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Structural Problems in Organization Theory*

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ABSTRACT

This paper suggests that Mathematical Systems Theory is appropriate as a tool for the development of analytical models of organizational situations. A simple decision making system, the executive committee of Bonini's simulation model of the firm, is described using the Mathematical Systems Theory approach and its implications for further research suggested.

Structural Problems in Organization Theory

1. Introduction

Vast amounts of explanatory literature about organizations exist with, unfortunately, little progress toward a generally applicable analytical (quantitative) description amenable to elaboration and manipulation through mathematical techniques of analysis in evidence. Scott [1] anticipates that the answer to this question may be obtainable through General Systems Theory. He suggests that modern organization theory almost inevitably leads into a discussion of general systems theory and states (p.24) that modern organization theory needs a framework, and it needs an integration of issues into a common conception of organization.

Scott, (as well as others who seek a generalized representation of organization, e.g., Haberstroh [2]) does not define "General Systems Theory" to be identical to Mathematical Systems Theory as developed at Case, but he might well have done so. Mathematical Systems Theory, as a general theory of systems, should have much to offer organization theorists in their search for a general organization system. Research in this area is currently in progress. The approach which has been adopted is to use Mathematical Systems Theory to describe a particular "organization" [3] in order to gain insights into the problems which will be encountered on the way to a more general organization system. This paper is a report on this research.

The organization chosen, Bonini's simulation of the firm [3] has many attributes which make it appropriate for this type of study. It has been well received by a wide audience of scholars in organization theory and related fields, it is a well defined organization in the sense that the relationships among its constituents are readily ascertained, and, although it is simpler than an organization like General Motors, it retains sufficient complexity so as to be representative of a variety of the complications found in its "real world" counterparts. Figure 1 suggests the general organization of the simulation.

The subject of this paper is the executive committee of the simulated firm. The executive committee is the master planning and control system of the simulated firm [3]. It receives information from sources within the firm, performs evaluations, and issues instructions to several subordinate units to make adjustments necessary for a satisfactory level of performance. The concern is to achieve a useful goal-seeking description of this activity.

Choosing a decision making system as the center of attention is consistent with the theme of organization theory. The abstract definitions and "satisficing" decision making system presented are consistent with the formalism of Mesarovic [4] and the "rational administrative man" posed by Simon [5], respectively.

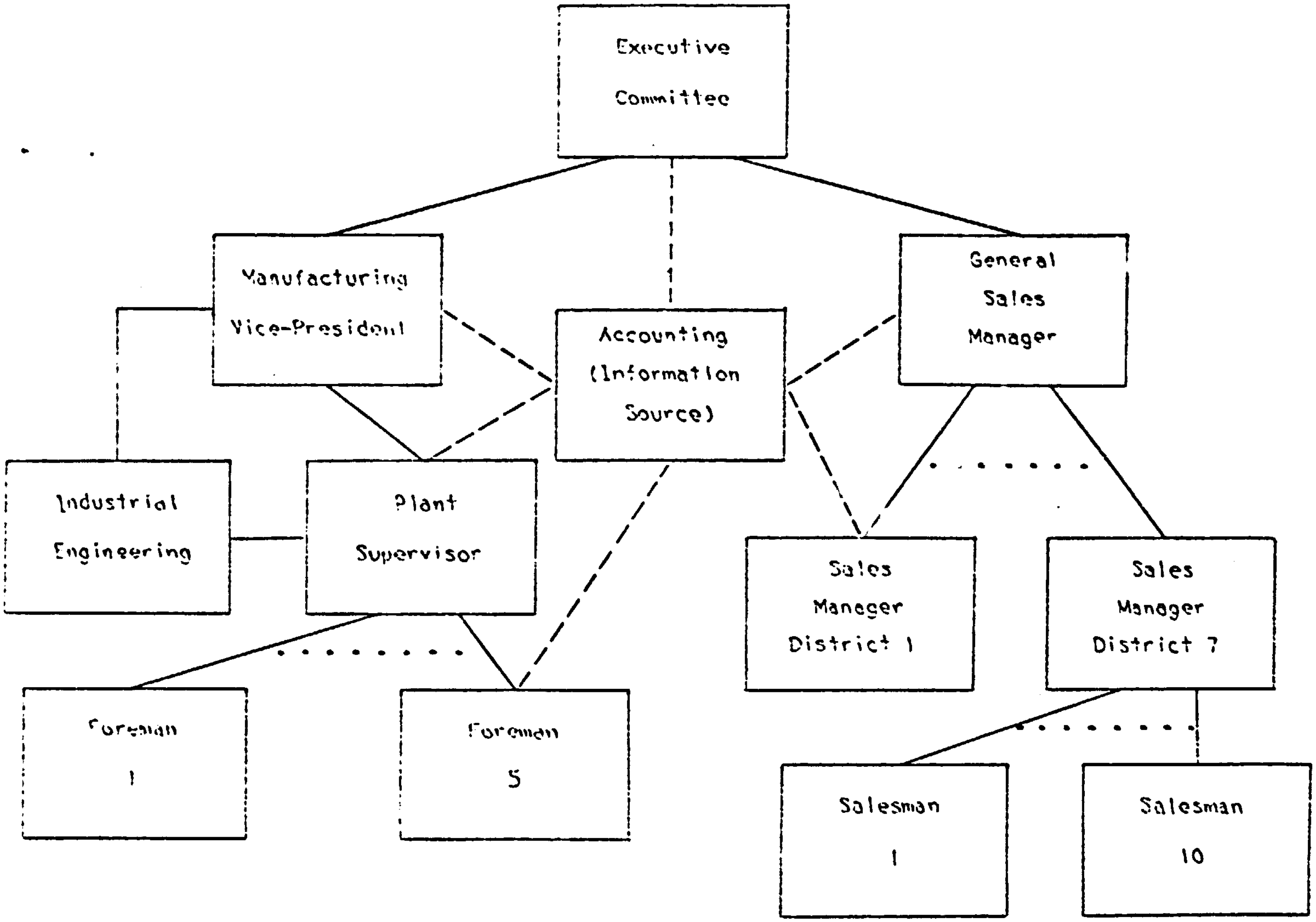

Figure 1 -- Organization of the Simulation

2. Basic Definitions

Although it necessitates the introduction of some slight notational variations in the papers of this group, it is convenient to make this paper self-contained and introduce the basic definitions which will be used to model the total system under consideration. The observant reader will note that although the symbolism is slightly different, the concepts implied are identical to those discussed by Mesarovic [4].

Three alternate representations suitable for description of the executive committee will be discussed. In the first, the operation of the unit is viewed as simply that of an input-output information processing system. In the second, the goal-seeking nature of its activity is recognized. The third, and most representative, details the exact nature of the executive committee decision process by discussion of a series of mappings in the context of the actual committee simulation operation.

The first possible representation is a terminal system representation. A terminal system S^* is simply defined as a relation established on the cartesian product of two sets, one representing an input object for the system and the other its output object, i.e. $S^* \subset X \times Y$ where X is the input object and Y is the output object. Upon introduction of a suitable state object[1], Z^*, an equivalent representation is $S^*: Z^* \times X \rightarrow Y$.

The second possible representation is a "simple" goal-seeking configuration. Relative to this description, the terminal system representation S^* is decomposed into two subsystems, S and D as illustrated in Figure 2. The three definitions following will be taken as axioms for construction of the goal-seeking system representation.

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[1] It is assumed that the idea of "state" is well enough known that further elaboration on it is unnecessary here.

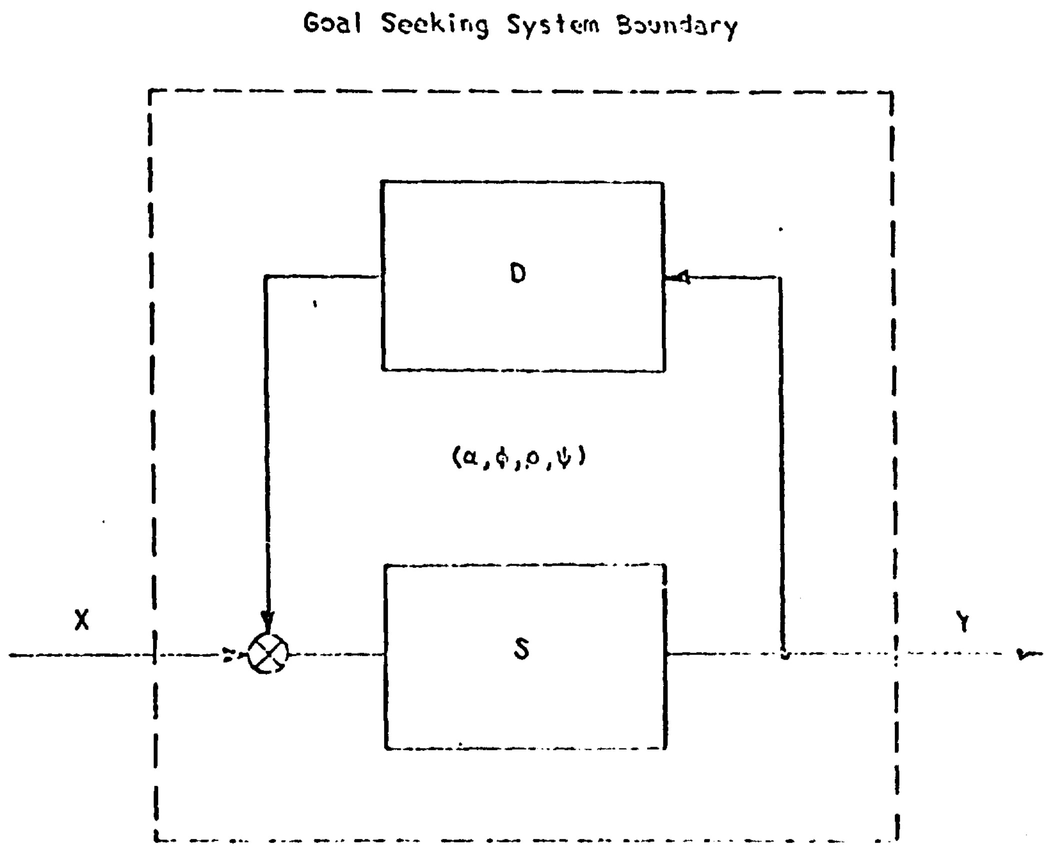

Figure 2 -- Goal Seeking System Schematic

Definition 1. A decision problem is a four-tuple (S, U, M, ϕ) where S is a terminal system, U is a set of uncertainties, M is a set of primitive alternatives, and ϕ is a performance mapping.

The idea behind this definition is that a decision maker D (e.g. an individual, group, or committee) recognizes some system S which it wishes to influence in some manner. To direct the activity of S it has at its disposal a set of adjustments or perturbation inputs represented by M which it can use to prescribe the output of S, and a performance mapping ϕ which it uses to establish the "utility" or "value" of any outputs observed as generated by S. The problem of selecting the alternative from M which will produce the desired output from S is complicated by the fact that the decision maker is not in possession of complete knowledge as to the exact status of S and hence is uncertain as to what result might occur if it chooses a particular element from M. Even so, it is able to assert that the state of S lies within some set of states. U, its uncertainty estimate, represents the set of (subjective) "probabilities" it assigns those states.

Definition 2. A goal is a four-tuple $(\alpha, \phi, \rho, \psi)$ where α is a function which defines a set of strategies A, ϕ is a mapping which defines a set of performance values Φ, ρ is a mapping which defines a set of satisfactory or acceptable performance values P, and ψ is a mapping relating observed performance values with acceptable performance values.

A goal (or goals) is generally a property of a decision maker. Usually, but not always, a decision problem is resolved with some definite purpose in mind, i.e. by reference to a conceived goal.

With respect to this procedure, α represents the process by which the decision maker constructs programs or possible plans of action as sequences of primitive alternatives drawn from M to serve as control inputs for S: ϕ is the performance mapping defined above; and ψ relates the utility assigned to an output of S to some standard level of performance required as defined by ρ.

<u>Definition 3</u>. A <u>goal-seeking system</u> is the feedback connection of a terminal system S and a terminal system D which attempts to achieve an associated goal $(\alpha, \phi, \rho, \psi)$.

Referring to Figure 2, S represents a simple processing system or transformation unit, and D a decision making control unit which directs the activities of S in an attempt to attain a total system state which will satisfy its goal $(\alpha, \phi, \rho, \psi)$. That is, D attempts to resolve a decision problem of which S is a part by reference to a selected goal. Both or either of S and D may be electronic devices, human beings or any conceivable type of casual system. Note that a goal-seeking system is only required to conscientiously try to achieve its goal; it is not required to fulfill it.

Any "real" processing system requires a finite time to produce outputs from its inputs. It is important therefore to specify how the basic subsystems S and D interact over time to achieve a solution to the total system decision problem. Figure 3, a slightly revised version of Figure 2, is meant to be illustrative of the system operating cycle to be discussed. To distinguish this version of the goal-seeking system from the former, it will be termed

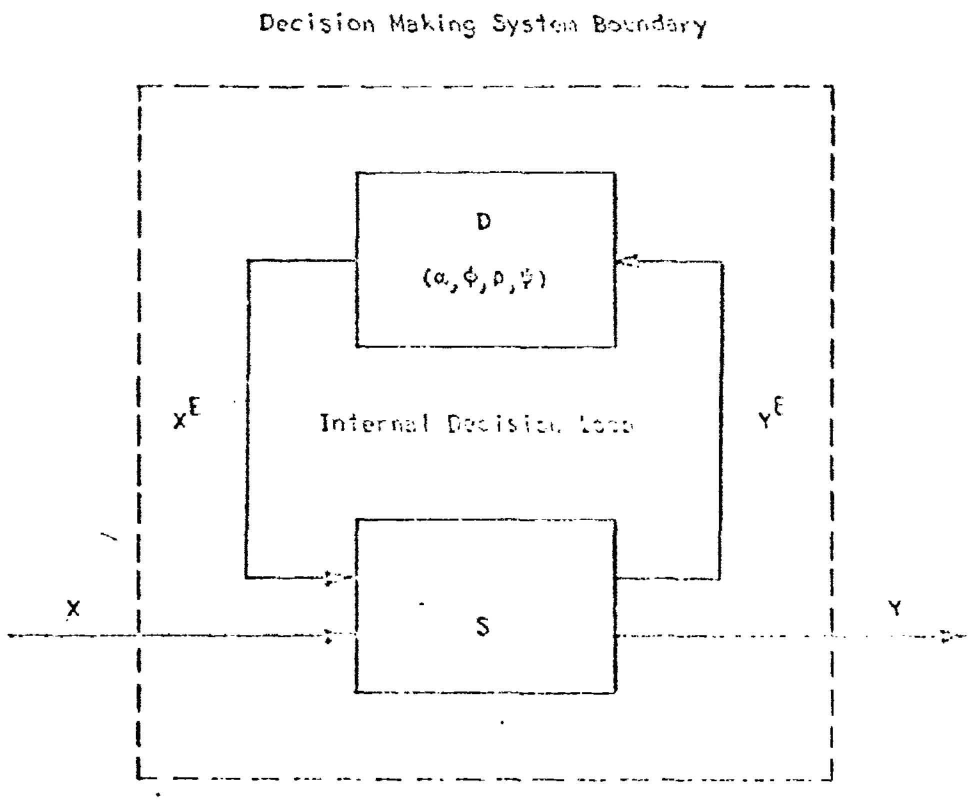

Figure 3 -- Decision Making System Schematic

"the decision making system."

Since S and D represent "real" systems, it may be safely assumed that the decision making system of Figure 3, as well as S and D, have finite time lags; they are nonanticipatory systems. Taking into account these lags, the time-evolution of the system operation that will be used to describe the executive committee unit and its procedure under consideration is given by the following sequence:

(i) S receives an exogenous input X or an endogenous input X^E and generates an endogenous internal output Y^E or an endogenous external output Y.

(ii) D receives and evaluates Y^E relative to the goal $(\alpha, \phi, \rho, \psi)$ if some Y^E is output by S.

(iii) After evaluating Y^E, D generates an endogenous internal input X^E which is either instructions to S to revise its activity base to produce an altered endogenous internal input Y^E or a signal to S to issue the latest endogenous output as an endogenous external output; Y.

(iv) S executes the instructions from D as suggested under (i) above.

Simply put, the decision making system receives an input X, switches to an internal decision making mode until a satisfactory result is obtained, and then produces an output Y.

The third possible representation is an extension of the second. It has as its purpose to detail the decision process which the decision making system uses over time to arrive at its solution to the decision problem. As it is purported to depict the typical decision making mechanism which might be found in a general class of organizations, it is not suprising that the final result can be construed as a simple model of a human decision maker's thought process. As mentioned earlier, other interpretations are also possible.

The extended description of the system is defined by the sequential series of mappings given below. Figure 4 is the corresponding block diagram representation.

(1) $S: Z^S \times X \times X^E \rightarrow Y^E \times Y$ — S receives an exogenous input X or an endogenous input X^E and generates an endogenous internal output Y^E or an endogenous external output Y.

(2) $\phi: Y^E \rightarrow Q$ — D assigns a "value" to the endogenous internal output Y^E through ϕ.

(3) $\rho: Y^E \times U \rightarrow P$ — D defines a set of acceptable performances P based on the uncertainty estimate U and the latest information Y^E.

(4) $\psi: Q \times P \rightarrow I$ — D evaluates the value of Y^E relative to the standard P by reference to ψ setting $i=0$ if it is not satisfactory, $i=1$ if it is. $I = \{i\} = \{0,1\}$.

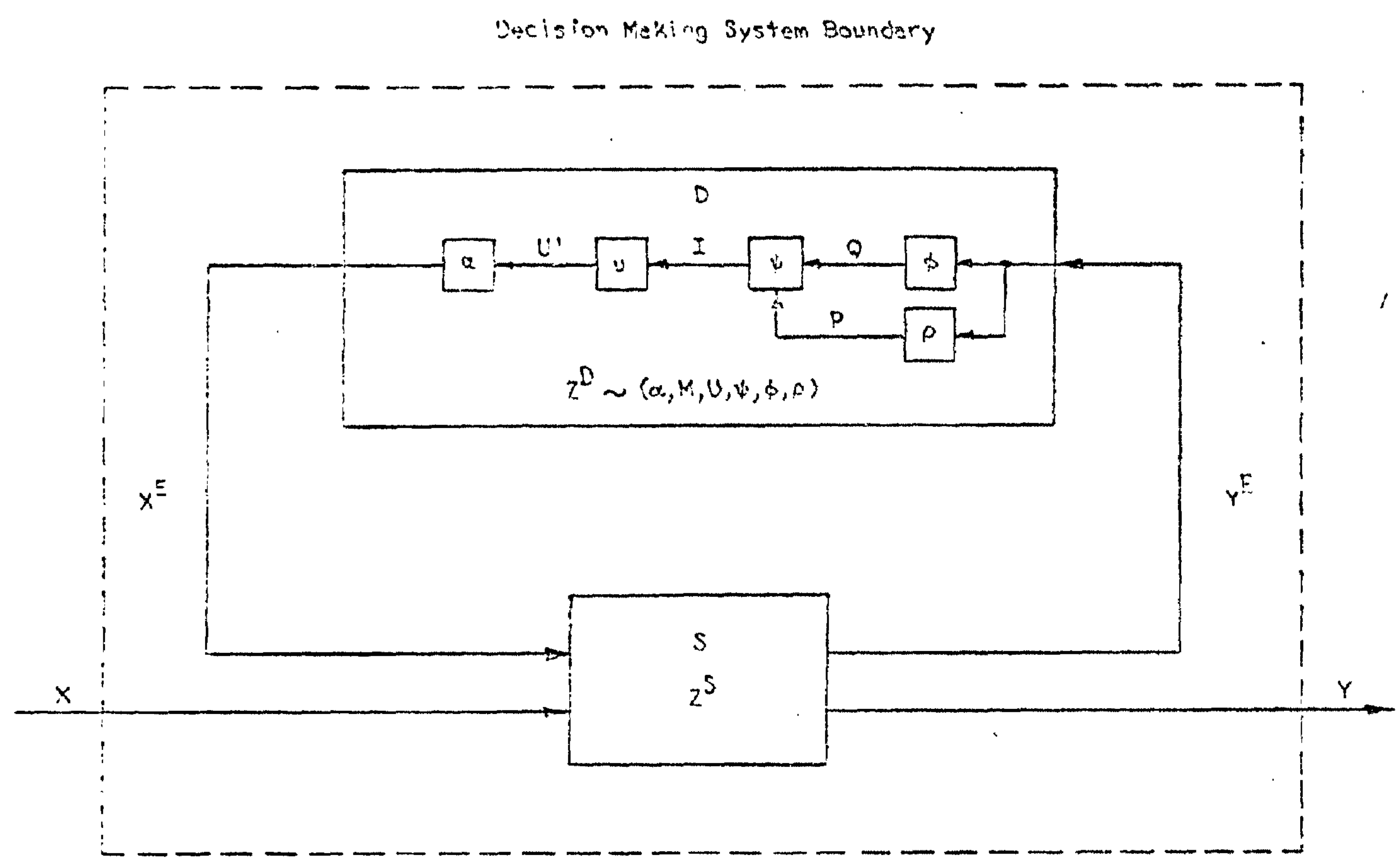

Figure 4 -- Decision Making System Detail

(5) $u: I \times U \to U$

As a result of the information content of the evaluation, D constructs a revised uncertainty estimate.

(6) $\alpha: M \times U \to X^E$

On the basis of the alternatives available and the new uncertainty estimate, D instructs S by X^E.

(7) $S: Z^S \times X \times X^E \to Y^E \times Y$

S executes the instructions from D and if Y^E has been found to be unsatisfactory by D, a new internal cycle begins.

Fundamentally the construction of Figure 3 is no more complicated than that first goal-seeking configuration. It appears so due to the fact that more of the constituents of the decision making environment have been placed in evidence. Besides concluding a more detailed description of the decision process, this representation has the added benefit of illustrating the rather intimate relationship which exists among the constituents of the decision problem, the goal, and the goal-seeking system.

3. The Executive Committee System

In the simulation, the executive committee functions as an information processor which converts quarterly incoming information into an operational plan for the following quarter. At the start of each planning cycle it is assumed to have an "index of pressure" of IP^0 and the profit realized by the firm for several previous quarters at its disposal (See [3] for a discussion of the concept of index of pressure). The information flow to and from the committee in a typical operation cycle is given in Figure 5.

The simulation establishes the committee planning activity as the following sequence of operations:

(1) Compute the profit forecast, P^f, for the next quarter based upon currently available information according to the equation

Profit Forecast = (Total Sales Forecast) − $\sum_{\text{Unit Types}}$ (Estimated Production Costs per Unit) x (Number of Units Sold in Current Quarter) − (Estimated Administrative Expenses) − (Estimated Salesman Commissions).

(2) Set a "profit goal" or "target profit", P^g, as the average of the several available quarterly profit figures.

(3) Compare the profit forecast with the target profit generated under (2) using $P^g \leq P^f$.

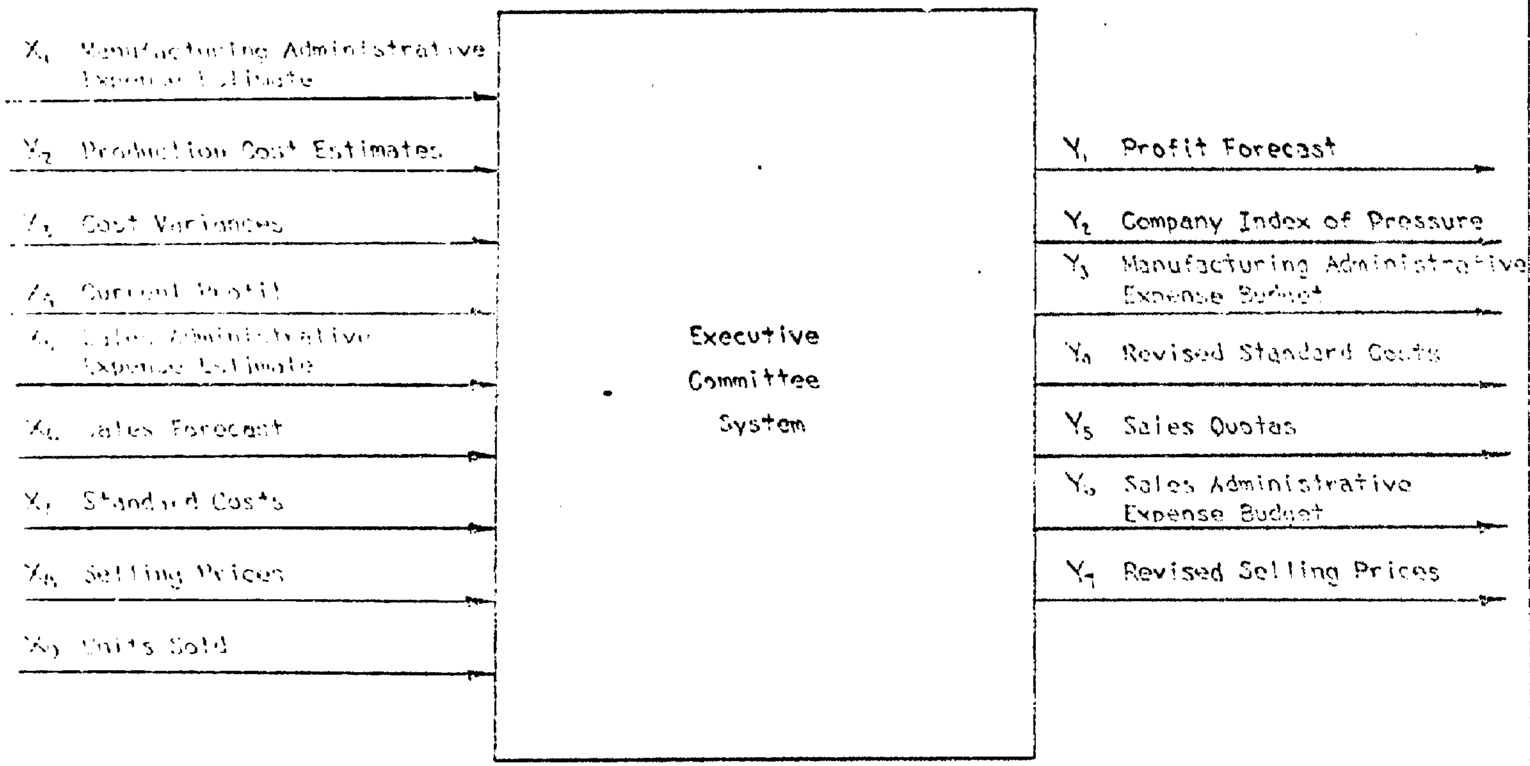

Figure 5 -- Executive Committee Information Flow

(4) (a) If profit forecast is greater than or equal to target profit, publish the information in its current status as the finalized company plan; subsequently reassign IP^0 as the committee index of pressure.

(b) If profit forecast is less than the target profit generated under (2), increase the executive committee index of pressure by Δ, make the information adjustment next in sequence as given below, and return to (1).

(i) Decrease by δ_1, the standard costs of the two manufacturing departments which had the greatest black variance with respect to costs experienced the previous quarter.

(ii) Increase by δ_2 the forecast sales for all those products whose sales last quarter were below those of the previous quarter.

(iii) Decrease by δ_3 the prices of the two products which have the highest expected percent gross margin.

(iv) Decrease by δ_4 the target profit.

(v) Decrease by δ_5 the standard costs of the remaining three manufacturing departments and decrease by δ_9 the administrative expense estimate.

(vi) Increase by δ_6 the forecase sales for the remaining products.

(vii) Decrease by δ_7 the prices of the two remaining products.

(viii) Decrease by δ_8 the target profit.

(ix) Take instruction (i) as the next instruction in sequence.

The above now constitutes a verbal description that can be used as a basis to develop a systems model. Actually, a "system" has been, at least implicitly, recognized already actually by defining the procedure (1)-(4). This implicitly defined system; henceforth termed the executive committee system, can now serve as a basis for the development of a formal, mathematical model of a real "system" the executive committee simulation.

This model will be evolved by applying the formal framework defined in the previous section of this paper to the given written description.

a) Terminal Approach

For the terminal representation it is only necessary to represent the incoming information items as the inputs and the outgoing instructions and plan as the outputs. Referencing Figure 5,

$$X = \{X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9\}$$

where

X_1 = Manufacturing Administrative Expense Estimate

X_2 = Production Cost Estimates

X_3 = Cost Variances

X_4 = Current Profit

X_5 = Sales Administrative Expense Estimate

X_6 = Sales Forecast

X_7 = Standard Costs

X_8 = Selling Prices

X_9 = Units Sold

and

$$Y = \{Y_1, Y_2, Y_3, Y_4, Y_5, Y_6, Y_7\}$$

where

Y_1 = Profit Forecast

Y_2 = Company Index of Pressure

Y_3 = Manufacturing Administrative Expense Budget

Y_4 = Revised Standard Costs

Y_5 = Sales Quotas

Y_6 = Sales Administrative Expense Budget

Y_7 = Revised Selling Price

If S^* represents the executive committee "box", obviously $S^* \subset X \times Y$. To complete the terminal description it is necessary to determine Z^*, so defining the system mapping $S^*: Z^* \times X \rightarrow Y$. The difficulty with the terminal approach is that it is very difficult to achieve a simple constructive specification of the system behavior which incorporates all of the characteristics of the planning cycle, i.e. to establish an algorithm based solely on a state object Z^* which will uniquely determine the output when the input is given. While there is no doubt that the system of concern is nothing but an information processing unit, a complete understanding and explanation of its behavior is enhanced through reference to its associated objective. Of course a terminal representation of the system could be obtained by listing all possible input-output pairs but that would be a very inefficient mode of representation and would not reveal the internal mechanism which determines the system operation. More importantly, tabular representation would be difficult to use as a building block to construct larger and more complex systems. These considerations suggest that a goal-seeking description of the committee's activity should be undertaken.

b. Goal-Seeking Approach

Referring to Figure 3, evidently to achieve a goal-seeking description of the executive committee planning function it is only necessary to define S, X, Y^E, X^E, D, Y, α, ϕ, ρ, and ψ in terms of the characteristics implied by the verbal description of its activity cycle.

S will be defined to be processing unit which performs three elementary tasks.

Task 1: S receives the incoming items $X_1,\ldots,X_9$ as the committee input X at the start of each planning cycle, calculates the average profit figure, and sends the first proposed plan (which includes the profit forecast P^f) plus the average profit figure to D as Y^E.

Task 2: S receives instructions from D as inputs X^E and executes these to produce revised proposals and sends them to D as Y^E.

Task 3: S publishes the final quarterly plan as a document Y which contains the information items $Y_1,\ldots,Y_7$ upon receipt of the proper X^E and prepares for the next planning cycle by resetting the index of pressure (IP) to IP^0.

Relative to these tasks, the state of S will be defined as $Z^S = (IP, W)$ where W is an ordered n-tuple of historical realized profit figures.

D will be defined to be a processing unit which receives Y^E as inputs and instructs S using instructions X^E to produce revised proposals Y^E for the final quarterly plan until a plan Y with $P^f \geq P^g$ is achieved. The existence of such a plan is guaranteed by the internal consistency of the simulation.

The structure of the goal $(\alpha, \phi, \rho, \psi)$ is implicit in this definition. In fact, ϕ defines P^f as the value of the proposed plan Y^E, ρ chooses P^g as the standard of comparison and ψ evaluates the value P^f relative to the standard P^S by inquiring whether $P^f \geq P^g$ or not. Based upon the result of the evaluation, α then determines the instruction to be sent to S. Figure 6 can now be said to represent the executive committee system in the form implied by Figure 3.

This sketchy outline is not sufficient to characterize the decision process of D. Although it suggests the goal-orientated activity of D it does not specify, among other things, the domain and range of α, ϕ, ρ, ψ. These and other matters will be cleared up by representing the committee's activity in the extended goal-seeking form.

c. Extended Goal-Seeking Approach

As before stated, the extended goal-seeking approach is based upon the "simple" goal-seeking description. To conclude the executive committee extended goal-seeking description, the set of

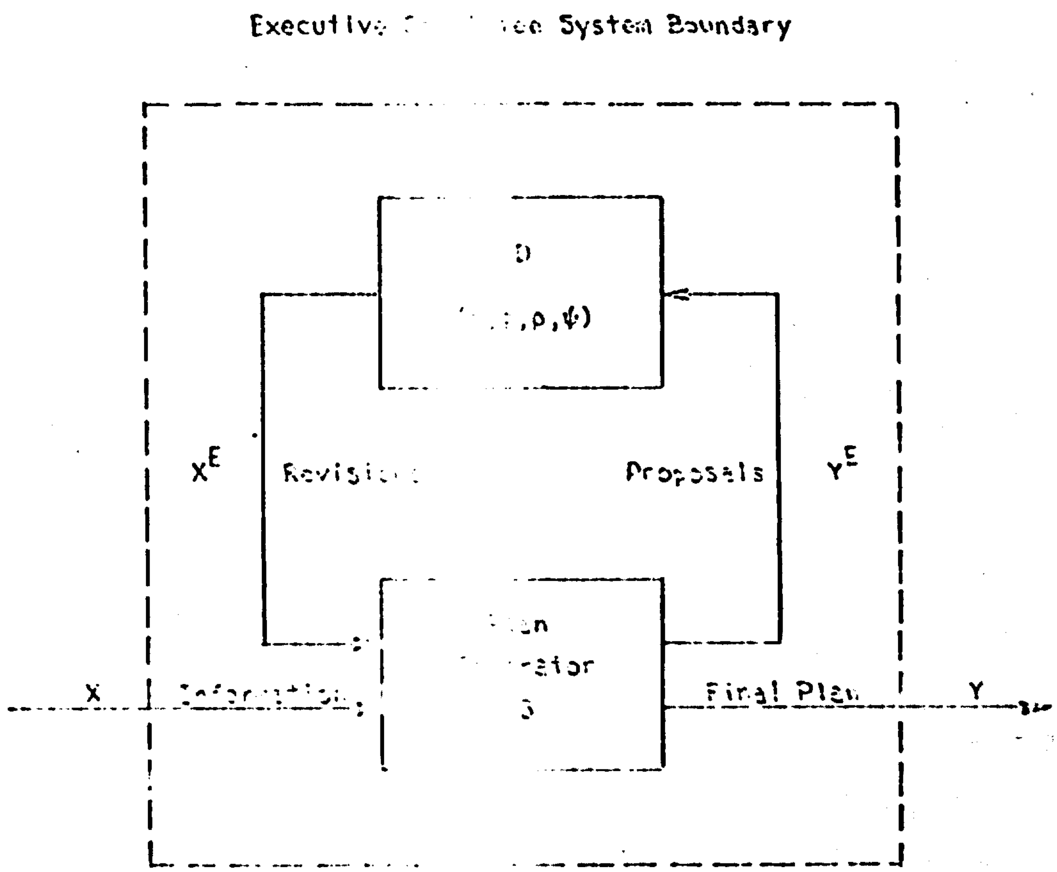

Figure 6 -- System Feedback Schematic

mappings (1)-(7) above must be defined in terms of the simulation activity cycle characteristics. Since mapping (1) is identical to mapping (7), for convenience mapping (2) will be explained first.

For this example, ϕ maps Y^E into the real line R by assigning P^f as the "value" of the plan proposed by S. Thus Q is the set of all real numbers R and ρ: $Y^E \rightarrow R$.

At the beginning of a planning cycle the a priori knowledge of the executive committee will be assumed such that the general form of X is known but that its exact character (i.e. the numerical magnitudes of the respective information items) is unknown. Thus the committee can be considered to be in a condition of anxiety or uncertainty with respect to the information sets to be received. In particular it is uncertain as to how many adjustments in the ordered sequence given under 4(b) above will be required to achieve a satisfactory plan. Since any countable number may be required, at the beginning of the cycle the committee's uncertainty set can be represented by $U^o = \{0,1,2,3,...\}$. Obviously as the committee continues to make adjustments its uncertainty set will be reduced. After one adjustment $U^1 = \{1,2,3,...\}$ is the uncertainty set, after two, $U^2 = \{2,3,...\}$; etc. This point is touched upon in greater detail below.

ρ defines the standard of performance on the basis of the latest decision information available to D; the current Y^E and latest uncertainty set. If the uncertainty set is U^o, ρ uses the average profit figure obtained from the historical profit figures as P^g so defining $P^o = \{P^f: P^f \geq P^g\}$. In addition, if the initial element of the uncertainty set estimate is 4,8,12,...(see 4(b) above) ρ redefines the standard of performance to $P = \{P^f: P^f \geq (1 - \delta_4)P^g\}$, $P^2 = \{P^f: P^f \geq (1 - \delta_4 - \delta_8)P^g\}$, etc. Therefore there has been defined a mapping $\rho: Y^E \times U \rightarrow P$.

Companion to ϕ is the mapping ρ. ψ relates the value assigned Y^E through ϕ to the profit goal P^g determined by ρ. If $P^g > P^f$ the value is "unsatisfactory" and $\psi(Q,P) = 0$. If $P^g \leq P^f$ the value is "satisfactory" and $\psi(Q,P) = 1$. In summary, $\psi: Q \times P \rightarrow I$.

Given the evaluation activity of the committee, it is possible to assert that it possesses a capability for revising its uncertainty estimate. For instance, if the committee receives X, forms P^f and P^g, and determines $P^f < P^g$ (implying i = 0) then certainly it knows it must make one or more adjustments before a satisfactory result is obtained. Thus on the basis of this single comparison the committee can revise U^o to $U^1 = \{1,2,3,...\}$. As more and more adjustments are made, more uncertainty elements of the sequence can be cast aside until a point is reached where $P^f \geq P^g$ (i = 1) and the uncertainty with respect to the input has been resolved. This uncertainty resolution procedure is clearly representable as a mapping $v: U \times I \rightarrow U$ where U represents an arbitrary uncertainty estimate in the committee's sequence of estimates.

The set M is defined by reference to 4(b) above also. M = {(0)*, (i)*, (ii)*, (iii)*, (v)*, (vii)*, (*)} where

(0)* denotes "increase IP by Δ points."

(·)* denotes "instruction (·) and increase IP by Δ points."

(*) denotes "publish the proposed plan as the final plan."

The strategy mapping α is representative of the solution of the decision problem $(S,U,M,\emptyset)$ if U is interpreted as the committee's revised uncertainty estimate at each point α is invoked. Referencing step 4 of the committee decision procedure and the set M, α is a mapping which chooses the "next" instruction in the cyclical, ordered sequence of instructions (i)*(ii)*(iii)*(0)*(v)*(vi)*(vii)*(0)*(i)*(ii)*... whenever the uncertainty with respect to the input remains unresolved, or, it chooses the instruction (*) if uncertainty with respect to the input no longer exists. Evidently then, $\alpha : U \times M \rightarrow X^E$.

Given $Z^S = (IP,W)$ and the instructions which D issues to S, the nature of the mapping representation for S can now be given. If $IP = IP^0$, that is, if $Z^{S0} = (IP^0,W)$ then the only input possible for S under the simulation program is the incoming information X. Upon receipt of X by S, S averages the historical figures, calculates the profit forecast and outputs the first Y^E, i.e. $S(Z^{S0},X) = Y^E$. After D receives the initial Y^E, the input to S will always be instructions to S drawn from the set M and issued by D as X^E. Now, unless D sends the instruction "publish the proposed plan as the final plan," the activity of S is defined by $S(Z^S,X^E) = Y^E$ where $Z^S \neq Z^{S0}$ due to the increase in IP specified by D. If D does send the instruction (*), then $S(Z^S,X^E)=S(Z^S,(*))=Y$ and the system goal has been obtained. On the basis of this description, mapping (7) which is identical to mapping (1) can be represented by

$$S: Z^S \times X \times X^E \rightarrow Y^E \times Y$$

The mapping sequence (1)-(7) given earlier now represents the extensive goal-seeking description of the executive committees planning activity. Figure 6 interpreted by reference to Figure 3 is the corresponding diagrammatic representation.

Extension

The decision making system presented has been developed with the particular purpose of applying it to the "structured organization" of the simulated firm [3]. At this point, it is certain that each of the "boxes" in Figure 1 which represent a simulated decision maker (e.g. the executive committee, district sales managers, or foremen) can be represented in this form. That the same description will suffice to describe the various internal decision loops of the simulated firm (e.g. the industrial engineering, plant supervisor, manufacturing vice-president loop) and their relationship to the rest of the system is probable but less certain.

It is anticipated that the definition of goal selected will be helpful in resolving the uncertainty. Given the goal $(\alpha, \emptyset, \rho, \psi)$ an equivalent representation is the triplet of associated sets (A, Φ, P) plus ψ. Through use of the natural ordering relationship established on sets by the "inclusion" operation, a concept of levels among goals, and therefore among the respective decision makers with respect to a given goal or goals seems possible. This, plus an investigation of the effects of the information items which impinge on the various decision making systems, should produce a better understanding of how information can influence decisions, of the nature of authority, and of the interactions among decision makers in the context of the model.

Given such insights, they can be generalized to include a broad class of organizations and, as Mathematical Systems Theory develops new concepts, these can be added also to achieve as complete a characterization as desired. Thus although a general conception of organization is not available at present, nor is it likely to result as an immediate consequence of this study, perhaps as Mathematical Systems Theory evolves so also will evolve an analytically orientated framework with the potential for fulfilling organization theory's most general requirements.

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