THE PLANNING PROCESS

AND ITS FORMALIZATION IN COMPUTER MODELS

James C. Emery, Assistant Professor

January 1965 No. 108-65

Paper delivered to the
Second Congress on the Information System Sciences
Hot Spring, Virginia, November 22-25, 1964
Revised January 1965

This study was supported in part by a grant to M.I.T. from the National Aeronautics and Space Administration. Computer time and programming assistance is being provided by M.I.T.'s Project MAC. I received valuable comments from a number of persons. Especially helpful were those from my colleagues, Billy Goetz, William Pounds, and Zenon Zannetos; and from Norman Waks and Frank Carr.

TABLE OF CONTENTS

role

Carroll (Bowman

Zannetos

Zannetos

THE PLANNING PROCESS AND ITS FORMALIZATION IN COMPUTER MODELS

ABSTRACT

This paper attempts to provide a conceptual framework for designing computer planning models. Planning is viewed as a sequential, hierarchical, and iterative process. Each level in the hierarchy involves essentially the same five-step planning sequence: 1) determine planning data; 2) propose alternative plans and generate their consequences; 3) select the best alternative analyzed; 4) translate the plan into a form for lower-level planning; and 5) control the plan. Planning at each level is subject to constraints imposed by the organizational structure and goals, resources and information available, and various forms of programmed behavior. Efforts to improve the planning process (and hence plans) must act primarily through these planning constraints. The role of computers in planning is examined in light of these concepts. It is concluded that a formalized computer planning model will, like all planning, have a hierarchical structure. Planning with such a model will involve a man-machine search through the hierarchical space of alternative plans.

1. INTRODUCTION

Planning is a universal component of management. And yet, to a considerable extent, it is not well understood by those who practice it. Many managers fancy themselves men of action, and view planning as an "unproductive" paperwork activity. In fact, however, it is through planning that a high-level manager can exert the greatest influence over his organization.

Although there persists a general lack of appreciation of the planning function, considerable progress has been made in gaining a better understanding of its role (Goetz, 1949; Newman, 1951; Koontz and O'Donnell, 1964). We have also witnessed in recent years great strides in the allied field of organization theory (Barnard, 1938; March and Simon, 1958; Cyert and March, 1963). The progress made in these more traditional areas of management has been accompanied by an explosive expansion of knowledge in related theoretical

fields. Developments in cybernetics, systems theory, and decision theory have provided extremely valuable insights into the planning and control process. Concurrent advances in information technology now make it economically feasible to manipulate vast quantities of data.

Despite this substantial progress, our understanding of organizational planning and control remains far from complete. We are victims of a cultural lag: Advances in the traditional and technical fields have not been sufficiently amalgamated to form a unified theory of planning. The lack of such theory accounts, in part, for some of the difficulties that have been encountered in applying information technology in organizations.

I have attempted in this paper to achieve a synthesis of the fields related to planning. In doing so, I have borrowed shamelessly from both traditional and theoretical literature. Accordingly, much of what I have written is not especially new, a fact I have tried to indicate by a profusion of references to past work. On the other hand, I would like to think that the resulting conceptual model--I hesitate to dignify it by the term "theory"--does provide a new and useful way of viewing the planning process.

The construct that I propose is intended to characterize any planning process, whether it involves elaborate formal procedures or very informal methods. It does not, however, provide a descriptive model that predicts or duplicates the behavior of a planner. Even less does it furnish a normative model that tells a planner how he _ought_ to make planning decisions.

The construct is intended to give deeper insight into the fundamental nature of the planning process. A designer of an improved planning system should approach his task with a clear viewpoint about the role of planning. The "model" that represents this viewpoint must meet two tests.

First, it must somehow provide a useful set of abstractions that facilitate thinking about the planning process. In order to do this, the model should be general enough to encompass all forms of planning, and it should be concise enough to become a ready part of the designer's vocabulary

of thought. Such a model makes it easier to perceive an over-all rationale behind the complex network of planning that takes place within any organization. In the absence of this point of view, each planning task appears as a special case rather than as part of a unified whole.

Second, the model should incorporate the best of the traditional wisdom about planning. Good planning practice should be capable of being explained or justified in terms of the model. The model should also be consistent with available theoretical knowledge.

I have tried to satisfy these criteria in developing a construct of planning. Although the model is necessarily abstract, certain practical ends motivated its construction. I am interested eventually in implementing formalized computer models to aid the planner, and the first step in doing this is the development of a suitable "world view" about the process. After describing the conceptual model of planning, I go on in this paper to outline a form that a computer planning system might take. However, my comments about implementation are, I must confess, mostly of the arm-waving variety, and only suggest a direction for further research.

2. THE ROLE OF PLANS

Planning has been given a variety of meanings. In its broadest sense, it is "deciding in advance what is to be done" (Newman, 1951, p. 15). Defined in such sweeping terms, planning necessarily precedes all action, if only in the mind of the person performing the action. Although the conceptual model described later is quite general, this paper deals primarily with relatively <u>formal</u> planning that involves the explicit evaluation of alternative courses of action, selection of one of the alternatives for execution, and formal communication of the decision to interested persons throughout the organization.

A great many different types of activities fall within such a definition. Among them are the design of the organizational structure and goals, selection of resources, specification of policies and procedures, budgeting, and detailed

scheduling (Goetz, 1949, p. 2). All of these varied activities together comprise the planning network by which the organization governs itself.

A plan constitutes the output from any planning process. Thus, organizational goals, policies, strategies, budgets, procedures, rules, programs, and schedules represent various forms of plans (Koontz and O'Donnell, 1964, pp. 74-78). The purpose of a plan is to bring about behavior that leads to desired outcomes. In order to do this, a formal plan must (1) describe actions and outcomes, and (2) serve as a formal vehicle of management. I will examine both of these in some detail.

2.1 The Plan as a Description of Actions and Outcomes

The planning and control function of an organization plays the role of central nervous system, and plans represent the "messages" by which the system communicates among organizational units. The form of communication may vary. A plan may continue in effect until explicitly rescinded or modified, and is then evoked under specified conditions or by a higher-level plan. Goals, policies, procedures, and "standing plans" (Newman, 1951, p. 18) have this characteristic. They represent continuing performance programs (March and Simon, 1958, pp. 141-150) by which higher-levels in the organization govern lower-level behavior. Their continuity increases the stability of the organization, and thus makes it easier for one subunit to predict the behavior of another (including the behavior of its own lower-level subunits).

On the other hand, *ad hoc* plans may be devised to describe behavior over a specified planning horizon. Project plans and periodic budgets and schedules are examples of these "single-use" plans. Occasionally it may be necessary to formulate two or more alternative "contingency" plans, deferring the choice of the specific alternative to execute until additional information is available (such as the strategy followed by a competitor or opponent). However, the added cost of generating multiple *ad hoc* plans is justified only in those cases in which plans cannot otherwise be formulated and disseminated within the required response time.

Sometimes it is advantageous to express a plan in a functional form in which the values of certain variables are initially left unspecified. For example, a "variable" budget might define overhead cost as a function of production quantity. Once the functional relationship is established, the determination of a specific plan involves merely the evaluation of the function when the values of the unspecified variables become known. This scheme offers the double advantage of drastically reducing planning response time and lowering the cost of repetitive planning. The functional relationship need not be formulated again until a significant change occurs in the underlying conditions on which it is based.

A plan may be quite specific, leaving very little discretion to those responsible for its execution. It may, on the other hand, merely provide loose guidelines, or it may prohibit or require only certain actions. The latter type of plan is illustrated by a policy that requires the purchasing department to maintain alternative sources of supply.

Plans, like computer programs, may be expressed in either procedural or declarative form.* A procedural plan specifies a step-by-step sequence of actions that presumably will lead to a known (and desired) outcome. Alternatively, a declarative plan only specifies a desired outcome, and leaves to those executing it the responsibility for choosing the sequence of actions necessary to achieve it. Often the same plan has both procedural and declarative aspects.

Whatever its form, a plan is described in terms of variables. A manufacturing schedule, for example, may be described in terms of units of production, manpower levels, and costs. The variables provide only an

---

*Procedural and declarative descriptions correspond, respectively, to process and state descriptions (Simon, 1962, p. 479) or to activity and product specifications (March and Simon, 1958, pp. 144-146).

abstract representation of planned behavior. This is particularly true of high-level plans dealing largely with gross aggregates. But even in its most detailed form, a plan specifies an extremely sparse set of variables out of the infinite set possible.

The specification of a given plan consists of placing values on its variables or establishing its functional form. Independence obviously does not exist among all of the variables and relationships that could be used to describe a plan. The choice of the decisions that are treated as independent is essentially arbitrary, and depends to a considerable extent on computational efficiency and on how the planner* chooses to express his decisions. Those decisions used for this purpose will be called <u>decision</u> variables. All other variables used to describe a plan will be termed <u>outcome</u> variables. The value of an outcome variable is implied by the choice of the decision variables.

These notions can be illustrated by an inventory control example. A given inventory plan may be described by such variables as the aggregate inventory investment, the planned stockout probability, and the imputed interest rate on funds invested in inventory. Once an algorithm has been specified for determining inventory decisions (constituting a higher-level plan), the stockout probability and imputed interest rate can be treated as decision variables. The resulting aggregate inventory investment represents an outcome variable. If, on the other hand, an algorithm exists for allocating aggregate inventory among individual items (see, for example, Emery, 1960), then aggregate inventory can be treated as a decision variable

---

*I use the term <u>planner</u> throughout this paper to describe the person having decision-making authority for planning at a given level in the organization. The planner may, of course, be assisted by a staff, and in practice it may be difficult to pinpoint the real locus of decision making due to a certain amount of diffusion of effective authority.

and stockout probability as an outcome variable.

In [illegible] a plan, the planner naturally tries to use a set of decision variables that will lead to satisfactory organizational behavior. The variables ignored are assumed to be irrelevant, insignificant, or implied by the accomplishment of the decision variables. (Significant variables may be simply overlooked, of course.) For example, meeting a production schedule defined in terms of units completed may imply satisfactory performance in terms of stability of employment, delivery performance, and inventory level. The decision variables must close "loopholes" sufficiently well that achievement of the defined plan will in fact have desirable consequences. Ordinarily this requires the specification of plans in physical units, cost units, and units that measure capital investment (Goetz, 1949, pp. 92-115).

The planner must guard against treating as a decision variable that which is implied by the choice of other variables. For instance, the planner in the previous illustration cannot simultaneously specify aggregate inventory level and stockout probability. Unless he just happens to choose consistent values, such a plan would prove infeasible. Under these circumstances, something must give: either the plan as described by the decision variables will not be achieved, or it will be achieved at the expense of some other variables (inventory reordering cost, say). Unfortunately, the complexity of organizational planning often makes it extremely difficult to determine the extent to which the value of one variable is implied by the choice of others.

Outcome variables provide a means of characterizing the consequences stemming from a given choice of decision variables. The planner may be interested in a vast number of different outcome variables, each of them furnishing a different view of the same underlying plan. A five-year corporate budget, for example, might be described by such outcome variables as profit, return on investment, sales, production, and the ending balance of current assets for each of the years included in the total budgeting

span. One outcome variable may be a function of other outcome variables--an aggregation of different cost classifications, say, or the discounted present value of similar costs incurred in different time periods.

If the planner does not know the relationship existing between two outcome variables, he might wish to describe a plan in terms of both, even though one is clearly subsumed under the other. For example, profit and the inventory stockout rate of finished goods might both be used as outcome variables, although presumably the latter is of no inherent interest except insofar as it has some (generally unknown) effect on long-range profit.

If it is feasible to do so, the description of a plan should recognize the fact that most outcome variables cannot be predicted with certainty. An outcome might, for example, be defined in terms of a confidence interval or a probability distribution, rather than by a single value. Unfortunately, the determination of such probabilistic variables can add enormously to the cost of planning and control. Often it is necessary to treat the world as though it were deterministic, leaving to the planner the task of compensating for uncertainty.

A decision variable such as aggregate inventory may have intrinsic interest in its own right, as well as serving as a description of controllable behavior. The complete description of an alternative should therefore include both decision and outcome variables. In most cases, of course, the simultaneous display of all relevant variables would be awkward and confusing. The important factor is not what _is_ displayed, but what potentially _can be_ displayed. Ideally, the planner should be able to call out selectively for display those variables in which he is currently interested.*

---

*Conceptually, it is often useful to think of a network of plans described in matrix form. Goetz (1965), for example, uses such a format, in which cost and revenue classifications are listed in one dimension and time periods in the other. The programming system for the Office of the Secretary of Defense (1962, pp. II-5 - II-9) uses a similar conceptual display of plans, in which physical or dollar resource inputs represent one dimension of the array and outputs (expressed in terms of _program elements_, or units of military force such as Minuteman squadrons) represent the other dimension.

2.2 The Plan as a Formal Vehicle of Management

A plan not only describes desired behavior, but it also serves as a formal vehicle for guiding lower-level activities and communicating throughout the organization. With this philosophy, the act of choosing a plan (or, equivalently, approving one proposed by a lower-level unit) constitutes one of the most important functions of management.

Upon approval, a plan becomes part of a network of plans that serves as the basis for execution and coordination. Any significant addition, deletion, or modification of a specific plan should be effected only through the same official approval mechanism that first authorized it. Failure to do this may rob the plan of its integrity and thwart the objectives of the original planner. This concept is very much in evidence in the programming system of the Department of Defense.

In order for the approved plan network to play this central role, it must be based on the best current predictions of future events (within allowed error tolerances). This, in turn, calls for a control system that takes periodic samples of actual events and compares them with the predictions on which the current plans are based. If a significant deviation occurs, the control system signals the need for new planning that takes into account the most recent available feedback information about the environment. With such a control system to "close the loop," planners at all levels in the organization can look to the latest plan network as a reliable source of information for execution and further planning.

Management under these circumstances can largely focus on the planning process. Far from being just a sterile paperwork or bureaucratic activity, planning should provide the basic means of directing the behavior of the organization. It is not exaggerating too much to view a high-level manager as a planner who lives largely in an analogue, abstract world involving the predicted future. He is affected by the real world only to the extent that its essence is captured in his analogue planning world. The planner, like the brain (Bishop, 1960), is forever cut off from the world "out there," and

can only perceive things through highly filtered information channels.*

3. THE SINGLE-LEVEL PLANNING PROCESS

A plan that guides behavior in an organization constitutes the output from a planning process. A given plan may be ephemeral, but the process that generates it tends to persist for a relatively long time. For example, basic changes may occur very infrequently in a planning system that generates weekly production schedules. Modification of a planning process has a more fundamental and lasting influence on the organization than does direct modification of its output. Understanding the planning process is therefore an obvious prerequisite to gaining insight into the way in which an organization can improve its behavior.

Conceptually, the steps involved in a planning process are largely independent of the level in the organization where the planning takes place. To be sure, the scope of the process varies greatly with level. High-level processes deal with aggregate variables extending over relatively long time

---

*John W. Gardner (1964, pp. 78-79) views formal information systems with some suspicion. Raw data are "sampled, screened, condensed, compiled, coded, expressed in statistical form, spun into generalizations and crystallized into recommendations" before reaching high-level planners. In the process, "emotions, feeling, sentiment, mood and almost all the irrational nuances of human situations" are filtered out, and therefore the information cannot convey what is really going on in the world.

The danger certainly exists that a high-level planner will not be provided relevant information about the world. But the real world is a very complicated place, and a high-level planner inevitably perceives it in an exceedingly abstracted form. This is true whether he obtains the information through firsthand observation or through a formal information system. Such a planner faces a world of vast scope, and therefore he must rely primarily on a formal information system to filter out "noise" and less important data and to provide an abstraction of the real world that preserves essential information about significant events. From the standpoint of information gathering, visits by the planner to the "front lines" can only furnish a small sample with which he can verify information provided by the formal information system. (But personal contact with lower levels in the organization serve other purposes besides information gathering, of course.)

intervals, while low-level processes deal in much finer detail. High-level planning, such as the determination of corporate marketing strategy, is typically much less clearly defined and structured than low-level planning involving, for example, the determination of production schedules. Nevertheless, the similarities, rather than the differences, best characterize the planning process at all levels.

Planning is an enormously complex process, and so defies any simple scheme for describing it. Much of its complexity stems from the hierarchical nature of planning, in which plans at one level impose constraints on planning at lower levels. Before going into this matter in more detail, I shall consider first the steps involved at a given single level in the total hierarchy.* The following sequence of steps is admittedly somewhat arbitrary and largely ignores the iterative nature of planning, but it at least describes the essential character of a single-level process.

3.1 Determine Basic Planning Data

The first step in planning is to determine the values of the basic data to be used. These planning data (or planning _factors_ in military terminology) constitute the "building blocks" from which plans are generated (Goetz, 1949, pp. 92-115).

The nature of the "basic" data depends very much on the level of the planning process. Basic data for a low-level process may be very detailed indeed. For example, a planner in a maintenance department might formulate his budget using such data as the costs of various types of supplies and the wage rate of different grades of labor. Basic data for high-level planning, on the other hand, are typically quite aggregated. A manufacturing division, for instance, might budget maintenance costs on the basis of a ratio of past costs to total dollar production.

---

*Manheim (1964, pp. 18-19) uses the term _single-level operator_ to describe the planning carried on at a given level.

Often basic planning data at one level are derived as a result of more detailed planning at lower levels. For instance, a figure for the average wage rate used in corporate planning may be derived from a detailed lower-level analysis. The data can also come from higher levels as a result of their planning--a sales forecast imposed on a manufacturing division, for example.

Basic planning data are not mere "facts" retrieved from the organization's data base. Facts are always historical, and planning involves the future. To be sure, the future can only be predicted on the basis of information about the past, but the transformation of historical data into predicted values of planning data may involve a complex series of operations. For example, an elaborate regression analysis might be used in sales forecasting. Sometimes past data call for "normalization" in order to wash out the effects of non-standard conditions prevailing in the past. The determination of planning data might also require what amounts to a policy decision, as in the case of the specification of an allowed scrap rate used for budgeting a manufacturing operation.

Any prediction is, of course, subject to error. In some cases the potential error is slight or insignificant. Under certain other conditions, the planning process is such that an unbiased estimate of the mean of a planning datum can serve as a <u>certainty equivalent</u>, even though the estimate is subject to considerable uncertainty.* When random variability

---

*In general, the available alternative that leads to the best expected results in the face of uncertainty is <u>not</u> the same one that would be selected if unbiased mean estimates of all planning data are used in evaluating alternatives; only under special circumstances are the decisions the same (Theil, 1961, pp. 414-424 ; Bellman, 1961). However, even if the necessary assumptions are not fulfilled, many "routine" decision processes tend to be relatively insensitive to the substitution of mean estimates for random variables. Conway and Maxwell (1963) and Muth (1963) discuss this issue in connection with job shop scheduling.

in estimates is either insignificant or irrelevant to decision making, the information system need only provide unbiased point predictions. This greatly simplifies the problems of data storage and computation connected with the prediction process and the subsequent use of the predictions in planning. If point estimates are not sufficient, the information system must provide additional data about variability in the form of interval estimates, estimates of variance or other parameters of probability distributions, or conceivably even a complete history of individual events.

Once planning data have been determined, their predicted values remain in effect over the prediction span or until feedback data from the control system provide clear evidence that the predictions are in significant error. Thus, feedback data are not used directly in planning, but only indirectly through the prediction process. The prediction process, in turn, filters much of the noise contained in the feedback data, and thereby stabilizes plans.

3.2 Propose Alternative Plans and Generate Their Predicted Outcomes

The second step in planning is the manipulation of the basic planning data in order to determine the consequences of proposed alternative plans. Each plan proposed by the planner is described by means of its decision variables, and the consequences stemming from these decisions are described in terms of outcome variables.

The transformation of decision variables into outcome variables requires some sort of model. This is true whether the planner uses a formalized model--expressed perhaps in the form of mathematical equations or a computer simulation program--or informal, "back of the envelope" methods. In every case he must rely on an abstract representation of reality (Craik, 1943, p. 61). Planning models of course vary greatly in their degree of accuracy in predicting outcomes, in their complexity and completeness, and in their formality.

3.3 Select the "Best" Alternative

From the list of alternatives proposed and analyzed in the previous

step, the planner must select the plan that appears most suitable. His choice is governed by the goals that have been assigned to him as a result of a higher-level planning process. If he has a single measurable goal, he can simply choose the plan that leads to the best performance in terms of that goal.*

Rarely does such a straightforward situation exist. Instead, a planner virtually always faces multiple goals and uncertain consequences of his actions. Under these circumstances, the decision process of the planner becomes very much more complex than merely choosing the alternative having the highest utility.**

When facing uncertainty and multiple goals, a planner cannot, in general, find a dominant alternative that is least risky and best along all goal dimensions.*** If this situation existed, it would generally be advantageous for the planner to explore more alternatives (perhaps in the "region" of the dominant alternative) in order to probe for his <u>efficiency frontier</u>, along which the improvement in one goal dimension implies a worsening in one or more other dimensions (Hitch and McKean, 1960, pp. 109-114).

Fig. 1 illustrates this concept. Suppose an inventory planner has two goals: reduce the aggregate inventory investment and reduce the stockout rate. Suppose further that he has generated alternatives A, B, and C.

---

*This, of course, will not represent the "optimum" plan unless <u>all</u> alternatives have either been considered explicitly or have been rejected by some logical means as being inferior to the set of explicitly considered plans. The true--but unknown--optimum recognizes the cost of searching for improved alternatives, and therefore rejects a stubborn hunt for the "perfect" plan.

**For brevity and consistency with economic literature, I will use the somewhat discredited term utility to describe the preference index by which the relative desirability of a plan is measured.

***Decision making under uncertainty is formally similar to decision making with multiple goals. The measures of uncertainty--probability or variance estimates, for example--constitute an additional dimension by which a plan is described.

In this case he would clearly choose alternative A, since it dominates the other two. However, further exploration might reveal alternatives D and E, which are not dominated by A and therefore call for a hard choice in trading-off improvement in one dimension at the sacrifice of poorer performance in the other.

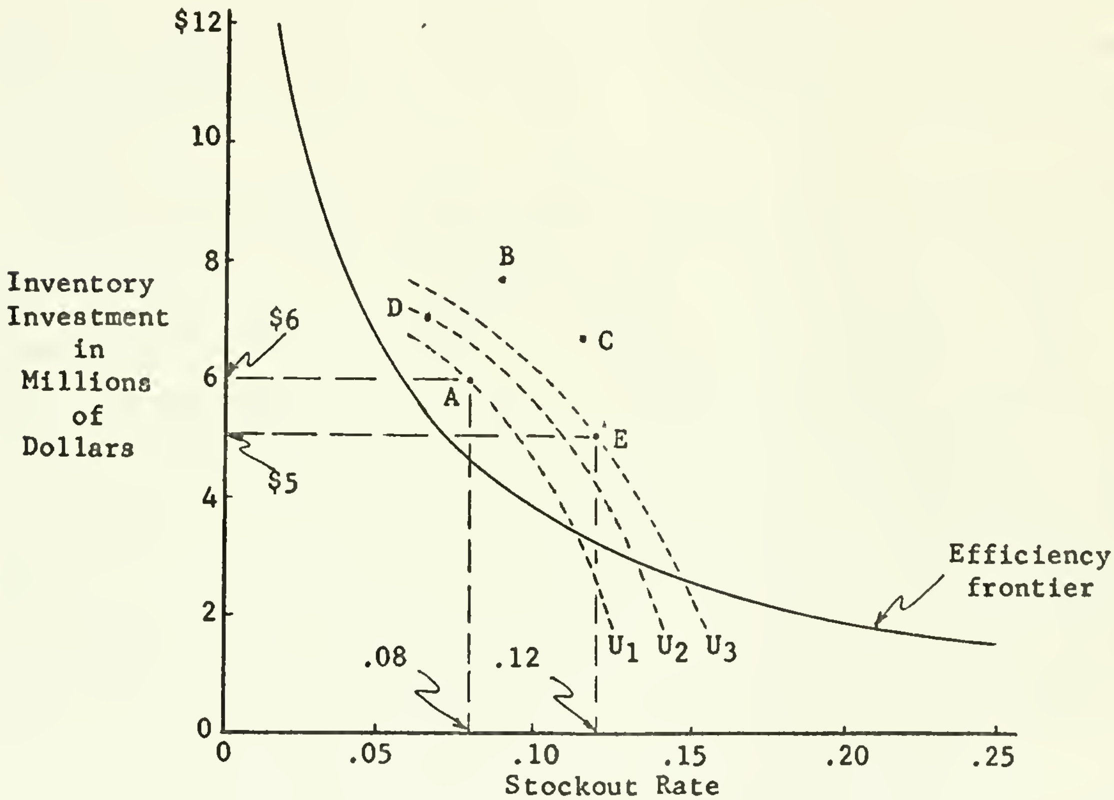


Fig. 1 - Choice of Alternative Inventory Plans

The efficiency frontier, by definition, defines the potential alternatives confronting the planner. As in Fig. 1, the frontier is generally not known, and available alternatives do not exhaust all possibilities for improvement. However, the cost of probing for improved plans may exceed the expected gain (at least in the opinion of the planner), and therefore the planner might settle for a choice among alternatives A, D and E (alternatives B and C being dismissed because of their dominance by A).

In resolving a choice that involves a trade-off among multiple goals,

the planner might specify an explicit utility (or trade-off) function that transforms all goals into a single compound goal (Klahr, 1958; Ackoff, 1962, pp. 42-44). Once this has been done, the choice becomes a trivial one: select the alternative with the highest utility in terms of the compound goal. In Fig. 1, the utility function is plotted in the form of three contour lines, U_1, U_2, and U_3, that pass through the alternatives A, D, and E. (These contours are, of course, the well-known indifference curves of the economist.) The contour line closest to the origin clearly has the highest utility, and so alternative A is the one selected out of the known alternatives available.

The specification of the explicit utility function obviously represents the critical step in the selection analysis. The function must embody the planner's "true" goals (and those of higher-level planners). In most cases these goals are extremely difficult to describe in analytical form.* A formal description would have to recognize the complex and subtle interactions that may occur among goals. For example, under normal circumstances, the survival of the organization is not threatened. The organization can thus indulge in research and development projects, improvements in the corporate image, added security and benefits for its employees, and other such future-directed goals of the affluent organization. If, however, the life of the organization (or the planner's existence within the organization) is at stake, then all other goals tend to be swamped in a single-minded quest for survival.

An attempt to develop an explicit utility may prove fruitful in guiding decisions and providing insights. However, it is unlikely to do more than that, particularly in the case of higher-level planning. The planner typically does not know enough about his utility function to formalize it completely, and he

---

*The difficulty in specifying a planner's utility function should not be too surprising. If the function could be captured once and for all in analytical form, one of the primary responsibilities of the manager would be eliminated: any clerk or computer can rank a series of single-dimensional numbers.

obviously cannot defer decisions until he does. Different goals are often hopelessly incommensurable (in the sense that no generally agreed trade-off exists among them); in this case, a spurious trade-off function suppresses information about alternative plans rather than simplifying the selection process (Hitch and McKean, p. 185).

Nevertheless, some formalization is extremely useful and, indeed, necessary in most cases. Even if all goals cannot be collapsed into a single compound goal, the number of separate goals can be reduced through the use of a trade-off function among a subset of the goals. Without this compression, the planner would be swamped with an unmanageable abundance of competing goals.* For example, in evaluating alternative aircraft designs, it may be possible to achieve a fairly general concensus about the trade-offs between various performance variables such as speed, range, altitude, rate of climb, and payload. By use of the trade-off transformation, each alternative design can be assigned a single index of performance. Similar indices might be developed for "cost" and "logistic support," say. The final choice of design is thus reduced to the comparison of alternatives described in terms of three incommensurable composite dimensions rather than a whole host of detailed dimensions.

The hierarchical aggregation of management information also illustrates the concept of goal compression. For most purposes, a particularly simple trade-off function is used: all variables within an aggregation are considered equivalent, or at most a weighting factor (dollar value, say) is applied to each of the different variables. Sales reports, for instance,

---

*Herberstroh (1958, pp. 68-69) concludes that any stable organization can deal with only a relatively small number of mutually independent goals. Schleh (1961, pp. 22 - 23) suggests no more than five separate goals should be assigned.

may be available at the lowest level by salesman and individual item. These detailed data may then be combined into state, regional, and national totals in increasingly large aggregations. The sub-totals available at each level presumably correspond to the goals appropriate to that level.

(It should be mentioned that the use of a trade-off function involves the risk of washing out relevant information. For that reason, a planner should be able to examine the components of a composite goal. Thus, the decision maker selecting an aircraft design might want to look at separate performance characteristics, and a national sales manager might want to examine the detailed sales within a region below its sales goal. The ability to trace the cause of major deviations through a hierarchical search of the details should be incorporated within any information system.)

The specification of a utility function can be made more feasible by reducing the resolution used in measuring alternatives. For example, the investment in inventory in a large company could be rounded to the nearest million dollars. Two plans might therefore differ by almost a million dollars and still be indistinguishable in terms of the inventory investment goal.

A constraint can be viewed as a special type of low-resolution utility function that distinguishes between only two values for a given goal, "acceptable" or "not acceptable." Thus, a planner might establish a constraint of $5 million on inventory; plans involving a projected inventory investment exceeding this figure would therefore be rejected. If all goal dimensions except one are constrained in this manner, the selection of a plan again is reduced to choosing the alternative having the highest rating in terms of the remaining goal. If constraints are attached to <u>all</u> dimensions, the planner follows a <u>satisficing</u> strategy and chooses the first alternative found that meets all constraints. (March and Simon, pp. 48-50 and 140-141).

The specification of constraints greatly simplifies the selection process by effectively eliminating the constrained dimensions from the evaluation of the alternatives that survive the constraints. However, the low resolution

of constraints carries the risk of failing to distinguish between alternatives that differ significantly. Because of this, a plan that is distinctly superior to its alternatives except in the constrained dimension might be overlooked because it fails to meet the constraint. If the planner were confronted with an explicit trade-off between the constrained dimension and the other dimensions, he might vastly prefer the rejected plan to all others (Hitch and McKean, p. 186). In Fig. 1, for example, a $5 million constraint on the inventory investment causes the rejection of alternative A and the acceptance of E. However, if presented with the option of a decrease in the stockout rate from .12 to .08 at the penalty of an additional $1 million in inventory, the planner might accept the trade-off and choose plan A.

Even if a planner cannot specify an <u>explicit</u> utility function, he must still make a choice among alternatives on the basis of his assignment of <u>subjective</u> utility values. By so doing, he implicitly establishes bounds on the trade-offs between goals. In the previous example, if the planner selects plan A in preference to plan E, he is implying that he is willing to increase inventory by <u>at least</u> $1 million in order to reduce the stockout rate from .12 to .08.* A trade-off decision obviously conveys less information than does the specification of an explicit utility function, but it is also much easier to make. Whenever a planner selects a given plan, he should, of course, be made aware of the trade-offs implied by his choice so that he can assess whether, in fact, the choice does represent his subjective utility function.

A subjective utility function, by its very nature, is ill-defined. It

---

*According to the explicit utility function in Fig. 1, the planner would actually be willing to increase inventory by over $2 million in order to achieve the specified reduction in the stockout rate.

is apt to change over time in response to changes in the planner's perceptions, insights, asperation level, and "judgment." Furthermore, there is no reason to suppose that the planner always assigns consistent utilities (in the sense that they exhibit transitivity).*

Regardless of how the planner assigns utilities, he may decide that none of the alternatives currently available to him is acceptable. He may therefore propose and analyze additional alternatives. He will continue to do so until he feels that the cost of further search exceeds the expected improvement in utility that it will bring (Goetz, 1949, pp. 173-175).

3.4 Translate the Selected Plan into a Form for Execution

The variables used in planning need not be the same ones employed to communicate with other parts of the organization. For example, a planner might factor variables into more detailed form before assigning them to lower-level planners. Thus, a production superintendent might factor an assembly schedule into several component schedules, and assign responsibility for each to a given foreman. (This obviously assumes that the outcome as predicted by the higher-level planning is essentially invariant with respect to the factoring.) In other cases, a planner might choose to aggregate variables before passing them down to lower-level planners. He might do this, for example, in the spirit of decentralization, relying on the lower-level planners to develop their own detailed plans constrained by aggregate variables that have been found feasible through a more detailed analysis. Regardless of how the translation is performed, however, the end result should be a clear-cut assignment of responsibility for carrying out

*Some "inconsistencies" may be more apparent than real. If the formal outcome variables do not include important but unquantified characteristics of a plan (pertaining to risk, say), then what appears to be formally "irrational" may merely reflect differences in the submerged variables. (Bowman, 1963).

every portion of the total plan.

3.5 Control of the Plan

The final step in the single-level planning process is the control of the approved plan. The control system compares actual performance against the plan, and determines the deviations that exceed control tolerances. Exception messages identify these deviations, and trigger any necessary replanning. Such planning involves the same sequence of steps used in the creation of the earlier plan. It examines the current situation anew, constrained only by higher-level plans and the consequences stemming from past actions. With an adequate control system, planning thus becomes more flexible and "continuous" rather than rigid and periodic.

The feedback information provided by the control system serves three important functions. For one thing, it encourages more realistic initial planning and closer adherence to plans once approved. Of course, the encouragement to adhere to current plans should not be so great that it causes lower-levels in the organization to stick with an outmoded plan. Nevertheless, there is ample evidence to suggest that without adequate control, planning tends to become a superficial exercise.*

Secondly, the control system guards against excessive deviations from current plans that cause a partial breakdown in coordination within the organization. As deviations grow larger, the myriad interrelated activities throughout the organization soon get out of mesh. Furthermore, the cost of getting a plan back in control (for example, by the use of overtime to recover schedule slippage) eventually may exceed the cost of replanning. The

---

*One need not search very far back within the archives of the Defense Department, for example, to discover past instances where original plans proved to be wildly unrealistic. Part of this is due to the advanced technology involved in modern weapons; but at least part of the blame rests with a system that positively encouraged over-optimistic initial plans and insufficiently discouraged cost escalations and schedule slippages. These problems have been widely recognized, of course, and many of them are currently being corrected.

tighter the control limits, the sooner deviations are detected and the earlier replanning can take place. Ideally, one would like to set control limits at the point that balances the cost of poor coordination against the cost of increasing the frequency of planning. (These costs may be extraordinarily difficult to estimate in practice, of course.)

Finally, the control system provides feedback data useful for later planning. These data are used to update the data base of the organization in order to keep it a more faithful analogue of the real world and thus provide a better basis for predicting planning data. The control system should, when feasible, identify sources of (and responsibility for) deviations from plans in such a way that continual improvement can be made in the planning process. For example, the system might distinguish between deviations caused by errors in the basic planning data and those caused by errors in the planning model.

4. THE HIERARCHICAL NATURE OF PLANNING

4.1 Factoring of Global Objectives

An organization engages in activities aimed at achieving certain overall, or *global*, objectives. A business firm, for example, may seek such objectives as a "fair" return on equity capital, "reasonable" growth and security of earnings, and a "favorable" community image. Determining a set of detailed actions designed to achieve the organization's global objectives constitutes a problem-solving task of enormous magnitude.

A problem of such complexity obviously cannot be handled as a single, monolithic task. The global objectives of the organization must be broken down, or *factored*, into more tractable subobjectives. This is done through a *means-ends* analysis that relates the desired end results--the multidimensional global objectives--to the means of accomplishing them.

The subobjectives thus generated may, in turn, require further factoring into still less comprehensive tasks. This process continues until the subtasks become manageable without further (formal) factoring (March and Simon, 1958, pp. 190-193). Each of the lowest-level subtasks is presumably linked

to the global objectives through a means-ends chain. In composite, the chains form an elaborate hierarchical structure of tasks within tasks within tasks (Newell, Shaw, and Simon, 1959).

The behavior of the organization depends largely on the way in which the hierarchical factoring is accomplished. Unfortunately, there exists no known method for doing this in any "optimal" fashion. The structure of the factoring basically rests on the notion of what constitutes a "manageable" subactivity. Fragmentation of the organization's global objectives into a hierarchy of subobjectives inevitably introduces problems of coordination, and so one would like to make each subactivity as comprehensive as the information handling capacity of the organization allows.

4.2 Planning Levels

The factoring of the organization's global objectives is achieved through hierarchical planning. Each node in the hierarchy constitutes a single-level planning process. Each of these processes is carried on subject to various types of goals and constraints. If one process generates a plan that imposes a goal or constraint on another, then the former is a higher-level planning process with respect to the latter. This definition of level is similar to Manheim's (1964, pp. 39-47). According to his definition (loosely translated), a plan at level B lies below level A if it partitions the behavior described by plans at level A into finer detail. A high-level plan can be amplified into two or more consistent but distinct lower-level plans.

(The number of alternative plans consistent with the high-level plan provides a useful conceptual measure of planning centralization: If the high-level plan imposes severe constrains that allow relatively few options, then that stage of the planning hierarchy can be viewed as being relatively centralized; if the high-level plan leaves a great many options, the process at that stage is decentralized (Emery, 1964, pp. 10-16).)

Thus, a one-to-many transformation exists between a high-level plan and its lower-level plans. It is the responsibility of lower-level planners

to perform this transformation in a way that maintains consistency between levels. If this is done, the complete set of plans throughout the organization constitutes a hierarchical description of intended behavior. Plans at all levels describe portions of the same total behavior, but the precision of the description increases as high-level plans are amplified into lower-level plans.

In the process of elaborating higher-level plans, each level in the planning hierarchy adds information to the description of intended behavior. Eventually the network (hopefully) describes desired behavior unambiguously enough to achieve the planned outcomes within reasonable limits. Even at the lowest planning level, however, plans by no means spell out every detail. Conceptually, one should continue the hierarchical planning process until the cost of additional formal planning exceeds the expected marginal improvement that it brings.

The increasing precision of specified behavior is manifested by the hierarchical nature of planning variables. High-level plans are normally expressed in terms of gross aggregate units and relatively long time periods. A high-level plan, for example, might deal in quarterly forecasts of major product lines, or--in the case of the Defense Department--fiscal year estimates of <u>program element</u> costs (e.g., Minuteman missile costs). Subject to the constraints imposed by higher-level plans, each level in the planning process typically breaks down higher-level variables into more detailed variables that extend over shorter time intervals. Thus, a quarterly product line schedule may be amplified into weekly schedules of individual items, and program element plans are expanded into much more detailed <u>program authorizations</u>.

A high-level plan can constrain lower-level planning in three ways: 1) through goals; 2) through basic planning data; and 3) through procedures. The specific way in which a constraint impinges on planning depends somewhat on the computational procedures used by lower-level processes. For example, an aggregate inventory level set by a high-level planner can be treated as a parameter in a procedure for allocating inventory subject to an aggregate

constraint. If the inventory level cannot be handled conveniently as a parameter, it becomes a goal that the lower-level planner considers in selecting alternative plans.

4.3 Determination of the Goal Hierarchy

The process of factoring global objectives creates a hierarchy of subobjectives that establishes the basic "charter" of each organizational unit. A manufacturing department might, for example, be assigned responsibility for manufacturing operations, purchasing, and industrial engineering; while the sales department is assigned responsibility for marketing and distribution.

The factoring of global objectives continues until a complex hierarchy of goals is created (Granger, 1964). One aspect of the hierarchy is associated with the authority structure of the organization. Each planner throughout the organization is assigned certain goals that are designed to induce behavior consistent with higher-level goals (and hence, through recursion, with the global objectives of the organization).

The hierarchy also has a time aspect. The basic objectives of each organizational must be factored into a hierarchy of goals that are increasingly more definitive and shorter term. In generating these goals, the planner at each stage is constrained--or perhaps "guided" would be a less negatively loaded term--by his longer-range goals. For example, the basic (but rather ill-defined) objectives of the manufacturing department provide a guide for the generation of its "long-range" plan that, in turn, constrains the preparation of its annual budget. The "constraints" imposed by longer-range goals may be loose and subject to revision, but it is difficult to see the purpose they serve unless they play a definite role in the generation of shorter-term goals.

4.4 Generation of Multidimensional Goals

As mentioned earlier, the goals generated at each stage of the factoring process are normally multidimensional. There are three principal reasons for this. In the first place, compression of incommensurables reduces the information content of the goals assigned to lower-level planners. Unless there

exists a general concensus about the trade-off between goals--one that is acceptable for purposes of all lower-level planning and control--then an arbitrary trade-off function suppresses information that lower-level planners should have in formulating their own plans. The incommensurable goals facing a high-level planner must therefore normally be passed down to lower-level planners in some translated multidimensional form. The incommensurable global objectives--dealing with profit, esthetics, and morality, say--thus tend to trickle down through the goal hierarchy.

Suppose, for example, that a plant superintendent is assigned the goals of reducing costs and preventing accidents. He naturally wants to assign goals to foremen that will lead to the accomplishment of his own goals. Conceivably, he could collapse his two goals into a single-dimensional cost goal by assessing a penalty charge for any accidents that occur in a foreman's department. However, it is unlikely that a generally agreed value could (or would) be placed on each type of accident, and an attempt to do so would blur rather than clarify the planning task of the foremen.

Secondly, multiple goals are often used as an approximation for a single "real" goal that cannot be measured in practice. Business profit provides an example of such a goal. The determination of real profit as the economist defines it requires the calculation of the present value of the firm at the beginning and end of the period over which profit is being measured (Alexander, 1962). This, in turn, requires a knowledge of future cash flows and a suitable discount rate. Such a goal provides little guidance for making most short-term planning decisions. In order to make the profit goal more operationally useful for lower-level planning, it must be translated into multiple substitute (or <u>surrogate</u>) goals that hopefully induce behavior consistent with the "real" goal.

Accounting "profit," for example, provides an operationally measurable approximation to real profit through a process of matching the revenues and costs associated with a given activity. This matching typically requires a great many essentially arbitrary allocations of costs and revenues

among different accounting classifications and time periods. Nevertheless, the conventions used for this purpose offer reasonably well-defined and operational procedures for calculating "profit."

Profit defined by accounting algorithms depends primarily on past costs, and therefore may be inconsistent with future profits. In recognition of this fact, managers are typically held accountable for subsidiary goals other than just accounting profit. For instance, each planner may be assigned certain "position" or "ending status" goals--Likert (1963, pp. 61-62) uses the term "intervening variables"--expressed in terms of such variables as market participation, product development expenditures, cost reduction targets, and employee turnover. These multiple goals are designed to measure the position (or "salvage value") of the firm at the end of the period for which profit is being determined. By means of these goals, the planner receives an early reading on the status of the organization--its ability to generate future profits--and therefore he need not wait until the future reveals the effects of current decisions. Subsidiary goals thus provide a feedback loop having a much shorter time delay than an "end result" goal such as profit* (Ashby, 1956, pp. 221-225).

Finally, multiple goals are sometimes generated as a means of coping with interactions among the subunits of an organization. It is often not possible to devise a single goal that embodies all of the relevant factors and interacting effects that a lower-level planner should consider in

---

*Position variables used as organizational goals serve the same purpose as they do in certain other types of problem-solving situations. For example, in the game of checkers or chess, the astronomical number of alternatives precludes an exhaustive tracing of every chain of moves to the completion of the game. Instead, the player (or a heuristic program) traces a selected chain of moves until he encounters a relatively stable position. He must at this point assess the relative merits of the resulting position in order to evaluate the sequence of moves that led to it (Samuel, 1959).

selecting a plan among the alternatives available. It may therefore be necessary to use multiple goals in order to convey sufficient information about desired behavior in the face of interactions.

Suppose, for example, that the president of a company wishes to assign goals to the vice-president of manufacturing that will lead to a satisfactory accounting profit. Certainly a single-dimension profit goal cannot be used, since he shares this responsibility with other departments.* Even though the manufacturing department may be primarily concerned with costs, it also affects sales revenues through such means as product quality and stock availability. Therefore, the vice-president cannot be held responsible only for costs; he must also meet quality and delivery goals. By such means, a high-level planner can factor his activities into subactivities having goals that recognize the more important interactions (Whinston, 1962, pp. VI 33-49).

4.5 The Behavior Induced by Assigned Goals

The organization must assume that each planner will take his goals seriously by attempting to "optimize" in terms of the goals assigned him. This is true whether or not the resulting behavior in fact contributes to the success of the organization as a whole. Thus, if a sales manager is held responsible solely for sales volume, he may strive for increased dollar sales even at the expense of reduced corporate profit (by granting too many price concessions to customers, for example). A planner, like the magic genie, is apt to interpret literally; and the organization must expect to get exactly what it asks for.

(One must, of course, distinguish between <u>formal</u> and <u>effective</u> goals: the organization may adopt a set of stated goals which may or may not be the effective ones. The real goals are those that receive emphasis in the complex reward and punishment structure of the organization. A plant

---

*Manufacturing "profit" can be computed by use of transfer prices, but in most cases this requires the specification of an essentially arbitrary figure. Under some circumstances, however, "shadow" prices that reflect current marginal costs can be used as a tool of resource allocation among interacting activities (Arrow, 1959).

superintendent may profess interest in good housekeeping, but if he bases all promotions and Christmas bonuses only on manufacturing costs, then he should not be too surprised if a foreman pays scant attention to the tidiness of his department. Similarly, if a president punishes his vice-presidents for their every failure, then he will breed extreme conservatism within the firm despite any amount of exhortation about the need for initiative and willingness to take justified risks.)

The choice of goals that lead to desirable behavior is by no means a trivial issue. For most purposes of planning and control it is necessary to express goals in an operational form that permits quantification of plans and measurement of results (Haberstroh, 1958, pp. 69-70). Non-quantitative goals are, of course, also employed; but quantified goals tend to drive out, in Gresham-like fashion, all other goals. Thus, college deans may find it easier to justify faculty promotions based on the number of research publications then on the quality of teaching.

A goal may not always be amenable to quantification. "High employee morale" and "effective research" may be laudable goals, but they are difficult to measure. In such cases, the organization must resort to the use of goal surrogates that presumably approximate the real goals (in the sense that the surrogates induce behavior consistent with the real goals). For example, morale may be gauged by the number of grievances filed by the union, and research effectiveness may be measured by the number of patent disclosures.

The use of measurable goal surrogates is essential, but it also carries some obvious hazards. The variables employed may not, in fact, be closely correlated to real goals, and therefore the resulting behavior need not be desirable in terms of real goals. For example, a foreman may be induced to browbeat employees or to make under-the-table deals with them so that they will not file formal grievances, and the research director may be induced to work on trivial projects offering the sole merit of a high probability of yielding a patent disclosure. Distortions of this sort cannot be avoided altogether, but a judicious selection of goal variables can mitigate their

undesirable effects.

As a partial solution to this problem, a planner may be assigned goals having upper and lower limits. The lower limit might represent performance considered attainable with a high probability. It can therefore serve as a standard of minimum acceptable performance and as a basis for all other planning throughout the organization. A cash budget, for example, could be developed on the assumption that all units will at least meet their minimum profit goal.

The upper limit under this scheme provides a standard of superior performance--a goal the planner must stretch to reach. Performance "better" than the upper limit would not be encouraged, since the planner might otherwise be induced to devote an undue amount of resources and effort to one goal at the expense of his other goals (Schleh, 1961, pp. 32-36). Thus, an upper limit on manufacturing quality would encourage the foreman to strive for "high," but not "excessive," quality.

4.6 Hierarchical Planning Constraints

Each single-level planning process must recognize the availability of such resources as capital equipment, managerial talent, manpower, material, and energy. Instead of "congealed" physical resources, a planner may be granted a flexible resource in the form of an aggregate money constraint (which of course congeals upon use). These resources are made available through a hierarchy of earlier planning decisions. The current amount of each available resource is reflected in the basic planning data used as capacity constraints in lower-level planning.

Information constitutes the raw material for planning. Each planner is constrained not on the basis of the "true" state of the environment, but rather on the perceived state as represented in the data base available to him. The data base may or may not provide a suitable analogue of the environment; the data it contains are certainly subject to errors, delays, and transformations of varying usefulness.

Higher-level planning partially governs lower-level planning by means

of the information it makes available. For example, the organization employs uncertainty absorption--in which variables subject to uncertainty are communicated as stipulated facts--as a way of achieving some direction and consistency over lower-level planning (March and Simon, 1958, p. 165). Transfer prices provide another means for guiding lower-level planning.

Technical knowledge represents a special kind of information. Although the fund of technical knowledge is by no means completely controllable by the organization, it is certainly subject to some control through the organization's allocation of resources to research and development activities.

Performance programs of one form or another are used by the organization to govern lower-level planning. Constraints on planning can be imposed through a hierarchy of standing plans, standard operating procedures, policies, and computational algorithms (March and Simon, 1958, pp. 141-150).

4.7 Adaptation Through Hierarchical Planning

Conceptually, the hierarchy of planning can continue indefinitely. Every single-level planning process is subject to constraints of one sort or another (including the constraints implied by goals). These constraints are imposed by higher-level processes that are themselves subject to constraints. For example, the generation of an inventory plan is subject to constraints imposed by the particular computational algorithms used. The search for improved algorithms involves planning--the comparison of alternative procedures and the selection of the best one. This planning is in turn subject to constraints. An operations research group developing inventory procedures is constrained by its organizational structure, goals, resource budget, information, policies, and procedures. One can develop recursively still higher-level planning processes (procedures to change procedures to change procedures, say).

The organization can improve its behavior by making appropriate adjustments to the planning constraints through a continual process of hierarchical adaptation. The adjustments should normally be "small" in

order to increase the stability of planning. To the extent that the organization can discern the effects of changes, those adjustments that bring improvements can be continued and strengthened, and those that worsen behavior can be rescinded.

The frequency of these adjustments varies with hierarchical level. A high-level constraint--such as organization structure and goals--requires infrequent changes, while low-level procedures may be revised relatively often (Simon, 1962, p. 477). Each execution of a planning cycle provides little evidence for making changes in the process, especially in the presence of random variations. Since high-level planning ordinarily has a relatively long cycle time, changes in high-level planning constraints should be correspondingly infrequent.* The stability thus provided contributes to the predictability of behavior and allows time for persons within the organization to learn their jobs and specialize their activities (Zannetos, 1965).

The notion that adaptation comes through changes in the planning process has exceedingly important implications for management. If a manager hopes to exert a lasting and fundamental influence over the behavior of the organization, he must work primarily through planning. He should not focus attention on *ad hoc* adjustments to plans, but rather on the process that generates the plans (and with the process that generated *that* process).

5. INTERACTIONS AMONG PLANNING PROCESSES

5.1 Means of Achieving Partial Independence

The factoring of the total planning task into a hierarchy of single-level

---

*The situation is perhaps analogous to nested loops in a computer program. The loop index of an outer loop is changed less frequently than the indices of the inner loops that it controls.

processes is only justified on the grounds that it makes the global objectives more manageable; if the task were manageable without factoring, it would not be factored. In order to reap the benefit of the simplifications introduced by this fragmentation, each planning process must be largely isolated from the rest. Without partial independence, a planner would require access to detailed information about all other activities with which his activity interacts, and in effect he would have to handle the global problem.

Despite the need for independence, interactions among activities are a fact of life; they exist universally in organizations composed of hierarchical subunits pursuing a common set of global objectives. They arise through elaborate couplings of material, energy, and information flowing between units; through the allocation of scarce common resources; and through effects on a common environment. The organization must therefore find some way of coping with interactions.

The organization structure itself has a major effect on the degree of independence among subunits. In general, closely interacting activities should be hierarchically "close" to each other. For example, the foremen of the assembly and shipping departments might report to the same supervisor. This reduces the amount of coordination required across hierarchical lines, and thus partially insulates each unit from other parts of the organization.

Unfortunately, this principle often conflicts with other aims, and one must strike a balance among them in establishing hierarchical structure. For example, a project (or <u>purpose</u>) organizational structure in its purest form assigns to a single branch of the hierarchy all of the tasks, and only those tasks, connected with an independent objective. This provides a high degree of independence. Alternatively, a functional (or <u>process</u>) organizational structure combines complementary activities that serve multiple purposes--all of the electrical engineering work associated with several different development projects, for instance. A functional structure typically allows a relatively high degree of specialization, with considerable

attendant efficiencies. It does this, however, at the possible cost of assigning closely interacting tasks to different branches of the organizational tree, thereby increasing the amount of coordination required across hierarchical lines.

The effects of interactions can also be reduced by partially decoupling closely related activities. This is accomplished by the standardization of the interfaces between units (for example, by the specification of material specifications or data formats); by the use of buffer inventories to provide a short-term cushion between the rate of production of a supplying unit and the rate of consumption of a using unit; and by providing each unit with excess resources in order to increase the probability of meeting its scheduled interface output requirements (March and Simon, 1958, pp. 158-160).

Each of these decoupling devices creates greater short-term independence among subunits. This independence provides a partial cushion for the myriad random disturbances that impinge on the subunits. The organization is thus rendered less sensitive to uncertainty, since each subunit can absorb minor ripples in random variables without transmitting their effects to other parts of the organization.

Achieving greater independence among subunits obviously has a price: combining related activities may result in forgone opportunities for specialization; tighter tolerances increase manufacturing costs; buffer inventories take money to acquire and maintain; and slack resources reduce capital and labor utilization. Furthermore, significant interactions will persist despite all efforts to increase independence by means of the organizational structure or decoupling devices: complete independence is impossible to attain and expensive to approach.

In the presence of the remaining interactions, each action taken in one subunit has almost endless ramifications throughout the rest of the organization. A planner faces an impossible and costly task if he attempts to trace all such effects. Fortunately, he need not try. He can simply ignore interactions--or at least the vast bulk of them.

For example, a production planner can often schedule his department without detailed consideration of the effects of his actions on others. He relies on other planners to cope within their own departments with such unfavorable effects as varying labor requirements, machine capacity limitations, and shortages of raw materials. He thus artificially isolates himself to a considerable extent by basing his plans on the fiction that most of the interactions with the other departments do not exist. The partitioning and decoupling of the activities within the organization should be such that this fiction represents a legitimate and useful approximation of reality.

Ignoring interactions has the undeniable advantage of greatly simplifying the task of each individual planner. However, failure to consider important interactions carries the well-known (but often overlooked) penalties of suboptimization--the achievement of local subgoals inconsistent with the global goals of the organization (Hitch and McKean, 1960, pp. 128-131 and 158 and 181). A schedule that appears attractive to the assembly section may, for example, cause extreme bottlenecks in some of the subassembly departments. An obvious need exists for coordinating the activities of separate subunits in a way that recognizes such effects.

5.2 Coordination Through Plans

Coordination of interacting activities within the organization represents one of the primary aims of planning. Significant interactions must be considered in generating plans so that the resulting behavior of each unit will be consistent both with higher-level goals and with the activities of other units.

A high-level planner should recognize the more important interactions that occur among his lower-level units. For example, a plant scheduler should take into account existing capacity limitations within the various departments of the plant. In selecting a given schedule, he must try to allocate available capacity in a way that serves the best interest of the organization as a whole, rather than that of any single lower-level unit.

He may not consider the detailed ramifications of his allocation decisions, but he should at least handle the significant aggregate effects.

The result of a compromise among conflicting objectives is communicated to lower-level planners in the form of an aggregate high-level plan. If the high-level plan is a "good" one, suboptimization within the constraints it imposes introduces only insignificant penalties. Thus, communication between levels is typically confined to aggregate variables. This provides a means of recognizing important interactions, while at the same time allowing each planner to formulate his plans without considering the detailed actions of others.*

Even if it is infeasible to formulate higher-level plans that explicitly consider all important interactions simultaneously, lower-level planners should still have some information about the expected behavior of closely related units. For example, it may not be possible to determine an "optimum" plant-wide schedule, but a subassembly planner must know the assembly schedule before he can establish his own schedule. In other words, even if the magnitude of the task prevents a higher-level planner from treating lower-level actions as variables, a lower-level planner should at least formulate his own plans with some knowledge about the value of the interface variables through which he interacts with other units.

Plans in their various forms provide the basic source of information for predicting the actions of others. This is true of both standing and single-use plans. Standing plans--in the broadest sense, policies, procedures, and all other types of programmed activity--play much the same role as habit in biological organisms. They provide organizational stability,

---

*The organization constitutes a nearly decomposable system (Simon, 1962, pp. 473-477). In such a system, each component is approximately independent of other components, and those interactions that do exist largely depend on aggregate, rather than detailed, variables.

and thus increase the accuracy with which one unit can predict the behavior of another. This allows a unit to formulate its own plan based on an assumed or provisional level of activity in other parts of the organization. The plan may then require iterative modification if the predicted behavior of other units proves to be significantly in error.

Single-use plans describe explicitly the anticipated activity of the units included in the plans. They are transmitted to appropriate planners throughout the organization as a basis for their own planning. Even though the plans give only an abstract description of behavior, their precision is normally sufficient for each planner to estimate the value of his interface variables. This is so because the interactions among distinct units are generally governed by aggregate, not detailed, behavior--otherwise the activities should be combined into a single unit.

5.3 The Need for Higher-Level Constraints in Dealing with Interactions

The strong downward bias of planning in the presence of interactions suggests that the more critical issues are resolved at the higher-level planning stages, and that the success of the organization depends less and less on plans generated at lower and lower levels. If this were not the case, the lowest levels could plan their own destiny unconstrained by higher-level considerations.*

---

*In a purely competitive economy, interactions are resolved in the market place. Adam Smith's "invisible hand," acting through the price mechanism, provides the "higher-level" constraints within which each firm attempts to optimize. If significant interactions--or externalities--exist, then prices alone do not contain enough information to achieve an efficient allocation of resources (in the Pareto sense). Additional information might be provided, for example, by a central planning agency that assigns production quotas. But even if this "solution" were politically acceptable, the technical and computational problems involved make it infeasible under most circumstances.

The transfer prices associated with the movement of goods within a single firm serve an analogous role. They also suffer from the same shortcomings. Within the firm, however, interactions are likely to be relatively more significant, and higher-level planning as a means of coping with them becomes more feasible.

The notion of the relative superiority of high-level plans seemingly conflicts with a popular view that an organization's total behavior is governed by the behavior of its lowest-level units. "For want of a nail, a kingdom was lost." "The Army is governed by its sergeants." "Take care of the pence, for the pounds will take care of themselves." These aphorisms ascribe the success or failure of the organization to its lowest levels.

It is true that the behavior of the organization does ultimately depend on the composite activity at its lowest levels. However, if the organization as a whole is to achieve purposeful behavior in the face of interactions, lower-level activity must be guided by a hierarchy of higher-level planning constraints. Otherwise, lower-level success tends to be local rather than global. The want of a nail may--although it is highly unlikely--cause the loss of a kingdom, but the best way to reduce this risk is to develop an improved inventory control system. Generals may organize logistic operations; they do not serve as blacksmiths.

Regardless of an organization's commitment to decentralization, higher-level planners inevitably impose constraints on lower-level planning. They do this through the specification of organizational structure and resources, goals, policies, procedures, programmed behavior, transfer prices, and various informal and unstated requirements. These constraints are designed to induce lower-level behavior that is consistent with the means-ends decomposition of global objectives.

To be sure, planning information has an upward as well as a downward flow. A higher-level plan may seemingly be generated merely as a composite of lower-level plans. However, even in extreme cases the higher-level planner has some power of veto over the proposed plans submitted to him. This represents a potent instrument for guiding lower-level planning, as

Secretary McNamara has demonstrated.*

6. CONSISTENCY AND ITERATIVE PLANNING

As we have seen, a high-level plan inevitably imposes constraints on lower-level planning. The plans generated at the lower level in turn constrain still lower-level planning. This process continues down to the most detailed plan. It is the detailed plan that guides behavior during the actual execution of a hierarchy of plans.

A higher-level plan thus affects actual behavior only indirectly through lower-level planning. The plan induces intended behavior only if lower-level plans are consistent with it, since the lowest-level plan shapes behavior whether or not it is consistent with higher-level constraints. The organization must therefore rely on hierarchical consistency in order to achieve purposeful behavior directed toward the accomplishment of its global objectives.

Consistency must also be maintained across hierarchical lines. The interdependent nature of organizations makes it essential that significant conflicts should not arise between interacting plans. For example, the resource inputs and outputs incorporated in the plans of a manufacturing department should mesh in quantity and time phasing with the plans of the

---

*A planner with veto power acts, in effect, as a _trainer_, exercising his authority through selective _reinforcement_ of lower-level behavior. He _rewards_ a planning process by accepting its output, and _extinguishes_ a process by rejecting its plans (Minsky, 1963, pp. 426-430). This mechanism offers the distinct advantage of not requiring the higher-level planner to have detailed knowledge of lower-level activities; he must only possess a means of distinguishing "acceptable" from "unacceptable" plans. Its great disadvantage is that it may be a much less efficient method of guiding lower-level behavior than more direct intervention. With only one-bit _go_, _no-go_ information, lower-level units may move very slowly--if at all--toward improved planning. In practice, of course, additional information is provided in the form of specific requests for modifications to plans, veto messages and so forth.

purchasing, personnel, and sales departments. The generation of a set of plans meeting all consistency requirements represents one of the major difficulties of planning.

A lower-level plan may fall within the constraints imposed by higher-level plans while still conflicting with other plans outside its own hierarchy. Higher-level constraints generally allow considerable flexibility in lower-level planning. Two different plans may therefore appear equally satisfactory in terms of high-level aggregate variables, but they may differ in their compatibility with the plans of other organizational units.

One would obviously like to devise higher-level plans such that hierarchical consistency also provides adequate universal consistency. If this is not the case--if higher-level goals and formal policies, procedures, and operating plans do not induce consistency throughout the organization--then consistency must be achieved through informal means.* Universal consistency may require the specification of essentially arbitrary higher-level constraints, such as a schedule of staggered lunch periods for all units within a plant.

Consistency among plans requires realistic planning and a control system that encourages compliance with plans. Without these, no logical assurance exists that consistency can or will be achieved. Conceivably, a higher-level plan may be completely infeasible, and therefore no feasible lower-level plan can be consistent with it.

Realism in planning can be achieved in two ways. The most common approach is to generate plans that differ only modestly from previous plans formulated under similar conditions. The continuity thus provided enormously simplifies high-level planning, since it permits the formulation of plans

---

*Consistency is always ultimately achieved at the execution stage, but perhaps at unacceptably high cost--by shutting down a production line for lack of requisitioned material, for example.

with a minimum amount of information--namely, information about past performance and the significant internal or external changes that have occurred subsequently (Cyert and March, 1963, pp. 111-112). (Determining the implications of such changes may be exceedingly difficult, however.)

Unfortunately, such conservatism bars the possibility of obtaining really fundamental improvements. To overcome this disadvantage, the planner must make a more far-reaching search for improved plans. To achieve realism with this more radical approach, the planner can no longer rely principally on information about past performance; he must have access to a much larger source of information in order to determine the probable consequences of untried plans.

In order to formulate a realistic plan, a high-level planner must be able to assess the detailed implications of different alternatives. Normally, the information handling capacity available to him precludes such analysis, because otherwise it would be unnecessary to fragment the total planning task into lower-level components. He must therefore choose a plan without detailed consideration of the lower-level plans used to implement it. Thus, strategists can only assume "reasonable" performance on the part of tacticians in conformity with higher-level constraints (Starr, 1964, pp. 67-75).

Ignoring details can often lead to significantly unrealistic plans. Within the limits of his available information handling capacity, a high-level planner must therefore find a means of generating plans that consider detailed matters. This can be done most efficiently through an iterative dialogue with lower-level planners.

The iterative cycle starts with the formulation of a high-level preliminary plan. With this plan as a guide, lower-level planners propose plans which they consider realistic (perhaps as a result of proposals submitted to them by planners at still lower levels). The higher-level planner may modify such proposals, but hopefully in a way that does not do violence to their realism. The iterative process continues until "convergence" is achieved within required tolerances.

The great advantage of the iterative scheme is that it provides an efficient means of transferring planning information between hierarchical levels. On the one hand, a lower-level planner receives information by means of a provisional high-level plan. He can therefore confine his search for a detailed plan to those alternatives that appear consistent with higher-level goals. A high-level planner, on the other hand, receives information about detailed factors submerged from his view at the time he formulates his provisional plan. Upon closer lower-level scrutiny, a plan that appeared attractive in terms of the low-resolution, high-level planning model may be revealed to be unrealistic in some respect.

Often the iterative nature of planning is not made explicit. In order to generate realistic plans through an explicit iterative process, lower-level planners have the responsibility to point out unrealistic aspects of higher-level plans. If the planning system is strongly biased against an upward flow of information, the organization will end up with unrealistic high-level plans and inconsistent lower-level plans.* The lower levels may bury the inconsistencies by an elaborate shuffling of their resources, by bookkeeping slight-of-hand, or by postponing as long as possible the inevitable exception report of deviations from the higher-level plan. When the deviations finally do come to light, an inordinate amount of bureaucratic effort may go into a quest for excuses and alibis.

Budgeting in the Defense Department illustrates the concept of iterative planning. The first step in the cycle involves the specification of preliminary budget "guidelines" for each of the military services. These guidelines are not intended to impose strict constraints on lower-level budgeting, but they do reflect basic military, political, and economic policy decisions regarding

---

*The issue is of course not as clear-cut as I might seem to imply. A lower-level planner obviously has his own biases, and probably they do not run in favor of a plan that presses him too energetically. A certain amount of gaming takes place when planners negotiate. Stedry discusses some of the issues involved (Stedry, 1962).

the general level of defense activity that is to be supported.

The military services budget their more detailed activities within the loose constraints imposed by the guidelines. The resulting proposed budgets may exceed the preliminary estimate, but presumably not by an unreasonable amount. The final budget is ultimately reached through a complicated series of iterative negotiations (Burkhead, 1956, pp. 88-94).

7. GEOMETRIC INTERPRETATION OF HIERARCHICAL PLANNING

It is useful, I think, to give a geometric interpretation to planning (Sisson, 1960, pp. 113-115; Manheim, 1964). In such terms, a composite lowest-level plan constitutes a point in an n-dimensional abstract space containing all alternative plans open to the organization.* Each <u>detailed</u> decision or outcome variable used to describe a plan (including those variables used to measure the uncertainty of the plan) represents a dimension of this space.

Every point has an associated utility value, a function of the variables that serve to define the point. The mapping into the utility value is, in general, many-to-one: two or more points may be indistinguishable from the standpoint of the goals of the planner.

A high-level plan defines a relatively large set of points that are consistent with its specified aggregate, low-resolution variables. In general, not all points included in such a set have the same utility. Therefore, a high-level plan typically does not have a single utility value, but rather a distribution of values (Manheim, 1964, p. 48).

---

*The plan space does not include all "real" alternatives, but only those that can be described in terms of the abstract variables used in formulating plans.

The utility ultimately achieved depends on the way in which a high-level plan is elaborated into the lowest-level plans, and typically this information is not available to the high-level planner at the time he selects a plan. He must therefore make a choice (probably not consciously) on the basis of a subjective estimate of the probability distribution of utility values (or their parameters) associated with each alternative high-level plan. The hierarchical planning process then successively narrows down the set of points remaining in the region constrained by higher-level plans. Ultimately there remains only a single point having a single utility value (but which reflects, of course, the probabilistic nature of outcomes and the planner's attitude toward risk and uncertainty).

The point finally selected in the abstract plan space guides the actual execution of the plan. Certain actions and outcomes are induced as a result of this guidance. The control system measures these actions and outcomes, and translates them into the abstract variables used in planning. In general, the "actual" point will not coincide with the planned point, since neither actions nor outcomes will necessarily occur as planned. This should be recognized in the control system by allowing some tolerance for deviations from the plan. Thus, a deviation is treated as significant only if the actual point falls outside a region surrounding the planned point.

A simple example will clarify these geometric concepts. Suppose that an organization has a three-level planning process. The highest level fixes the "budget." Production and marketing "plans" are then generated at the intermediate level, consistent with the higher-level budget. Finally, at the lowest level detailed "schedules" are formulated to implement the plans.

Assume that plans at all levels can be described in terms of only two dimensions, "sales" and "profit." However, a lower-level plan extends over a shorter time span than the corresponding higher-level plan. Thus confined to two dimensions, we can represent a composite schedule as a point in a plane. A higher-level plan is represented by a region containing the set

of points consistent with its plan variables. This is shown in Fig. 2.*

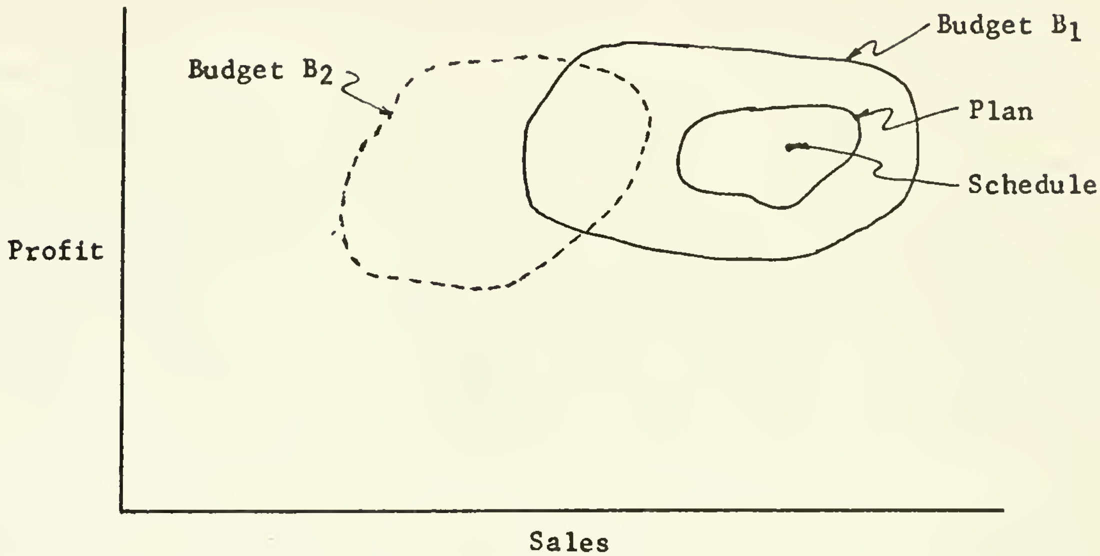


Fig. 2 - Geometric Representation of Hierarchical Planning

A given budget includes only certain portions of the total plan space. Points outside this region cannot be reached within the constraints imposed by the budget. In Fig. 2, for example, budget B_1 restricts the set of points to the region surrounded by the solid curve labeled B_1. A different budget, B_2, has associated with it a different region, the one included within the broken curve. Suppose that the highest-level planner chooses budget B_1 over budget B_2, presumably because he perceives it to include a more satisfactory set of points as measured by the distribution of utility values associated with each set.

Intermediate planning further narrows the region of alternative schedules available to the organization. In order to be consistent with budget B_1, the points included within the feasible region of the production and marketing plan

---

*Fig. 2 is similar to Manheim's representation of hierarchical planning (1964, p. 21).

must all lie within region B_1. Scheduling, the final steps in the planning process, then selects a point within the region constrained by this plan.

Consistency among hierarchical plans has an obvious geometric representation. For a plan to be perfectly consistent with a higher-level plan, it must lie wholly within the region of the latter. Therefore, a set of consistent hierarchical plans is represented by a set of nested regions and a point in the innermost region associated with the most detailed plan. A higher-level region serves merely to confine the next lower-level region, which in turn confines the next region, and so on down to the most detailed plan. It is this detailed plan that guides behavior during the actual execution of a hierarchy of plans.

Because of the aggregate, low-resolution nature of high-level planning, a high-level planner does not know the precise set of points implied by a given plan. He may, in fact, select a high-level plan that is totally infeasible, or one that has unsuspected and undesirable consequences. In general, the high-level planner cannot include sufficient information within his planning model to guard against all possibility of overlooking important factors. He must therefore rely on iterative modifications of his plan to eliminate significant distortions caused by his gross model.

The total planning process involves a hierarchical search through the organization's plan space. The highest-level planning model deals in aggregates and gross approximations, and therefore the space of its perceived alternatives is very much smaller than that of the composite lower-level models. (It is, however, still enormous and largely unfathomable.) Within this space, the high-level planner employs a sequential search in order to locate a region having a high utility (at least in terms of the variables used in high-level planning). The success of the search process rests on the usefulness of information acquired through preceding probes of the space in directing the planner to regions with improved outcomes.

The highest-level plan selected by the planner in this sequential fashion confines the next lower-level search to a tiny fraction of the total

plan space. Within this highly restricted region, the planner again employs a sequential search process to locate a still smaller region having attractive outcomes. This hierarchical process continues down to the lowest level. Each level slashes the remaining search region by a high factor, reducing the total plan space exponentially.

The hierarchical search process makes the total planning task both feasible and efficient by permitting each planner to concentrate on relatively small and independent aspects of the global problem. The use of a sequential search adds to the efficiency of the process, since each probe furnishes information useful for making further probes. The iterative nature of the process allows higher-level planning to deal with aggregate factors, on the assumption that any significant issues submerged from view of the high-level models will be revealed by the more detailed lower-level models.

8. THE ADVANTAGES OF FORMAL PLANNING

The amount of resources devoted to the planning function represents one of the most fundamental decisions facing the organization. The organization has a wide choice in the degree of formality of its planning, the detail of information handled, the approximations used in planning models, the length of the planning horizon and the number of alternatives considered at each planning stage.

The decision is a vital one. Increased formal planning can, on the one hand, lead to improved behavior directed toward the accomplishment of the organization's global goals. On the other hand, increased planning adds to the cost of data collection, data transmission, computation, and--often the most significant factor--the cost of designing the planning system. A planner must balance these two conflicting effects in establishing an appropriate system.

Virtually every organization of any size engages in some formal planning, and no organization plans everything in the most minute detail. For any given subactivity, however, a choice exists as to whether or not a formal

plan will be used. In the absence of a formal plan, an informal one is generated concurrently in "real time" as actual events take place. At the very least, some planning occurs in the minds of those participating in the activity. In the following discussion, the planning I refer to is of the formal type.

Planning represents a "dry run" of organizational activities prior to their actual execution, and can thus be viewed as a form of simulation. From this simulation process emerges a network of plans that describes desired behavior on the part of all units within the organizaion. With the plans as a guide, then, the organization carries on activities that (hopefully) result in desirable outcomes.

One must justify formal planning on the grounds that the outcomes reached by this indirect route are somehow superior to the results that would be achieved without such planning. Although the logic of making decisions is very much the same in simulated time as it is in real time, the simulated world has at least three distinct advantages. Let me examine them.

8.1 Access to Increased Information Handling Capacity

The ability of a person to manage an activity in the absence of a formal plan is severely restricted by his limited information handling capability. The relatively low capacity of his human sensory channels limits his ability to perceive the current state of the environment. His information storage is slow and unreliable. His modest computing power permits him to deal with only simple mental images of the real world. Furthermore, without a plan he is closely tied to real events, and his limited computing rate imposes a constraint on his ability to analyze a current situation: Time moves inexorably forward; it cannot be stopped to allow for additional gathering and processing of information before he must make an urgent decision.

A formal planner has available much greater information handling capacity. He is not limited to his own human facilities, but can draw upon various computational procedures and information handling equipment. As a result, the planner can develop and manipulate formal models that take into account a

great number of interacting variables. His behavior can therefore be based on a much more comprehensive picture of the world than the myopic view of the non-planner.

Because the planner lives in a simulated world, he has much greater access to essential information about his (imaginary) environment than does his non-planning counterpart. Simulated time moves as the planner directs. The time required to make a decision about a simulated event bears no relation to the time required to execute it--the two are not coupled. Therefore, a planner is constrained not by his instantaneous information processing rate, but rather by the total available processing capacity over the required planning response time.

The modest information handling capacity available to the non-planner limits his ability to make predictions about the future. The formal planner suffers from no such limitations: in the simulated world, the timing of an event can be specified. (The degree of correspondence between these simulated events and later real events is, of course, another matter, and represents the ultimate test of the usefulness of planning.) Because the planner can view the simulated future with precision, he can incorporate in a plan the earlier steps required to implement desired events. It is, in fact, the sole aim of the planner to determine current actions that are consistent with anticipated future actions (Drucker, 1964, pp. 8-9). In the absence of planning, allowance cannot be made for the lead times required to accomplish all of the antecedent steps.*

8.2 Generation of Alternatives.

The second advantage of planning is that simulated history is not irrevocable: The moving finger writes; and, having writ, may be cancelled.

---

*Experimental results in physical control systems demonstrate dramatically the importance of anticipating future actions (Sheridan, et. al., 1964).

A planner can simply discard an alternative that fails to satisfy his goals, and can continue to generate plans until he finds it advantageous to stop.

The final plan that emerges from this process must, of course, be chosen from the set of alternatives considered. Therefore, with a given planning process, the larger the number of alternatives evaluated, the better the final plan selected. The search for improved plans is subject to diminishing marginal returns, however, and eventually the cost of further search exceeds the expected gain.

8.3 Simulation in an Abstract Space.

The third advantage of planning is that it deals with an abstraction that greatly facilitates the process of searching for desirable outcomes. The variables used in planning furnish only the barest outline of the real world. The vast bulk of variables are omitted altogether or aggregated with other variables, most interactions are ignored, and functional relationships are greatly simplified. The resulting abstract model of the real world may be embodied in a formal mathematical or computer language or in such form as the conventional budgeting model.

The usefulness of these abstractions depends on the fulfillment of two requirements: First, the planner must find the abstract world somehow more congenial to formulating satisfactory plans than he does the real world; and, second, a satisfactory plan in the abstract world must translate into a satisfactory plan in the real world.

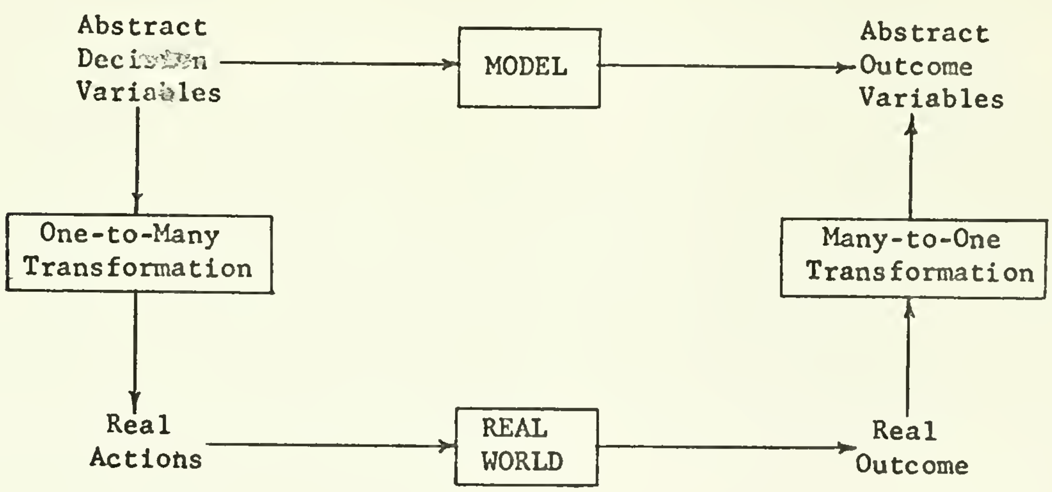
The first requirement offers no great problem. The real world is, by design, abstracted in a way and to a degree that allows the planner to manipulate the resulting model with relative ease. Within the abstract world, then, the planner searches for a satisfactory plan by whatever means seem appropriate. In particular, he might compute an "optimum" plan if his abstract model permits the application of available optimization techniques (and if it is optimal to compute the "optimum").

The second requirement presents more serious difficulties. The success of a plan hinges on whether it leads to satisfactory performance judged in

"real" terms. The planner, in developing his abstraction of the real world, attempts to achieve a close correspondence between performance predicted by a plan and the resulting behavior in the real world. Only if his model passes this test will a "good" plan necessarily lead to "good" behavior. This is by no means a simple requirement.*

The correspondence between a plan and the ultimate outcome achieved depends on three factors: the realism of the planning model used to generate the plan, the accuracy with which basic planning data are predicted, and the fidelity with which the plan is carried out.

A planning model is realistic to the extent that the transformation of decisions into outcomes, when measured in terms of the abstract planning variables, is the same in both the model and the real world. The relation between the planning model and the real world is diagrammed in Fig. 3.



* It might be added parenthetically that planning in an organization plays precisely the same role as planning in a heuristic program (Minsky, 1963, pp. 441-443). In both cases, an inductive transformation first takes

Ideally, the model should represent a homomorphism of the real world. If it does, a one-to-many transformation exists between any given plan (as described by a specific state of the model) and a set of detailed real actions that are consistent with the plan. The resulting real outcomes stemming from the alternative real actions will all have the same outcomes in terms of the variables used in the abstract model.

The second factor affecting the correspondence between a plan and the eventual real outcome is the accuracy achieved in predicting values of the basic planning data used in the planning model. Because of prediction errors, a model may provide a perfect structural homomorphism of the real world and yet fail to predict outcomes. This problem can be mitigated by increasing the accuracy of prediction through the use of more elaborate computation or by having more detailed and timely information; by maintaining a control system that quickly detects significant deviations from the most recent predictions; or, if the other approaches prove infeasible, by changing the planning model to conform to the predictability of planning data.

The outcome achieved ultimately rests on the persons responsible for executing it. Although plans are often not followed with precision, the failure often lies in the plan's imperfections and not in human perversity. A plan obviously cannot be adhered to if it is infeasible. But a feasible plan is only a necessary condition, and not a sufficient one. A plan may be "perfect," but it fails in its purpose if it is not followed due to faulty communications, poor motivation, or other management shortcomings.

---

footnote continued from p. 51

place from a complex world into a simplified model of that world. The model is then manipulated in order to find a "solution" in abstract terms. Finally, this solution is transformed back into the complex form. The transformed version of the abstract solution may or may not provide a real solution. Failure signifies that some essential characteristics of the real world were lost in the transformation.

A job shop schedule illustrates these concepts. Because of limited information handling capacity, a planner might have to use an unrealistic planning model--for example, the standard backdating scheme that implicitly assumes infinite capacity. Under these circumstances, the schedule can provide only a loose guide to action and a rough approximation of outcomes (in terms of such variables as scheduled delivery times, machine and labor utilization, and work-in-process inventory levels).

Alternatively, the schedule might be generated through a detailed simulation of the shop (Emery, 1961). The model itself may be a perfect abstraction, but the predicted values of capacities and processing times may--and, in general, will--be somewhat in error. As a result, the shop may not be able to follow the schedule precisely. Hopefully, however, the predictions will be good enough to serve as a useful guide between scheduling intervals.

9. THE LIMITATIONS OF PLANNING

Like all factors of production, the optimum allocation of resources for the planning function occurs at that point where its expected marginal value equals its marginal cost. In order to assess the value of additional planning information, one must first determine the effect of the information on organizational behavior (Marschak, 1960 and 1963). Once this has been done, the evaluation of alternative planning systems involves the same sort of selection process as required in any planning.

A planner obviously selects a planning system that he feels will, on the average, induce desirable lower-level behavior. However, the plans generated by any system are virtually always ambiguous to some extent, and they may be unrealistic in the sense that they call for infeasible actions or actions that are inferior to alternatives that can be perceived by those constrained by the plan.

Under these circumstances, it is difficult to predict the precise effects of a plan. It will obviously have some influence on lower-level

behavior, but the decision process by which an ambiguous or unrealistic plan is resolved often depends on a number of subtle factors not considered by the high-level planner. Despite these difficulties, the planner presumably feels that the plan is justified on the grounds that the behavior it induces has a higher expected utility than that achieved in the absence of the plan.

Let me use again the case of a job shop schedule to illustrate this point. Suppose that the schedule assigns to a machine more work than it can perform during a given time period. This may happen, for example, if actual processing times turn out to take longer than originally predicted, or if the schedule did not explicitly consider machine capacities because of the added effort that this would have entailed.

In this case, the original schedule cannot be executed as planned, and the dispatcher responsible for executing it must make some adjustments. In doing this, he must employ some sort of decision process to resolve conflicts among jobs. His decision process might call for running the jobs in the order scheduled, or it may involve more complex considerations.

Given the unpredicted circumstances, it might very well be better if the dispatcher deviates from the processing order originally scheduled. A critical job, for example, might be unduly delayed by a slavish adherence to the job order shown in the original schedule. In this situation, it is difficult to predict how the dispatcher will react. His actions depend, among other things, on the organizational pressures exerted by the control system to conform to schedules even though they become clearly unrealistic.

Thus, an essential factor in determining the effect on behavior of a given planning process is the detail and realism of the plans that it generates. In order to generate increasingly unambiguous and realistic plans, the planning process must be increasingly complex and must handle an increasing volume of data.

Realism in planning also calls for the accurate prediction of basic planning data subject to varying degrees of uncertainty. Uncertainty exists

about such matters as competitors' strategies, future technological developments, and the value of variables subject to random fluctuations (Hitch and McKean, 1960, pp. 188-192). The organization has several ways of improving planning in the face of such uncertainty.

It can, for example, improve the accuracy of predicting planning data by various institutional means. One way of doing this is to enter certain contractual arrangements to create a "negotiated environment" (Cyert and March, 1963, p. 118). Hedging, insurance, and long-term fixed-price contracts with suppliers illustrate this approach. The organization can also employ general-purpose equipment and manpower in order to impose more aggregate--and hence more predictable--constraints on planning. The use of various decoupling devices also increases predictability, since they allow each subunit to absorb most of the minor random disturbances that impinge on it.*

Greater accuracy in predicting planning data can often be gained by collecting additional data and performing more complex transformations on them--a sophisticated regression analysis, say. Sequential decision making, short planning cycles, and a control system providing rapid feedback reduce the planning horizon over which predictions must be made, and thereby increase the accuracy of prediction.

Planning models can be used to provide information about the sensitivity of outcomes to uncertainty. Instead of using single estimates for planning data, a range of estimates might be employed. For example, some planning systems use a "pessimistic," a "most likely," and an "optimistic" estimate to characterize the uncertainty of a given prediction. The planner can then assess the outcomes of alternative plans under varying degrees of

---

*See p. 34.

pessimism or optimism.

The reduction of uncertainty is not achieved without a cost. Risks transferred in an effort to achieve a negotiated environment must be assumed by someone else, and this person must be compensated for his risk-taking. Flexibility in resources adds to their cost. Increased sophistication in predicting planning data increases the cost of data collection, storage, retrieval, and computation. Explicit consideration of multiple values of planning data increases factorially the number of alternatives that must be evaluated (Hitch and McKean, 1960, p. 193).

A planner faces a limitation on the cost and time he can devote to planning. There comes a point where it is cheaper for the organization to "play it by ear" than it would be to spend additional effort in formulating more realistic plans. And even if this were not the case, the processing time required to generate more elaborate plans may simply exceed the allowed response time. The planner must recognize these cost, time, and uncertainty limitations. He must try to strike a balance between the costs of improved planning versus the costs of muddling through with somewhat ambiguous and unrealistic plans.

10. COMPUTER PLANNING MODELS

The planning process discussed up to this point represents a conceptual viewpoint largely independent of the methods used to implement it. The topic I now want to consider is the role that computers might play in this process--particularly at the higher-levels within the organization. My comments are necessarily somewhat speculative, and are therefore no doubt subject to the usual hazards of speculation: wild, unsupported fancies and pius hopes on the one hand, and unimaginative commonplaces on the other. I will try my best to avoid these risks.

Despite a few caveats, there seems to be a general concensus that computers will contribute increasingly to planning at all levels. Nevertheless, skeptics would certainly have no difficulty in marshalling ample empirical

evidence to support a less sanguine view. The results achieved to date in using computers for high-level "strategic" planning have been relatively drab and meager compared with their widespread use for low-level "operational control" (Deardon, 1964).

I can see in our past experience no compelling evidence to support a view that inherent limitations preclude the use of computers in strategic planning. Developing formal computer models to aid the planner obviously presents a task of great difficulty--but not a unique one. A planner cannot avoid the use of a model, whether he relies on a formalized model or his own intuition. There is every reason to suppose that formalized computer models can assist the planner in doing this.

The use of computers in planning certainly does not imply that the planner must abdicate his responsibilities to the machine. In order to make a major improvement in the planning process, we will have to draw upon the best characteristics of both man and machine.

The meager evidence that we have suggests that a symbiosis between the man and the computer will prove especially powerful and fruitful in coping with the enormously complex problems encountered in organizational planning. To the human component in a <u>man-machine</u> system is relegated the responsibility for proposing alternative plans and placing a utility value on the predicted consequences. The machine is assigned the computational task of determining the consequences of each alternative by means of a formal model.

The great advantage of such a system is that it does not require the complete formalization of the total decision process. Those decisions and utility functions that are well understood and capable of being described formally can be incorporated into the computer model. Decisions and utilities that cannot be so formalized are simply reserved for the human decision maker.

The formalized planning model is used by the computer to transform decision variables into outcome variables. For example, in determining the consequences of a proposed increase in the aggregate production rate,

the computer must make some assumptions about the allocation of production capacity. In doing this, the computer should distribute production in an "optimal" fashion subject to the specified aggregate capacity constraint. Based on these detailed "decisions," the computer can then determine such outcome variables as manufacturing costs and expected stockouts. To the extent possible, the computer should also provide the planner with information helpful in making the aggregate production rate decision--the relation of the projected to the "optimal" inventory level, for instance.

Does this encroach on the planner's authority for decision making? Exactly the opposite is the case. The planner must participate in the development of the algorithms by which his aggregate decisions are amplified into detailed plans. If the algorithms incorporate the planner's goals, he can then formulate high-level plans with a reasonable confidence that the resulting detailed plans will be satisfactory.

In the absence of such a formalized model, the high-level planner has little assurance that his plans will be translated faithfully. Although he may participate in the specification of policies, the development of procedures, and the selection and training of personnel to generate detailed plans, nevertheless a great deal of "noise" is introduced during the hierarchical translation of high-level plans into low-level plans. Lower levels in the organization have a vast catalogue of devices for frustrating the execution of grand strategy, most of which are evoked merely out of misunderstanding and confusion. Computer planning will certainly not eliminate these problems, but it can mitigate them by transferring part of the translation process to a formalized model.

Computer planning models, like the less formal ones, will have a hierarchical structure (Dalkey, 1962; Manheim, 1964). Factoring will be necessary, as before, in order to break up the global task into manageable subtasks. However, a given planner can have access to a hierarchy of models, rather than just a single-level model. He can first formulate a high-level plan by means of a sequential search through a low-resolution plan space described

by an aggregate model. Upon finding a satisfactory plan, he can then immediately explore the plan in greater depth by using more detailed, higher-resolution models.

The partial fragmentation of global planning obviously introduces the problem of coordination. Nevertheless, the problem is much less severe with man-machine systems than it is with conventional planning.

For one thing, the global task need not be fragmented to the same extent as before, since the computer can handle much greater complexity than the unaided planner. In effect, each model can have a wide "span of control," thereby reducing the number of submodels and the hierarchical depth of global planning. "Suboptimization" will still occur, but the more comprehensive nature of the planning models will reduce the penalities typically associated with this process.

In addition, the enormous input-output capacity of modern computers permits a close link of a computer model with the data base of the organization.* Every planner can therefore have much closer access to information about the plans of other organizational units as reflected in a common data base. This will greatly facilitate the coordination of activities throughout the organization, thus further reducing the penalties of suboptimization.

Computer models will not change the iterative nature of planning. This scheme provides an efficient means of communicating between hierarchical levels in formalized as well as conventional planning. However, man-machine iterative planning offers the advantage of explicitly identifying unrealistic high-level plans during the detailed amplification by lower-level models. As a result, the high-level planner can immediately

---

*The weakest link between the computer and the data base is no longer the input-output hardware, but rather the language by which wanted data are described and retrieved. Lombardi (1964) argues this point cogently, and suggests possible approaches to the problem.

make appropriate modifications to his plan. In conventional systems, such modification may not be made until long afterwards, when an exception message identifies deviations in an unrealistic plan.

A man-machine system offers the obvious advantage of speeding up all phases of the planning process. Plans can thus be formulated on the basis of more recent information about the current state of the environment. Greater speed in planning also permits quicker response to changes in existing plans if that should prove necessary.* Of far greater importance, the computer's speed permits relatively quick response to the planner's proposed plans. The planner can therefore evaluate a larger number of alternative plans, and consequently he stands a better chance of finding a superior one. Furthermore, with a short response time it is reasonable to expect better decisions, since the planner can retain a closer grasp of a complex problem over the reduced response interval.

Finally, the relatively low cost of processing information in a man-machine system will induce a change in the balance between the cost and value of additional planning. The economic balance point will shift sharply toward the use of greater detail in planning, the consideration of more alternatives, a more explicit evaluation of uncertainty, and a closer link of planning and control.

11. MODIFICATION OF THE MAN-MACHINE SYSTEM TO ACHIEVE ORGANIZATIONAL ADAPTATION

A man-machine search scheme has as its purpose the location of a

---

*The need for quick response applies almost exclusively to low-level plans extending over a short planning horizon. Seldom is it desirable--and often it is extremely undesirable--to alter high-level plans on the basis of the scanty evidence furnished by very recent and "timely" data. To do so is likely to introduce more "noise" than "signal" into the planning process, since the data would normally represent too small a sample of the environment to contain much information.

satisfactory plan out of the set of all alternative plans that can be generated and described by the algorithms and variables used in the composite hierarchical planning model available to the planner. This set by no means includes all "real" alternatives, since not every possible alternative can be generated by a given planning model. The plan space defined by a model's decision and outcome variables represents only an infinitesimal portion of the organization's "real" plan space. Furthermore, only a very small fraction of the points included in even this reduced space remains accessible to the planner. For example, the model will not generate an inventory distribution that is "non-optimal" in terms of the model's algorithm for allocating aggregate production.

The planner naturally seeks improved plans out of the real alternatives available to him, and not just the potential candidates found in the space of the existing planning model. This does not mean, however, that he should have complete access to every conceivable alternative. On the contrary, the very purpose of the planning model is to confine the planner's search to a "good" region of the real space, and to exclude "bad"--and therefore irrelevant--portions. The planner must aim at improving the model so that it provides access not to a <u>greater</u> number of alternatives, but rather to <u>fewer</u> and <u>better</u> alternatives.*

This philosophy leads the planner to employ modifications in the man-machine planning model as the predominant mechanism for generating improved plans. The planning model should be highly <u>parameterized</u> to facilitate these changes. For example, an inventory control algorithm should include a carrying cost parameter that can be modified readily. If a temporary shortage of funds within the organization forces a reduction

---

*The ideal model makes accessible only a single plan--the optimum one in terms of the real alternatives and real goals of the organization. Such a model would obviously have to formalize all decision processes and all utility functions for the organization.

in inventory, the planner can accomplish this by increasing the carrying cost parameter. The "knob" to adjust the parameter can simply be turned until a satisfactory level of inventory is found through a trial-and-error process. The system can aid the planner in setting the parameter value by providing him with information such as the implied trade-off between inventory dollars and the expected number of stockouts.

A change in an algorithm represents a more basic type of modification in the planning model than does a change in its parameters. For example, an inventory distribution algorithm may be revised to include some refinement--the explicit consideration of capacity constraints, say. The planning model should be designed to permit great flexibility in making such changes. This can be done, for instance, by the use of "modular" programming techniques and "higher-level" languages (Emery, 1962).

Even more fundamental changes in the planning model can be made. For example, the structure of the model may be altered by combining two or more activities that previously were planned independently. This might occur, say, when the scheduling of two factories is combined in order to find joint optimum schedules instead of independently suboptimized schedules.

Making adjustments of the type described requires planning, and therefore involves a search among alternative plans. Once again, the planner confronts a vast space of undefined alternatives--in this case, the space of alternative planning models rather than alternative operating plans. In order to find a fundamentally improved model he must employ efficient search techniques.

Ad hoc "knob-turning" adjustments to an existing planning model provide a means of searching for improved models. However, even the most efficient sequential search techniques reveal only a minute part of the abyss of alternative models. The planner must employ more powerful techniques in order to find really fundamental improvements. A hierarchical search can again prove useful for such a purpose. This requires the development of a higher-level *metamodel* designed specifically for the purpose of exploring for

improved models.

For example, industrial dynamics models could be used for such experimentation (Forrester, 1961; Roberts, 1963). Industrial dynamics models are particularly appropriate for an investigation of systems having many interacting variables, and this is precisely where one must focus attention when seeking fundamental systems improvements. The structure of the organization and the links between its components are basic determinants of organizational behavior.

In developing the metamodel, one must choose appropriate outcome variables that provide a means of comparing the performance of alternative man-machine planning models. Stability and dynamic response characteristics are among the most important measures for describing the behavior induced by a given planning system. An industrial dynamics metamodel can provide a useful display of dynamic behavior by means of a trajectory through time of any desired variable.

Using such a metamodel, the planner can explore the space of alternative man-machine models until he judges that the cost of further search would exceed the expected gain. The terminal values of the metamodel variables--decision rules, delays, and the flows of resources and information--are then transformed into the corresponding values in the planning model. If the metamodel provides a sufficiently accurate abstract representation of the planning model, then the planning model should have roughly the same dynamic characteristics as the chosen metamodel.

12. CONCLUSIONS

I would not deny for a minute that a man-machine planning system requires an extremely ambitious program to implement. A prudent manager would do well to treat very gingerly any suggestion that such a system be developed for his organization. I am convinced, however, that man-machine systems roughly of the type described in this paper (for which I claim no great originality, of course) will play a central role in the management of organizations.

An organization currently pays an inordinate price for planning. It pays in the form of the costs required to sustain its present planning "model"--the organizational hierarchy engaged in the amplification of high-level plans into more detailed form. It also pays in the form of unnecessarily poor performance.

The generation of substantially better plans is so complex a task that only through an elaborate man-machine system can we hope to come to grips with it. Such a system will provide an efficient means of performing a sequential, iterative search through a hierarchical plan space of the organization.

REFERENCES

Ackoff, R. L. 1962. Scientific method: optimizing applied research decisions. John Wiley, New York.

Alexander, S. S. 1962. Income measurement in a dynamic economy. In W. T. Baxter and S. Davidson, Studies in accounting theory, 2d Edition. Irwin, Homewood, Illinois.

Arrow, K. J. 1959. Optimization, decentralization, and internal pricing in business firms. In Contributions to scientific research in management, Graduate School of Business Administration, U.C.L.A., Los Angeles. Pp. 9-18.

Ashby, W. R. 1956. An introduction to cybernetics. Chapman & Hall, London.

Barnard, C. I. 1938. The functions of the executive. Harvard University Press, Cambridge.

Bellman, R. 1961. A mathematical formulation of variational processes of adaptive type. In Proceedings of the Fourth Berkeley Symposium, Berkeley, California. Vol. 1, pp. 37-48.

Bishop, G. H. 1960. Feedback through the environment as an analog of brain functioning. In M. C. Yovits and S. Cameron (eds.), Self-organizing systems. Pergamon Press, New York. Pp. 122-146.

Bowman, E. H. 1963. Consistency and optimality in managerial decision making. Management Science, 9, 2 (Jun 1963), 310-321.

Burkhead, J. 1956. Government budgeting. John Wiley, New York.

Conway, R. W. and Maxwell, W. L. 1963. Network scheduling by the shorest-operation discipline. In J. F. Muth and G. L. Thompson (eds.). Industrial scheduling. Prentice-Hall, Englewood Cliffs. Pp. 277-299.

Craik, K. J. W. 1943. The nature of explanation. Cambridge University Press, Cambridge, England.

Cyert, R. D., and March, J. G. 1963. A behavioral theory of the firm. Prentice-Hall, Englewood Cliffs, N. J.

Dalkey, N. C. 1962. Command and control--a glance at the future. Proceedings of the First Congress on Information System Sciences. Hot Springs, Va., November 1962.

Deardon, John. 1964. Can management information be automated? Harvard Business Review, 42, 2 (Mar-Apr 1964), 128-135.

Drucker, P. F. 1964. Long-range planning means risk-taking. In D. W. Ewing (ed.), Long-range planning for management. Harper and Row, New York.

Emery, J. C. 1960. Control of finished goods inventory. In C. West Churchman and Michael Verhulst (eds.), Management science--models and techniques. Pergamon Press, Oxford, England. Vol. 1, pp. 560-576.

Emery, J. C. 1961. An approach to job shop scheduling using a large-scale computer. Industrial Management Review, 3, 1 (Fall 1961), 78-96.

Emery, J. C. 1962. Modular data processing written in COBOL. Communications of the Assoc. for Comp. Mach., 5, 5 (May 1962), 263-268.

Emery, J. C. 1964. The impact of information technology on organization. Proceeding of the 1964 annual meeting, Academy of Management, Dec 1964.

Forrester, Jay W. 1961. Industrial Dynamics. MIT Press and John Wiley, N.Y.

Gardner, John W. 1964. Self-renewal. Harper and Row, New York.

Goetz, Billy E. 1949. Management planning and control. McGraw-Hill, New York.

Goetz, B. E. 1965. Quantitative methods: a survey and guide for managers. McGraw-Hill, New York.

Granger, C. H. 1964. The hierarchy of objectives. Harvard Business Review, 42, 3 (May-Jun 1964), 63-74.

Haberstroh, C. J. 1958. Processes of internal control in firms. Unpublished Ph.D. thesis, University of Minnesota, Minneapolis.

Hitch, C. J. and McKean, R. N. 1960. The economics of defense in the nuclear age. Harvard University Press, Cambridge.

Klahr, C. N. 1958. Multiple objectives in mathematical programming. Operations Research, 6, 6 (Nov-Dec 1958), 849-855.

Koontz, H. and O'Donnell, C. 1964. Principles of management, 3d Edition. McGraw-Hill, New York.

Likert, R. 1961. New patterns of management. McGraw-Hill, New York.

Lombardi, Lionello A. 1964. Towards automatic management information systems. (Unpublished).

Manheim, M. L. 1964. Highway route location as a hierarchically-structured sequential decision process. Ph.D. Thesis, Mass. Institute of Technology Cambridge, Mass. (Research Report R64-15).

March, J. G. and Simon, H. A. 1958. Organizations. John Wiley, New York.

Marschak, J. 1963. The payoff-relevant description of states and acts. Econometrica, 31, 4 (Oct 1963), 719-725.

Marschak, J. 1964. Problems in information economics: general concepts, and a case of increasing returns to information. In Bonini, Jaedicke, and Wagner (eds.), Management controls: new directions in basic research. McGraw-Hill, New York.

Minsky, Marvin. 1963. Steps toward artificial intelligence. E. A. Feigenbaum and J. Feldman (eds.). Computers and thought. McGraw-Hill, New York. (Originally published in Proceedings of the I.R.E., 49, 1 (Jan 1961), 8-30.)

Muth, J. F. 1963. The effect of uncertainty in job times on optimal schedules. In J. F. Muth and G. L. Thompson. Industrial scheduling. Prentice-Hall, Englewood Cliffs. Pp. 300-307.

Newell, A., Shaw, J. C., and Simon, H. A. 1959. The process of creative thinking. RAND document P-1320 (Sep 1958, revised Jan 1959).

Newell, A., Shaw, J. C., and Simon, H. A. 1960. A variety of intelligent learning in a general problem solver. In M. C. Yovits and S. Cameron (eds.), Self-organizing systems. Pergamon Press, New York. Pp. 153-189.

Newman, W. H. 1951. Administrative action--the techniques of organization and management. Prentice-Hall, New York.

Roberts, E. B. 1963. Industrial dynamics and the design of management control systems. Management Technology, 3, 2 (Dec 1963), 100-118.

Samuel, A. L. 1959. Some studies in machine learning using the game of checkers. IBM Jour. of Res. & Dev., 3 (Jul 1959), 211-219.

Schleh, E. C. 1961. Management by result. McGraw-Hill, New York.

Sheridan, T. B., Johnson, W. M., Bell, A. C., and Kreifeldt, J. G. 1964. Control models of creatures which look ahead. Proceedings of the fifth national symposium on human factors in electronics (May 5-6, 1964). Institute of Electrical and Electronic Engineers. Pp. 229-240.

Simon, Herbert A. 1962. The architecture of complexity. Proceedings of the American Philosophical Society, 106, 6 (Dec 1962), 467-482.

Sisson, Roger L. 1960. An appraisal of current computer applications. In D. G. Malcolm and A. J. Rowe (eds.), Management control systems. John Wiley, New York. Pp. 97-119.

Starr, Martin Kenneth. 1964. Production management--systems and synthesis. Prentice-Hall, Englewood Cliffs, N. J.

Stedry, A. C. 1962. Budget control and cost behavior. Prentice-Hall, Englewood Cliffs, N. J.

Theil, H. 1961. Economic forecasts and policy. North-Holland Publishing Co., Amsterdam.

Whinston, A. 1962. Price coordination in decentralized systems. O.N.R. Research Memorandum No. 92, Carnegie Institute of Technology, Graduate School of Industrial Administration, Pittsburgh, Pennsylvania.

Zannetos, Zenon S. 1965. On the theory of divisional structures: some aspects of centralization and decentralization of control and decision making. Management Science. Forthcoming.

Programming system for the office of the secretary of defense. 1962. Department of Defense, U. S. Government Printing Office, Washington, D. C. (Jun 1962).