basic concept is that of the probability of the outcome. Therefore, probabilities are measures of uncertainty.

It is convenient to distinguish three probability concepts:[43] relative frequency, degree of confirmation, and subjective probability.

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[41] Ibid., p. 85

[42] Miller, D.W. and M.K. Starr, op. cit., p. 58.

[43] Helmer, O. and N. Rescher, op. cit., pp. 33-36.

Of these, the first is an objective, empirically ascertainable property of classes of physical objects or physical events; the second is also purely objective, namely a logical relation between sentences; the third is a measure of a person's confidence that some given statement is true, and is thus an essentially subjective matter. Each of these concepts is discussed in more detail by Helmer and Rescher and is outlined below.

Relative Frequency:

Relative frequency requires the statement of a reference class of objects or events, also called a population. If the class of objects is finite it is simply the ratio of the number of elements having some property or trait divided by the total number of events in the class.

Degree of Confirmation:

The degree of confirmation is a logical relation between two sentences, the hypothesis H and the evidence E. The degree of confirmation of H on the basis of E is intended to be a measure of the credibility rationally imparted to the truth of H by the assumed truth of E.

If E does not have the simple form of a statistic or H does not just affirm another like instance, then some plausible extension of the definition of the degree of confirmation is required; this may lead to cases where no single number can reasonably be specified but where the evidence merely warrants a narrowing down of the probability of H to several possible numbers or an interval of numbers. For instance, if H is the hypothesis that a certain Irish plumber will vote Democratic in the next election, and the evidence E amounts solely to saying that 70 percent of the Irish vote Democratic and 20 percent of the plumbers do, then all that one might reasonably assert is that the required probability lies somewhere between .2 and .7.

Subjective Probability:

Subjective probability is a measure of a person's confidence in, or subjective convictions of, the truth of some hypothesis. In terms of statistics it is measured behavioristically in terms of the person's betting behavior.

A person might be called "rational" if (1) his preferences are mutually consistent or at least, when inconsistencies are brought to his attention, he is willing to correct them; (2) his personal probabilities are reasonably stable over time, provided he receives no new relevant evidence; (3) his personal probabilities are affected (in the right direction) by new relevant evidence; and (4) in simple cases where the evidence E at his disposal is known, and E and H are such that the degree of confirmation of H and E is defined, his personal probability regarding H is in reasonable agreement with the latter; in particular, he is indifferent as to which side to take in a bet which to his knowledge is a "fair" bet.

A predictive "expert" in some subject-matter is a person who is rational in the sense discussed, who has a large background knowledge E in that field, and whose prediction with regard to hypothesis H in that field shows a record of comparative successes in the long run.

Helmer and Rescher[44] state that a knowledge about past instances or about statistical samples, while indeed providing valuable information, is not the sole and sometimes not even the main form of evidence in support

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[44] Ibid., p. 38.

of rational assignments of probability values. In fact the evidential use of such *prima facie* evidence must be tempered by reference to background information, which frequently may be intuitive in character and have the form of a vague recognition of underlying regularities, such as analogies, correlations, or other conformities.

The consideration of such underlying regularities is of special importance in the social sciences because in this sphere we are constantly faced with situations in which statistical information matters less than knowledge of regularities in the behavior of people or in the character of institutions, such as traditions and customary practices, fashions and mores, national attitudes and climates of opinion, institutional rules and regulations and group aspirations.

This non-explicitness of background knowledge, which nonetheless may be significant or even predominantly important, is typical of the social sciences, as is the uncertainty as to the evidential weight to be accorded various pieces of *prima facie* information in view of indirect evidence provided by underlying regularities. Hence the great importance which must be attached to experts and to expertise in these fields. For the expert has at his ready disposal a large store of (mostly inarticulated) background knowledge and a refined sensitivity to its relevance, through the intuitive application of which he is often able to produce trustworthy personal probabilities regarding hypotheses in his area of expertness.

The decisions which professional decision makers are called upon to make inevitably turn on the question of future developments. Thus a reliance upon predictive ability is nowhere more overt and more pronounced than in the area of policy formation, and decision making in general. For this reason, decision makers surround themselves by staffs of expert

advisors, whose special knowledge and expertise must generally cover a wide field. Some advising experts may have a great store of factual knowledge. Others may excel through their diagnostic or otherwise predictive abilities. Others may have a special analytical capacity to recognize the structure of the problems in hand. The availability of such special expertise constitutes for the decision maker a promise of increased predictive ability essential to the more effective discharge of his own responsibilities. Thus the ultimate function of expert advice is almost always to make a predictive contribution.

For the decision-supporting uses of predictive expertise, there is in general no necessity for an anticipation of particular future occurrences. It suffices that the expert be able to sketch out adequately the general directions of future developments, to anticipate some of the major critical junctures on which the course of these developments will hinge, and to make contingency predictions with regard to the alternatives associated with them.

Remembering that we are considering prediction about the status of uncontrollable variables that characterize states of nature, we may concur from the above discussion that the urban planner must seek to obtain decision-supporting predictive expertise from the many areas of concern in the urban environment if he is to adequately deal with this element of decision theory analysis. Generally he will not have a staff capable of such a broad range of expertise. However, he may be able to adequately deal with this situation by supplementing his predictive capacity with consultation and recommendation from experts in the area of concern. The important point is that in decision theory the method of analysis considers this highly important aspect of a decision problem. It is the task of the decision maker to formulate predictions as accurately as is possible considering the resources at his disposal.

This phase of the decision theory analysis is without doubt the most critical factor in the formulation of plans by the urban planner. The complexity of the urban environment makes the enumeration of uncontrollable variables a nearly impossible task notwithstanding the prediction of associated outcomes. If the planner, however, can develop an array of the major states of nature which can be expected to affect a given strategy, there is a better chance that he will be able to make a decision with more insight and assurance than if he did not go through this formal process. In this regard, Starr[45] lists four vital considerations concerning states of nature and their assoicated predictions. The considerations are:

(1) How many states of nature are relevant?

(2) Are we able to identify all the relevant states of nature?

(3) Can we determine the true frequencies of occurrence of these states of nature?

(4) Are these frequencies fixed, that is, is the state of nature (causal) system stable?

At this point in the analysis we have detailed the elements of strategies, states of nature, outcomes and predictions. Assembled in a decision matrix, the elements have the following relationships.

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[45] Starr, M.K., op. cit., p. 93.

State of Nature:	N_1	N_2	N_3
Likelihood of Occurrence:	0.2	0.5	0.3
Strategy 1	O_{11}	O_{12}	O_{13}
Strategy 2	O_{21}	O_{22}	O_{23}
Strategy 3	O_{31}	O_{32}	O_{33}

FIGURE 5. Decision Matrix Showing Outcomes.

5. The Decision Criterion:

If the decision matrix representation of a specific decision problem is accepted, then we can proceed to the decision theory approach to the decision approach. Decision problems are classified in accordance with what the decision maker knows about the likelihood of occurrence of the various states of nature. The three major kinds of decision problems with regard to this classification will be investigated further -- namely, decision problems under certainty, decision problems under risk, and decision problems under uncertainty.

For decision problems under certainty, there is, in effect, only one possible state of nature. These are problems for which the outcome is determined only by the decision maker's selection of a strategy. The outside world has no effect in the determination of the outcome and the decision matrix would therefore have only one column as shown in FIGURE 2, page 114.

With a specific decision problem represented in a decision matrix, it is necessary for the decision maker to select a strategy. In decision theory this means that some decision criterion must be applied to the decision matrix which will lead the decision maker to select the strategy that best satisfies the objectives. A decision criterion is a procedure for selecting one strategy from the available possibilities represented in the decision matrix. Under certainty, then the decision criterion is simply to select the strategy which is in most accord with the objectives.

One possible source of difficulty in problems of certainty is that the number of possible strategies may be so great that it is impossible to evaluate the outcomes for each one of them. This, however, is a problem of handling and evaluating data and does not represent a problem about the decision criterion for this kind of decision problem.

The defining characteristic of decision problems under risk is that the probability distribution governing the occurrence of the states of nature is known. This means that the probability of occurrence of each state of nature is known.[46] It is obvious that in this type of problem two or more states of nature are relevant.

When a problem conforms to the specifications of decision making under risk the generally accepted criterion is the use of expected values, or averages. According to this criterion the fluctuations of a system over a period of time will average out to the results given by the expected values. According to this criterion for any series of decision problems under risk the total return or benefit will be the largest if the decision maker selects each time that strategy which has the largest expected value.

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[46] Miller, D.W., op. cit., p. 323.

Decision making under uncertainty includes the problems where the probability of occurrence of the states of nature are not known or where such predictions have a low value of believability. In this condition, as in the decision problem under risk, at least two states of nature are assumed to be relevant.

The problem of decision making under uncertainty is one of finding an adequate decision criterion. There are a number of decision criteria which have been developed by individuals to select the best available strategy. The Wald, Laplace, Savage, and Hurwicz criteria are the most notable. Each criterion has some argument in its favor and each may indicate a different best strategy. The details of the criteria will not be discussed here, but a different general philosophy of the approach to uncertainty problems will be mentioned which will be of interest to the urban planner's approach to this problem.

When probabilities of the relevant states of nature are not available, the proponents of this more general subjectivist position maintain that probabilities can be used in a different way.[47] This is as measures of the degree of belief of the decision maker in the likelihood of occurrence of the various states of nature. They propose to measure such degrees of belief in a way that the resulting measures will behave exactly like probabilities. They maintain that most decision problems classed as uncertainty problems can be converted to problems under risk by measuring the degrees of belief of the decision maker.

The main basis of this approach is the fact that any competent decision maker has a wealth of information concerning the states of nature relevant

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[47] Ibid., p. 326.

to his decision problems. The aim then is to make this information explicit and to put it in a usable form. This approach again puts importance on the expertise of a decision maker and his staff, and the arguments proposed in the previous section on predictions, concerning the expertise available to the decision maker, pertain in a similar way here.

These various decision criteria, then, can be used in the relevant conditions of certainty, risk, or uncertainty. The objective is to use the decision criteria linked to the state or states of nature to arrive at the "best" strategy from those selected for analysis in the decision matrix.

In making complex decisions, decision makers, including urban planners, have generally made decisions by supplementing meager data with the use of intuitive judgment. The use of decision theory focuses attention on the estimation of probabilities of success and failure. Improvement in the estimation of probabilities is the most dominant feature of this tool of analysis. It is achieved through continued effort to approach reality, as well as through experience.

Decision theory, for the decision maker engaged in urban planning, is a tool which has been used in a very limited and probably indirect way, if it has been used at all. However, the type of problems which pertain to this form of analysis, as well as the procedure and method of analysis, seem to include those which deal with the urban environment. In the planning operation there is usually a selection to be made from among different strategies and often a range of relevant states of nature complicates the choice of a strategy. In these cases, a chief function of the decision maker is to determine the most likely state or states of nature to apply to the available strategies. Applying the available expertise in these situations can be approached in terms of decision theory so that predictions concerning future states or events take the form of probabilities or occurrence.

From what has been said relating decision theory to decision making, it seems vaguely apparent that some of the complex decision problems which an urban planner resolves actually are put through an analysis similar to that described for decision theory. Possibly only the formal structuring of the problem into the decision theory format is missing. If this is the case, and it may or may not be, depending on the decision maker and the problem under analysis, decision theory has something to offer him. The use of the formal methodology of this tool will help the decision maker consider the full range of planning possibilities in a systematic way, thereby decreasing the possibility of overlooking a relevant strategy or state of nature. It will also help him consider the many relationships and interrelationships in turn and may thereby increase the chances of selecting the "best" outcome for the given structure.

For the urban planning decision maker who does not approach this type of analysis when considering complex urban decisions, and treats most problems as though only one state of nature existed, decision theory may form the basis for a totally expanded way of approaching urban decision making. Whatever form or method of analysis is used for decision making in the complex urban environment, it seems apparent that decision theory should be considered and used where the situation demands this type of analysis. Most decisions of course are not worthy of this extensive form of analysis. Furthermore, the majority of problems and decisions which occupy the efforts of the urban planning decision maker do not require and are not worth spending resources for any sophisticated form of analysis. The use of available analytical aids then requires the decision maker to both understand the nature of the problem and understand the form and method of the applicable analytical tool.

CHAPTER V

SUMMARY AND CONCLUSIONS

Decision makers in urban planning are being faced with the problem of increasing complexity in the urban environment and with the need to provide unity of direction, vision, and effort in the fulfillment of present day goals and objectives developed from our emerging planning ideals. These needs are not going unsatisfied. Planners are consistently developing improved and effective methods and tools to enable them to plan rationally and professionally. The planning structure and philosophy are being evolved specifically to strengthen both the ability to make decisions, and the authority to make and to implement decisions.

In addition to the specific applications of the techniques which were stated, it is pertinent to emphasize that transportation studies in major metropolitan areas have provided the greatest impetus to changes in planning methods. The traffic or land-use model offers the planner a means of expressing the complex relationships between the variables in the development of metropolitan areas.

The earliest models developed in transportation planning were used to forecast traffic behavior. Early land-use models were simply mathematical formulas expressing such theories as the decrease of residential dwelling density with increasing distance from the city center. Efforts are being made in newer models to simulate the complex behavior of humans.

Models were developed for transportation studies because complex interrelationships among land use and traffic had to be analyzed and forecasted, large amounts of data were available, and funds had been allocated for improvement of techniques.[1]

Growing out of this evolving planning structure is the need for the ability to do, in organized and systematic fashion, what before had to be done piecemeal or sporadically. This need is a product of many factors, one of which is the increasing complexity of planning operations.

Increasing complexity results from growth, technological developments, operational diversity, the lengthening futurity of planning decisions, the impact of new and complex laws and governmental regulations, and from social pressure. These conditions indicate the need for a higher degree of precision in decision making and implementation. These conditions also seem to point to the need for an expanded body of analytical, logical and conceptual skills to establish realistic alternative solutions, to recognize key factors in such solutions, and to develop measures of their effectiveness.

Another factor is the requirement for a properly organized body of data out of which relationships have been determined and evaluated to the point where a manageable body of knowledge is available. From this background common interests may be discerned and heeded.

The flow process of planning is a factor dealing with physical things as well as with information. The need for integration comes both from within and without any specific organization. The flow process is not broken by institutional or organizational divisions but extends from the realization of a planning objective through the organizational chain to the basic resources. Where this interdependence is not recognized,

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[1]Clark. R.A. "New Techniques for City Planning," Public Management, Vol. 44, No. 11, Nov. 1962, p. 250.

barriers establish points of distortion in such fundamental flow processes and hinder the overall planning function.

A factor of ever increasing importance is the requirement for the decision maker to study and know the environment in which his organization exists and functions. His knowledge of the environment may help him identify uniquely relevant phenomena and relationships, calculate the relative stability of such phenomena, evaluate the range of expectancy of each phenomena, and establish methods by which he can measure the tendencies of such phenomena and thereby more adequately supplement his intuition and his past experience.

To meet the need expressed in part by the factors mentioned above, the use of techniques and methods of analysis of different kinds have been advocated by some authorities in the planning field and in other fields. Glenn W. Ferguson has written the following:[2]

> "Traditionally we have assumed that certain individuals are endowed with the innate ability to make 'good' decisions. We have accepted the stereotype that it is not feasible to teach a potential administrator 'how to make decisions,' but at the same time, we are aware of the multiplicity of factors which must be considered in the contemporary decision-making process. It was possible for yesterday's planner to appraise the relatively limited number of alternatives, to react intuitively, and in the majority of cases, to render the 'right' decision. In contrast, the planner of tomorrow may discover that the attributes of 'good sense,' intuition, and practical experience are inadequate to cope with the complexity of modern urbanism. He will be expected to appraise a mushrooming maze of confusing, complicated, conflicting and interrelated facts and concepts before reaching a decision. He will be asked to understand the seamless web of jurisdiction, the changing mores of a dynamic urban population, the impact of mass and rapid transit, and a hundred other

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[2] Simon, H., "Decision Making and Planning," in H.S. Perloff, Planning and the Urban Community (Carnegie Institute of Technology and the University of Pittsburgh Press, 1961) p. 192.

> profundities. Time will be of the essence, the margin of excusable error will be reduced, and the planner will become the focal point upon whom more than 70 percent of our population will depend for intelligent leadership. In this labyrinth, is it not reasonable to assume that the planner will expect and require assistance in meeting the decision-making challenge?"

It is to this question that the focus of attention has been drawn in the preceding chapters. Techniques and methods of analysis have been described and linked to examples of applications which appear to have a potential usefulness for the urban planning decision maker. The techniques and methods covered are, of course, not the only ones that are applicable to planning, and it may be found that some of those included will prove to be of marginal use. However, the main point that is contended is that the decision maker in urban planning should consider the usefulness of analytical aids in approaching the increasing complexity and diversity of contemporary and future urban decisions. If it is not feasible to formally use such analytical aids, the basic formulation of problems into a decision-oriented structure basic to a specific technique or method of analysis, may provide the analyst with the insights into the full range of the problem and thereby increase his inclination to consider the total problem. The <u>need</u> of developing measures of assistance for making decisions is only a part of the issue; techniques and methods of analysis provide a significant <u>opportunity</u> as well.

The opportunity for the urban planner to meet the decision needs imposed by the character of the urban environment is subject to his capacity to deal with variables or states of nature. The probabilistic nature of events concerning planning functions, the multi-dimensional nature of planning problems, the measurement and interrelationships of these problems, the discontinuity and the alternatives posed by the problems, and the predictions necessary for the determination of change are some of the variables the decision maker must cope with in working out his decisions. The opportunity involved might be considered in two ways. First there is the opportunity of considering some of these variables as a part of the problem structure, thereby adding dimensions to the probable decision formulation. The second opportunity is that of utilizing some technique of analysis, possibly developed in another discipline for a different but similar problem, for arriving at a more complete and thorough basis for dealing with the pertinent variables of the problem. If the application of a tool of analysis is pertinent to a decision problem, the utilization of the tool may give the key to fully developing the decision framework. It may also be that the outcome, while not being altered by the use of the tools, will be handled with more assurance because of the validation of the outcome by the analysis.

The increased usefulness of tools of analysis in business and in other areas seems to have direct implications for urban planners. This is pointed out to some extent in an article written by a systems engineer:[3]

> "Current research activities in the control engineering field points toward the increasing combination of computer and control technologies, particularly in the extension of the concept of adaptive control to more and more elaborate systems. Similarly, considerable effort is being devoted to the planning and design of global communications networks in which real-time operation is strongly dependent on decisions provided by digital computers. At the same time, the use

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[3]Amara, R.C., "Systems Engineering: Its Principles, Practices and Prospects," in J. Peschon (Editor), Disciplines and Techniques of Systems Control (New York: Blaisdel Publishing Co., 1965) p. 342.

> of geographically distributed data gathering devices, interconnected to regional or centralized decision making centers for the purpose of control of passenger space, air traffic, inventories, etc., are growing rapidly in business, industry, and government. In a very real sense, then, the era in which computers, control systems, and communications networks are being employed to operate in a highly integrated and interdependent fashion is practically here. During the next decade the enormous advances that will be made in their application will leave few areas untouched."

Some planners have expressed concern over the systematic and more rational approach in dealing with planning situations. However, even they must admit to the increasing complexity surrounding strategic decisions and to the need for making decisions consistent with the parameters and variables involved. The problem of striking a balance in making these decisions revolves around two issues.[4] The first of these springs from the fact that in all work of this kind there is a reciprocal relationship between method and tools on the one hand and content on the other. Many consultants who are highly skilled on the technical side lack substantive knowledge of planning and urban problems, and consequently must, to some extent, be educated as to the content of the work. On the other hand, traditionally trained planners and urban analysts are familiar with the problems but not the techniques, and must be educated in them.

Concern and conflict at times seems to be stimulated because it is not made explicit what function the analytical tools are concerned with. It is possible to make highly systematic objective decisions within pre-

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[4] Harris, B., "Organizing the Use of Models in Metropolitan Planning," a paper prepared for a Seminar on Metropolitan Land Use Models at Berkeley, California, March 19,20, 1965, p. 19.

scribed areas. But while systematic decision techniques are highly useful tools within those areas, they do not make good decisions by themselves any more than good saws, planes and chisels turn out a good cabinet. The decision techniques do not themselves set goals, determine the scope of the decision, formulate the alternatives in the set, (though they may help discover some alternatives) determine the weights for different kinds of costs or values, determine which decision technique to use, or determine whether information is worth its costs. Systematic decision techniques can thus assist decision makers, but never supplant them.

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