ON THE DESIGN OF

INFORMATION-PROCESSING AND DECISIONMAKING ORGANIZATIONS*

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ABSTRACT

An effectiveness measure for comparing alternative organizational structures is derived and then applied to the evaluation of two three-person organizations. The modeling and analysis of the organizations is carried out using an information theoretic framework in which decisionmakers are described by a two-stage model consisting of a situation assessment and a response selection stage. The total rate of internal processing of each decisionmaker is constrained by bounded rationality, while the performance of the organization must satisfy specified goals. The inter-relationship between performance and bounded rationality is expressed in a generalized strategy space that forms the basis for the effectiveness analysis.

I. INTRODUCTION

A command control and communications (C^3) system is defined as the collection of equipment and procedures used by commanders and their staff to process information, arrive at decisions, and communicate these decisions to the appropriate units in the organization in a timely manner. Implicit in this definition is the notion that the role of the human decisionmaker is central to the design of organizations and the C^3 systems that support them. A basic model of an interacting decisionmaker, appropriate for a narrow but important class of problems, was introduced by Boettcher and Levis [1]. In subsequent work, Levis and Boettcher [2],[3] considered the modeling of organizations consisting of multiple decisionmakers that form a team. In this paper, consideration is given to comparing alternative organizational structures which have been modeled using the methodology already developed.

An information theoretic framework is used for both the modeling of the individual decisionmaker and of the organization. The basic departure from previous models is in the modeling of the internal processing of the inputs to produce outputs. This processing includes not only transmission (or throughput) but also internal coordination, blockage, and internally generated information. Consequently, the limitations of humans as processors of information and problem solvers are modeled as a constraint on the total processing activity. This constraint represents one interpretation of the hypothesis that decisionmakers exhibit bounded rationality [4].

The task of the organization is modeled as receiving signals from one or many sources, processing them, and producing outputs. The outputs could be signals or actions. The input signals that describe the environment may come from different sources and, in general, portions of the signals may be received by different members of the organization. Consideration in this paper will be restricted to structures that result when a specific set of interactions is allowed between team members. In this case, each team member is assigned a specific task, whether it consists of processing inputs received from the external environment or from other team members, *for which he is well trained and which he performs again and again for successively arriving inputs.* The overall mapping between the stimulus (input) to the organization and its response (output) is determined by the internal decision strategies of each decisionmaker. The total activity of each DM as well as the performance measure for the organization as a whole are expressed then in terms of these internal decision strategies. For each set of admissible internal decision strategies, one for each DM, a point is defined in the performance-workload space. The locus of all such points is characteristic of the organizational structure. For particular bounded rationality and performance constraints applied in this space, the effectiveness of a given organizational structure can be assessed and then compared to alternative structures.

In the next section, the model of the interacting organization member is reviewed. In the third section, the extension of the methodology to teams with acyclical information structures is reviewed by presenting results from the modeling of two specific three-person organizational structures. In the fourth section, a method for comparing alternative organizational structures is presented and applied to the two structures considered in section three.

II. MODEL OF THE ORGANIZATION MEMBER

The complete realization of the model for a decisionmaker (DM) who is inter-
acting with other organization members and with the environment is shown in Fig. 1.
The detailed description and analysis of this model has been presented in [1]. There-
fore, only concepts and results needed to model the organization are described in
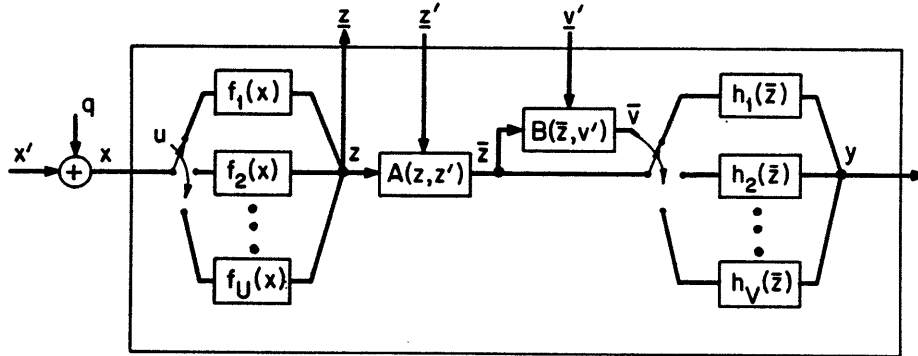this section. The presentation is similar to that in [3].

Figure 1 Single interacting decisionmaker model

Let the organization receive from the environment a vector of symbols, X'. The
DM receives x which is a noisy measurement of a portion, x', of X'. The vector x
takes values from a known finite alphabet according to the probability distribution
p(x). The quantity

$$H(x) = - \sum_X p(x) \log_2 p(x) \tag{1}$$

is defined to be the entropy of the input measured in bits per symbol generated. The
conditional entropy is defined as

$$H_x(z) = - \sum_X p(x) \sum_z p(z|x) \log_2 p(z|x) \tag{2}$$

If input symbols are generated every τ seconds on the average, then τ, the mean
symbol interarrival time, is a description of the tempo of operations [5].

The situation assessment stage consists of a finite number U of procedures or
algorithms f_i that the DM can choose from to process the measurement x and obtain
the assessed situation z. The internal decisionmaking in this stage is the choice
of algorithm f_i to process x. Therefore, each algorithm is considered to be active

or inactive, depending on the internal decision u. In this paper, it is assumed that the algorithms f_i are deterministic. This implies that once the input is known and the algorithm choice is made, all other variables in the first part of the SA stage are known. Furthermore, because no learning takes place *during* the performance of a sequence of tasks, the successive values taken by the variables of the model are uncorrelated, i.e., the model is memoryless. Hence, all information theoretic expressions appearing in this paper are on a per symbol basis.

The vector variable $\underline{z}'$, the supplementary situation assessment received from other members of the organization, combines with the elements of z to produce $\bar{z}$. The variables z and $\bar{z}$ are of the same dimension and take values from the same alphabet. The integration of the situation assessments is accomplished by the subsystem which contains the deterministic algorithm A.

If there is no command input vector $\underline{v}'$ from other organization members, then the response selection strategy $p(v|\bar{z})$ specifies the selection of one of the algorithms h_j that map $\bar{z}$ into the output y. The existence of command input $\underline{v}'$ modifies the decisionmaker's choice v. A final choice $\bar{v}$ is obtained from the function $b(v,\underline{v}')$. The latter defines a protocol according to which the command is used, i.e., the values of $\bar{v}$ determined by $b(v,\underline{v}')$ reflect the degree of option restriction effected by the command. The result of this process is a response selection strategy $p(\bar{v}|\bar{z}\underline{v}')$ in place of $p(v|\bar{z})$.

The mutual information or transmission or throughput between inputs $x, \underline{z}'$, and $\underline{v}'$ and outputs y and $\underline{z}$, denoted by $T(x,\underline{z}',\underline{v}:y,\underline{z})$ is a description of the input-output relationship of the DM model and expresses the amount by which the outputs are related to the inputs:

$$G_t = T(x,\underline{z}',\underline{v}':y,\underline{z}) = H(x,\underline{z}',\underline{v}) + H(y,\underline{z}) - H(x,\underline{z}',\underline{v}',y,\underline{z})$$

$$= H(z,y) - H_{x,\underline{z}',\underline{v}'}(\underline{z},y) \tag{3}$$

A quantity complementary to the throughput G_t is that part of the input information which is not transmitted by the system. It is called blockage and is defined as

$$G_b = H(x,\underline{z}',\underline{v}') - G_t \tag{4}$$

In this case, inputs not received or rejected by the system are not taken into account.

In contrast to blockage is a quantity that describes the uncertainty in the output when the input is known. It may represent noise in the output generated within the system or it may represent information in the output produced by the system. Generalizing this concept to include the total system uncertainty which remains when the input is known gives the quantity G_n:

$$G_n = H_{x,\underline{z}',\underline{v},}(u,W^1,\ldots W^{U+V},W^A,W^B,\underline{z},z,\bar{z},\bar{v},y) \tag{5}$$

where W^i is the set of internal variables of algorithm i and α_i is the number of elements in the set.

The final quantity to be considered reflects all system variable interactions and can be interpreted as the coordination required among the system variables to accomplish the processing of the inputs to obtain the output. It is defined by

$$G_c = T(u:w_1^1:\ldots:w_{\alpha_V}^{U+V}:w_1^A:\ldots:w_{\alpha_B}^B:z:\bar{z}:\bar{v}:\underline{z}:y) \tag{6}$$

The Partition Law of Information [6] states that the sum of the four quantities G_t, G_b, G_n, and G_c is equal to the sum of the marginal entropies of all the system variables (internal and output variables):

$$G = G_t + G_b + G_n + G_c \tag{7}$$

where

$$G = \sum_{i,j} H(w_i^j) + H(u) + H(z) + H(\bar{z}) + H(\underline{z}) + H(\bar{v}) + H(y) \tag{8}$$

When the definitions for internally generated information G_n and coordination G_c are applied to the specific model of the decisionmaking process shown in Fig. 1 they become

$$G_n = H(u) + H_{\bar{z}}(v) \tag{9}$$

and

$$G_c = \sum_{i=1}^{U} [p_i g_c^i(p(x)) + \alpha_i \mathcal{H}(p_i)] + H(z) + g_c^A(p(z)) + g_c^B(p(\bar{z}))$$

$$+ \sum_{j=1}^{V} [p_j g_c^{U+j}(p(\bar{z}|\bar{v}=j)) + \alpha_j' \mathcal{H}(p_j)] + H(y)$$

$$+ H(z) + H(\bar{z}) + H(\bar{v},\bar{v}) + T_z(x':\underline{z}') + T_{\bar{z}}(x',\underline{z}':\underline{v}') \tag{10}$$

The expression for G_n shows that it depends on the two internal strategies $p(u)$ and $p(v|\bar{z})$ even though a command input may exist. This implies that the command input $\underline{v}'$ modifies the DM's internal decision after $p(v|\underline{z})$ has been determined.

In the expressions defining the system coordination, p_i is the probability that algorithm f_i has been selected for processing the input x and p_j is the probability that algorithm h_j has been selected, i.e., $u=i$ and $\bar{v}=j$. The quantities g_c represent the internal coordination of the corresponding algorithms and depend on the distribution of their respective inputs. The quantity $\mathcal{H}$ is the entropy of a random variable that can take one of two values with probability p:

$$\mathcal{H}(p) = - p \log p - (1-p) \log(1-p) \qquad (11)$$

The quantity G may be interpreted as the total information processing activity of the system and, therefore, it can serve as a measure of the workload of the organization member in carrying out his decisionmaking task.

III. TEAMS OF DECISIONAMKERS

In order to define an organizational structure, it is necessary to specify exactly the interactions of each decisionmaker within the organization. A decisionmaker is said to interact with the environment when he receives inputs directly from sources or when he produces outputs that are all or part of the organization's output. The internal interactions consist of receiving inputs from other DMs, sharing situation assessments, receiving command inputs, and producing outputs that are either inputs or commands to other DMs. If these interactions are shown graphically in the form of a directed graph, then the organizational forms being considered have directed graphs which do not contain any cycles or loops. The resulting decisionmaking organizations are defined as having acyclical information structures. This restriction in the structure of the organizations is introduced to avoid deadlock and also messages circulating within the organization. It prohibits a DM from sending commands to other DMs from which he is receiving command inputs. However, simultaneous sharing of situation assessment information is allowed.

The types of information-processing and decisionmaking organizations that can be modeled using the methodology are discussed in detail in [3]. A simple example has been constructed to illustrate the approach based on aspects of the problem of organizing batteries of surface to air missiles. Let a trajectory of a target be defined by an ordered pair of points located in a rectangle that represents a two-dimensional (flat) sector of airspace. From the ordered pair, the speed and direction of flight of the target can be determined. On the basis of that information either fast or a slow missile could be fired or no missile fired at all. The overall task,

then, is to observe the targets, identify their speed and direction, and select an appropriate response. The size of the sector and the frequency of target arrivals is such that a single decisionmaker cannot perform the task; it is necessary to design an organization.

Two specific three-person organizational structures are considered. The first, Organization A, is a pure parallel structure and is defined as follows. The rectangular sector is divided into three equal subsectors and a decisionmaker is assigned to each one. Each DM is capable of observing only the points that appear in his subsector. He can assess the situation, i.e., estimate the trajectory, and select the response, i.e., which weapons to fire, for targets with trajectories totally within his subsector. This is the case when both points that define the target are within his subsector. Since it is possible for trajectories to "straddle" the subsector boundaries, it is necessary that situation assessment information be shared. Thus, DM^1 and DM^2 share information that relates to their common boundary. Similarly, DM^2 and DM^3 share information that relates to targets that cross their common boundary. To keep the computational effort small the situation assessment stages of DM^1 and DM^3 are assumed to contain a single algorithm f; that of DM^2 contains two algorithms, f_1^2 and f_2^2. In contrast, the response selection stage of DM^2 contains a single algorithm h, while the RS stages of DM^1 and DM^3 contain two algorithms h_1^i and h_2^i, i=1,3. Therefore, the internal decision strategies are $p(u^2)$, $p(v^1|\bar{z}^1)$ and $p(v^3|\bar{z}^3)$. The detailed structure of this organization is shown in Figure 2.

Analytic expressions for the total processing activity of each decisionmaker are obtained by specializing the expressions (3), (4), (9), and (10) given in section one.

The second organization, Organization B, contains a decisiomaker who performs a supervisory function and is defined as follows. The rectangular sector is divided into two equal subsectors for which DM^1 and DM^3 are responsible for assessing the situation and selecting a response. The two DMs do not share situation assessment between themselves; however, data from the area adjacent to the boundary between DM^1 and DM^3 is transmitted to the coordinator or supervisor, DM^2, who resolves conflicts and assigns targets either to DM^1 or to DM^3, as appropriate. This is accomplished through command inputs v'^{21} and v'^{23} from the coordinator to the two commanders, where the first superscript designates the decisionmaker of origin and the second denotes the DM of destination. The commanders, in turn, exercise their response y^1 and y^3, respectively. Again, for computational simplicity, it is assumed that DM^1 and DM^3 have a single algorithm f for their SA stage and two algorithms h_1^i and h_2^i for the RS stage. The coordinator, DM^2, has an algorithm A for processing the assessed situations z'^{12} and z'^{32} and two algorithms, h_1^2 and h_2^2, in the
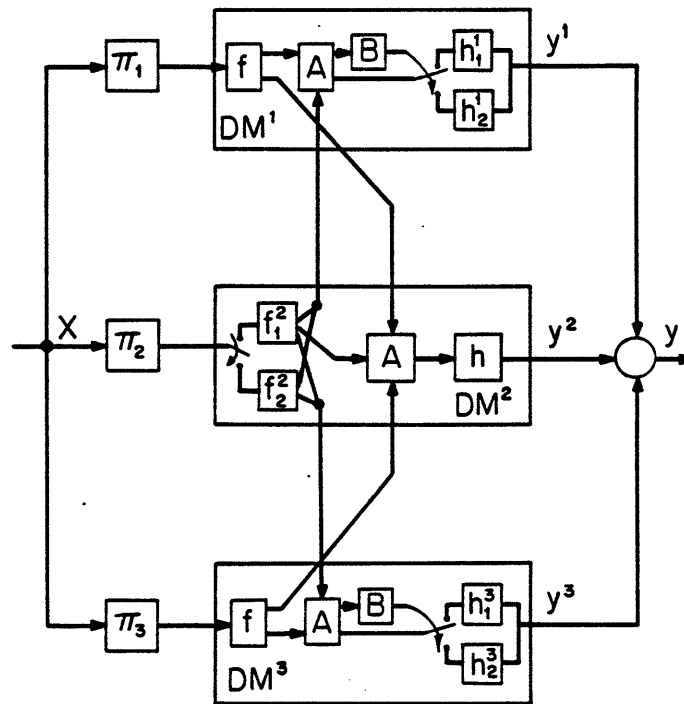
Figure 2 Organization A: Parallel

RS stage. The internal decision strategies are $p(v^1|\bar{z}^1)$, $p(v^2|\bar{z}^2)$ and $p(v^3|\bar{z}^3)$. The structure of this organization is shown in Figure 3.

The complete organization design in each case consists of the partition of the organization input, the specification of all the algorithms f, h, A and B, and the protocols for information exchange. For a given probability distribution on the targets, the total processing activity of each decisionmaker can be computed for the design as a function of internal decision strategies. To evaluate the design, it is necessary to account for the bounded rationality of organization members as well as to consider the organization's performance of the overall task.

Bounded Rationality and Performance Evaluation

The quantitative notion that the rationality of a human decisionmaker is not perfect, but is bounded, has been modeled as a constraint on the total activity G:

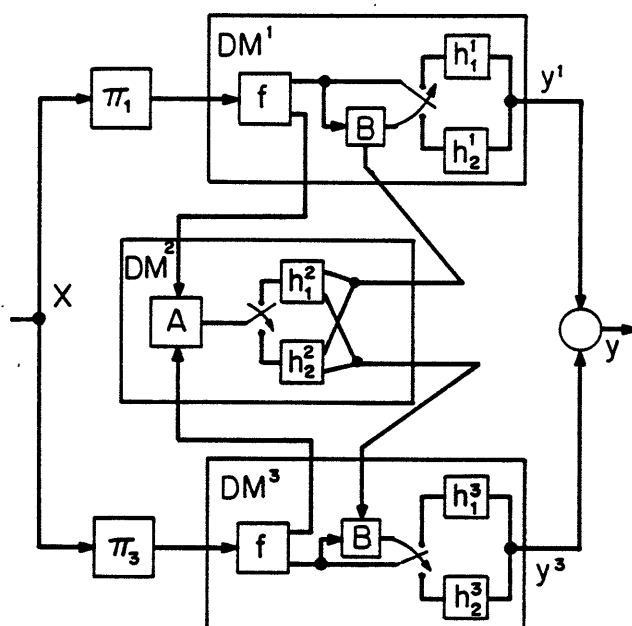$$G^i = G^i_t + G^i_b + G^i_n + G^i_c \leq F^i \tau \tag{12}$$

Figure 3   Organization B: Hierarchical

where τ is the mean symbol interarrival time and F the maximum rate of information processing that characterizes decisionmaker i.   This constraint implies that the decisionmaker must process his inputs at a rate that is at least equal to the rate with which they arrive.   For a detailed discussion of this particular model of bounded rationality see Boettcher and Levis [1].

The performance of an organization in accomplishing its task is evaluated using the approach shown in Figure 4.   The organization designer has a function or table L(X) which specifies a desired response Y for each input X.   The organization's actual response y can be compared to the one desired and a cost assigned using a function d(y,Y).   The expected value of the cost can be obtained by averaging over all possible inputs and serves as a performance index J.   For example, if the function d(y,Y) takes the value of zero when the actual response matches the desired response and the value of unity otherwise, then

$$J = E\{d(y,Y)\} \quad = p(y \neq Y) \tag{13}$$

which represents the probability of the organization making the wrong decision in response to inputs X, i.e., the probability of error.
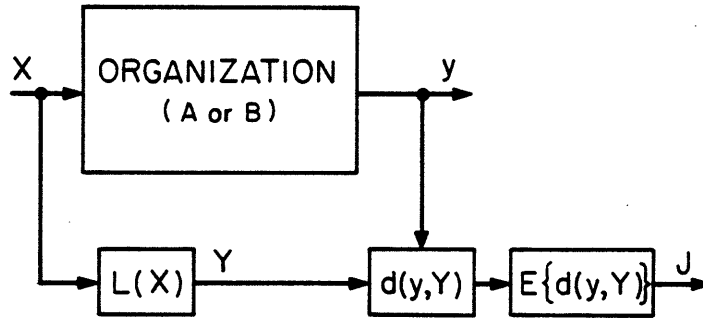
Figure 4   Performance evaluation of an organization.

Organizational Decision Strategies

As stated earlier, once the structure of the organization is determined, the actual values of total processing activity for DM^i, G^i, and the value of organizational performance J are functions of the internal decision strategies selected by each decisionmaker.   Let an internal decision strategy for a given decisionmaker be defined as pure, if both the situation assessment strategy $p(u)$ and the response selection strategy $p(v|\bar{z})$ are pure, i.e, an algorithm f_r is selected with probability one and an algorithm h_s is selected also with probability one when the situation assessed as being $\hat{z}$:

$$D_k = \{p(u=r) = 1; \quad p(v=s|\bar{z}=\hat{z}) = 1\} \tag{14}$$

for some r, some s, and for each $\hat{z}$ element of the alphabet $\bar{Z}$.   There are n possible pure internal strategies,

$$n = U \cdot V^M \tag{15}$$

where U is the number of f_i algorithms in the SA stage, V the number of h_j algorithms in the RS stage and M the dimension of the set $\bar{Z}$.   All other internal strategies are mixed [7] and are obtained as convex combinations of pure strategies:

$$D(p_k) = \sum_{k=1}^{n} p_k D_k \tag{16}$$

where the weighting coefficients are probabilities.

Corresponding to each $D(p_k)$ is a point in the simplex

$$\sum_{k=1}^{n} p_k = 1, \quad p_k \geq 0 \ \forall \ k \tag{17}$$

The possible strategies for an individual DM are elements of a closed convex hyper-polyhedron of dimension n-1 whose vertices are the unit vectors corresponding to pure strategies.

Because of the possible interactions among organization members, the value of G^i depends not only on $D^i(p_k)$ but also on the internal decisions of the other decision-makers. For the two structures under consideration, a pure organizational strategy is defined as a triplet of pure strategies, one from each DM^i:

$$\Delta_{k,\ell,m} = \{D_k^1, \ D_\ell^2, \ D_m^3\} \tag{18}$$

Independent internal decision strategies for each DM, whether pure or mixed, induce a behavioral strategy [7] for the organization, which can be expressed as

$$\Delta = \sum_{k,\ell,m} \Delta_{k,\ell,m} \ p_k \ p_\ell \ p_m \tag{19}$$

where p_k, p_ℓ, and p_m are the probabilities of using pure strategies, D_k^1, D_ℓ^2 and D_m^3, respectively. Because each DM is assumed to select his strategy independently of other DMs, the strategy space of the organization S^o is determined as the direct sum of the individual DM strategy spaces:

$$S^o = S^1 \oplus S^2 \oplus S^3 \tag{20}$$

where S^i denotes the individual DM strategy space. The dimension of S^o is $(n_1-1) + (n_2-1) + (n_3-1)$. For the specific structures of Organizations A and B $n_1 = n_3 = 4$ and $n_2 = 2$. Thus the possible organizational strategies are elements of a 7- dimensional closed convex hyperpolyhedron. The locus of performance and workload is constructed parametrically as Δ ranges over S^o:

Performance-Workload Loci

For organizations A and B the performance workload space is four-dimensional, namely (J, G^1, G^2, G^3). The G^i of each decisionmaker is a convex function of the Δ, eq. (19), in the sense that

$$G^i(\Delta) \geq \sum_{k,\ell,m} G^i(\Delta_{k,\ell,m}) p_k \ p_\ell \ p_m \tag{21}$$

where Δ_{k,ℓ,m_i} is defined in eq. (18). The result in eq. (21) follows from the definition of G^i as the sum of the marginal entropies of each system variable, eq. (8), and the fact that the possible distributions p(w), where w is any system variable, are elements of a convex distribution space determined by the organization decision strategies, i.e.,

$$p(w) \; \varepsilon \; \{p(w) \,|\, p(w) = \sum_{k,\ell,m} p(w|\Delta_{k,\ell,m}) P_k \; P_\ell \; P_m\} \tag{22}$$

The performance index of the organization can also be obtained as a function of Δ. Corresponding to each $\Delta_{k,\ell,m}$ is a value of $J_{k,\ell,m}$ of the performance index. Since any organization strategy being considered is a weighted sum of pure strategies, the organization's performance can be expressed as

$$J(\Delta) \quad \sum_{k,\ell,m} J_{k,\ell,m} \; P_k \; P_\ell \; P_m \tag{23}$$

From eqs. (21) and (23), it is possible to construct the locus of possible (J, G^1, G^2, G^3) points parametrically by varying Δ. To illustrate the characteristics of this four-dimensional locus, it is convenient to examine projections into spaces of lower dimension. Because of the similarity of DM^1 and DM^3 in each organization, the projections into the (J,G^1), (J,G^2) and (J,G^1,G^2) spaces are representative of the organization and are shown in Figure 5(a,b) and 6(a,b).
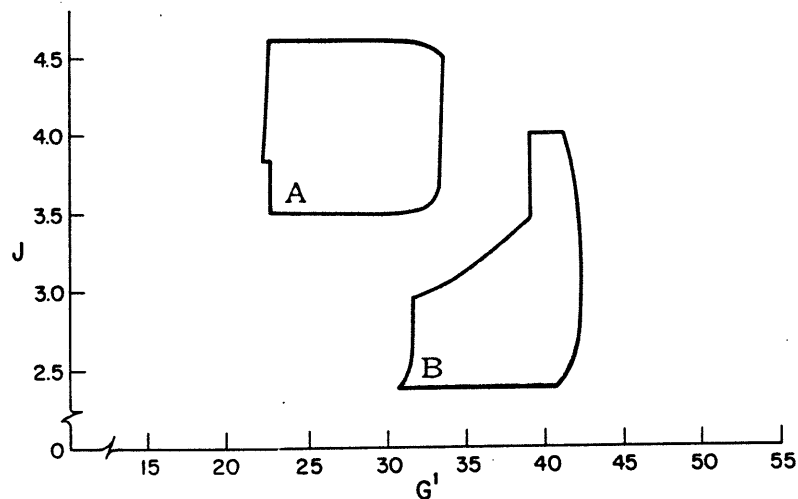

Fig. 5(a) Performance-Workload locus for DM^1 in Organizations A and B

Preliminary assessment of the two structures shows that Organization B is able to achieve a better performance than A. However, the realizable performances are overlapping, that is, depending on the particular strategies chosen, A may at times be better than B with respect to performance. In addition, the effect of a decision-maker's bounded rationality must also be considered. For DM^i, eq.(12) takes the form of a hyperplane orthogonal to the G^i axis and the value of $F^i\tau$ may be such that only
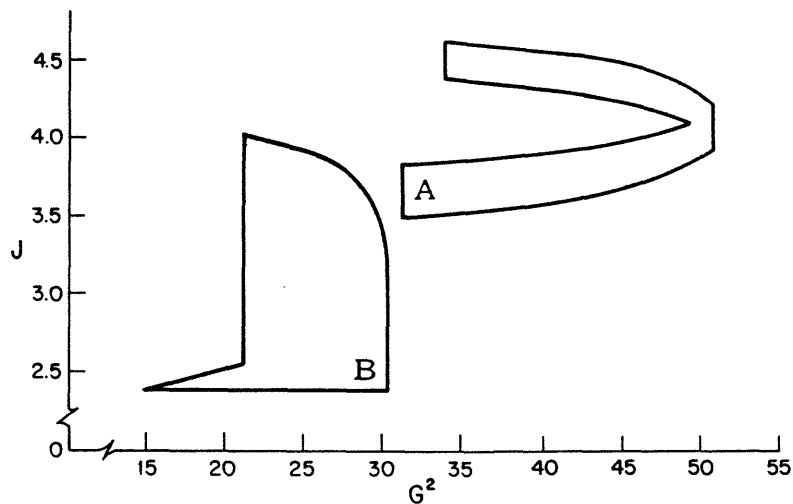
Fig. 5(b) Performance-Workload locus for DM^2 in Organizations A and B

a subset of the original locus satisfies the processing load constraint.

The possible constraints or design objectives expressed in terms of J and τ necessitate a method for evaluating alternative designs as a function of these quantities. In the present case, the choice is restricted to be between the two proposed structures. If the design criterion is such that $J \leq 5.0$ is required and τ is large enough, then both structures are acceptable. ·Conversely, for τ small
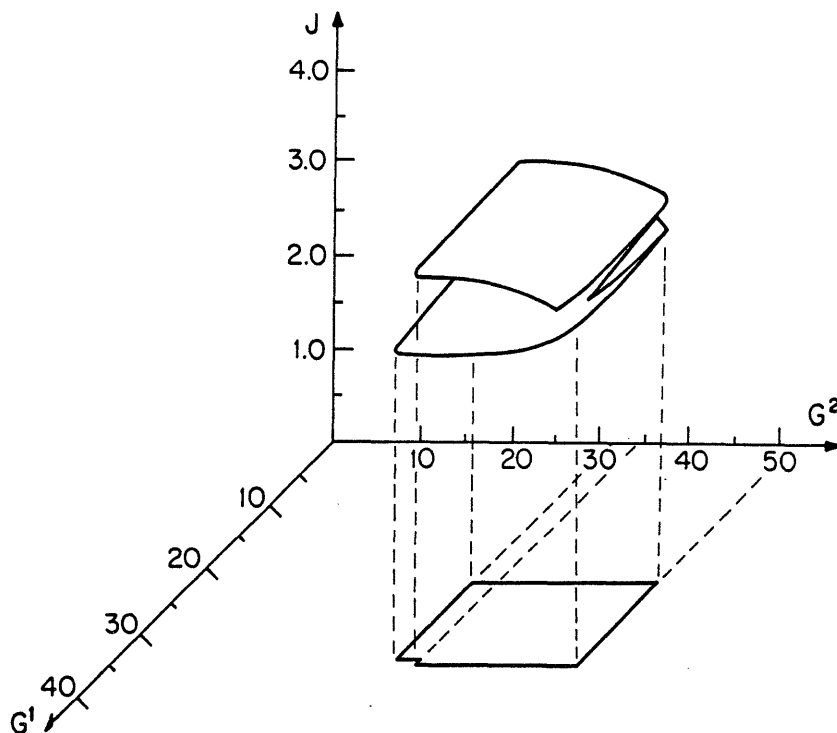

Figure 6(a) Projection of Performance-Workload locus of
Organization A in (J, G^1, G^2) space
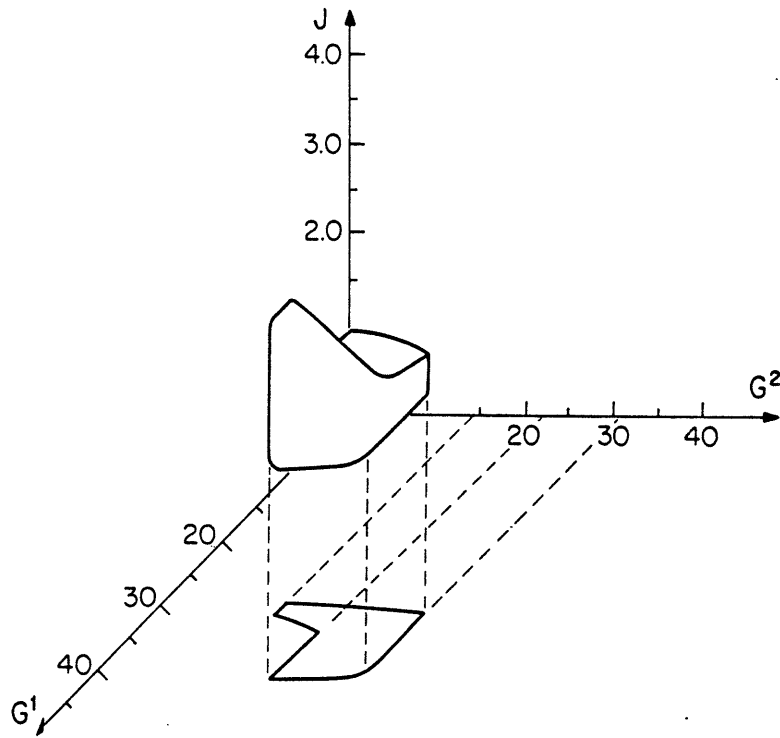
Figure 6(b)   Projection of Performance-Workload locus of
              Organization B in (J,G^1,G^2) space

enough and/or a performance requirement of $J < 2$, neither design is appropriate. Suppose, however, that $F^1 = F^3 = 20$ bits/sec and $F^2 = 25$ bits/sec. Then for $\tau = 2$ secs/symbol and a performance objective of $J \leq \bar{J} = 4$ it is not apparent which design is preferable. A means of making this assessment is the subject of the next section.

IV.   ASSESSING AND COMPARING ALTERNATIVE ORGANIZATION DESIGNS

From the viewpoint of the organization designer, specification of a structure means the allocation of information processing and decisionmaking tasks to the organization's members so that the overall task is performed without anyone being overloaded. In the implementation of a designed structure, however, individual decisionmakers select their own internal decision strategies independently of all other organization members. For given constraints on processing load and performance, a particular structure can yield a broad range of performance depending on the actual strategies chosen by the DMs. The designer must therefore also assess the likelihood that strategies which are organizationally acceptable will be selected, i.e., it must be insured that individual decision strategies are mutually consistent.

Organization design begins with a set of specifications to be met, a task to be performed. With the present framework, the designer proposes a particular structure and specifies the protocols and sets of procedures to be used by individual organi-

zation members. The selection of a specific procedure as the organization operates is left as a free variable, the organization decision strategy. To determine whether the design will meet the specifications, the designer must consider whether the possible combinations of individual member decisions which may arise will be consistent, on the whole, with design goals. For the present case, the design specifications include tolerable cost, $\bar{J}$, i.e., performance must be at least as good as $\bar{J}$, and a maximum tempo of operations, τ, with which the organization must be able to cope.

A possible measure of mutual consistency can be obtained as follows. Design specifications or constraints on performance, J, and total processing activity, G^i, eq. (12), taken individually, partition the space of organization strategies into subspaces of feasible strategies. The intersection of such subspaces represents those strategies which are mutually consistent for the given constraints. Comparison of the volume occupied by the feasible strategies with the total volume of the organization strategy space S^o is an indication of the likelihood that an acceptable organization strategy, eq. (19), will be obtained as a result of the individual choices of organization members. It is therefore an indication of how close the organization may come to satisfying the design specifications.

The problem is to determine, for a three-person organization and for given τ and $\bar{J}$,

$$\tau = \tau_o \quad ; \quad \bar{J} = \bar{J}_o$$

the subspaces A^i of organization strategies which are feasible with respect to the bounded rationality constraint of each DM:

$$A^1 = \{\Delta \mid G^1(\Delta) \leq F^1\tau_o\}$$

$$A^2 = \{\Delta \mid G^2(\Delta) \leq F^2\tau_o\}$$

$$A^3 = \{\Delta \mid G^3(\Delta) \leq F^3\tau_o\} \tag{24}$$

$$A^J = \{\Delta \mid J(\Delta) \leq \bar{J}_o\}$$

$$A^o = A^1 \cap A^2 \cap A^3 \cap A^J$$

The subspace A^J contains the feasible Δ's determined by the maximum cost value $\bar{J}$, and A^o is the overall feasibility subspace of the organization. The volume of A^o, denoted by $V(A^o)$, is compared with that of S^o, $V(S^o)$, to determine the measure of mutual consistency, Q, i.e.,

$$Q = V(A^o)/V(S^o)$$

In general, Q is a monotonic function of $\bar{J}$ and τ, with minimum zero and maximum one. The former case, Q = 0, implies that no combination of strategies of individual decisionmakers will satisfy the design specifications, while the latter implies that all organizational strategies are feasible, i.e., satisfy the bounded rationality and performance constraints.

The general characteristics of the various partitions of S^o which arise are subjects of current research. For the two organizational structures A and B of the example, however, the quantities in eqs. (24) are well-defined and can be computed to illustrate how one might compare and evaluate alternative structures using the measure Q.

The two independent variables in Q are the performance constraint $\bar{J}$ and the minimum task interarrival time τ. Therefore, Q can be plotted as a function of $\bar{J}$ and τ. The results for Organization A, the parallel structure, are shown in Fig. 7. Since low values of τ imply fast tempo and low values of $\bar{J}$ imply almost error-free performance, it follows that for low τ and $\bar{J}$ the value of Q is zero. As the constraints are relaxed, more and more organization strategies become feasible until all are feasible. This is shown by the surface Q = 1 in Fig. 7.
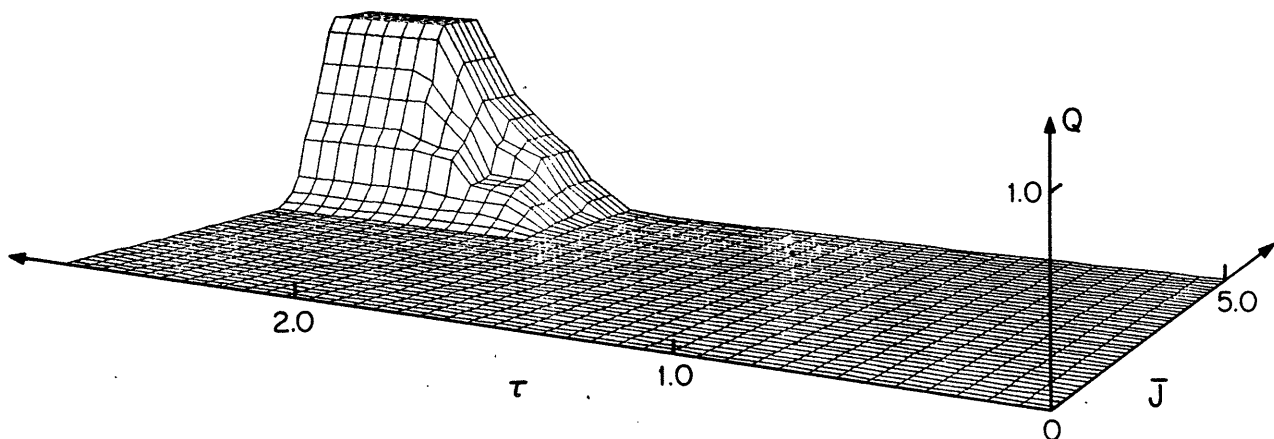

Figure 7   Mutual consistency measure Q vs. $\bar{J}$ and τ for Organization A.

Contours of constant Q have been plotted in the $(\bar{J},\tau)$ plane for each organization and are shown in Figs. 8 and 9. The shaded regions in each case represent values of $\bar{J}$ and τ for which the entire space of strategies is feasible or for which no strategies are feasible. It is possible that a practical design consideration might be to make sure that Q is equal to unity at the design specifications $(\bar{J}_o,\tau_o)$ Furthermore, it may also be desirable that the boundary of the unity contour be maintained a reasonable distance away from the design specifications. Such a consideration would provide for margins in the design to compensate for uncertainties

caused by unmodeled effects. On the other hand, it may well be that a likelihood of 80%, say, in selecting an acceptable organization strategy (Q = 0.8) provides adequate assurance that the design specifications will be met on the average.
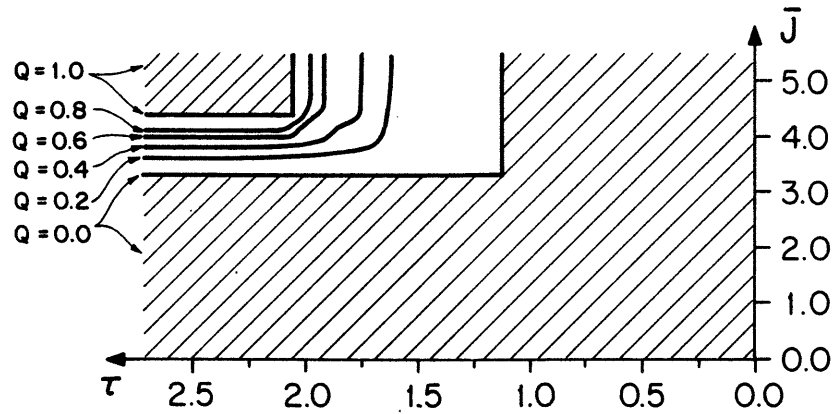

Figure 8 Constant Q loci for Organization A

Consider now the specific characteristics of the two organizations at hand. It is evident that organization B is able to meet a more stringent requirement on $\bar{J}$ than Organization A. However, A can cope with faster tempos of operation than B. If the design specifications are $(\bar{J}_o, \tau_o) = (2.0, 4.0)$ then the values of Q for A and B are 0.43 and 0.51, respectively. This implies that B is a more effective structure, in the sense that at that particular point a greater percentage of the possible strategies of Organization B yield satisfactory operation of the organization than those of A. Of course, depending on the desired or anticipated operating point, the comparison of Q values may result in the opposite conclusion. It is also necessary to consider how robust the value of Q is with respect to variations about an operating point. This requires information on the sensitivity of Q which can be determined from the surfaces generated as shown in Fig. 7 or can be assessed from the equi-Q contours shown in Figures 8 and 9.
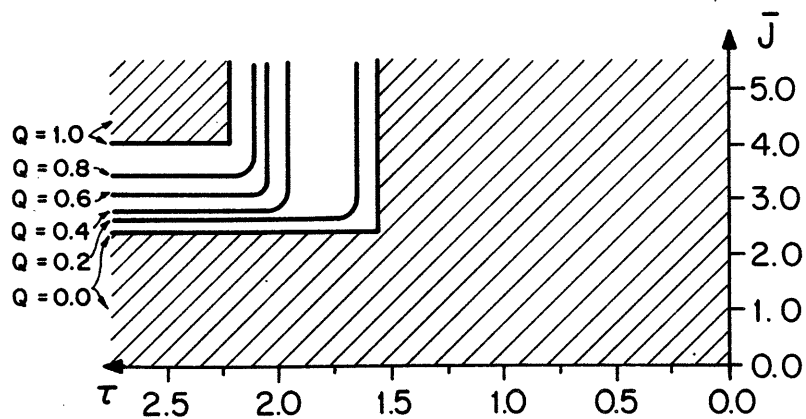

Figure 9 Constant Q loci for Organization B

V. CONCLUSION

In recent work, an approach to modeling an evaluation of information processing and decisionmaking organizations has been developed. The emphasis has been on describing an organization in a generalized performance-workload space where the performance refers to organizational performance and workload to the workload of each individual member. In this paper, a quantitative procedure has been presented for comparing alternative organizational structures. It is based on a comparison of how well the alternative structures can satisfy the design specifications for a minimum tolerable performance and for maximum tempo of operations.

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