NOT FOR QUOTATION
WITHOUT PERMISSION
OF THE AUTHOR

C^3 OR GARBAGE CAN—ALTERNATIVE MODELS OF ORGANIZATIONAL PERFORMANCE

John A. Buzacott

March 1981
CP-81-11

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
2361 Laxenburg, Austria

ABSTRACT

Two alternative approaches for modelling the performance of organizations are discussed--C^3 (command-control-communication) systems and the garbage can approach. Existing formal models using each approach are reviewed and some extensions and alternative models are proposed. The implications of the models are discussed, with particular emphasis on the impact of information technology developments on organizations.

ACKNOWLEDGMENTS

The motivation for the research in this paper grew from the author's involvement in the "Problems of Scale" task in the Management and Technology Area at IIASA. It was apparent that formal models are needed in order to clarify the relationship between organization structure and performance, in particular if it is desired to investigate the potential impact of information technology developments.

My thanks are due to IIASA for providing me with the opportunity to visit and write this paper and to the University of Toronto for financial support of the visit.

CONTENTS

C^3 OR GARBAGE CAN—ALTERNATIVE MODELS OF ORGANIZATIONAL PERFORMANCE

John A. Buzacott

INTRODUCTION

In order to understand the impact of new information technologies on organizational performance it seems desirable to have some model (or set of models) to describe the functioning of organizations. Such models should be based on clear concepts and assumptions and have a logical and, where possible, mathematical development and structure. The limitations on their validity can then be identified and further refinements can subsequently be incorporated.

The complexity of organizations is such that no one model can be fully comprehensive, if it were then it would be very difficult to understand its implications. It would probably give no more insight than a study of organizations as individual, isolated phenomena.

Thus, one is led to use a systems approach, selecting aspects and relationships in such a way that the essential features of the organization required to understand the issues of interest have been captured.

Since our concern is with the effect of information technology developments on the organization, it is obvious that information processing aspects will be central to the models. Further, since we are concerned with the performance of the organization, a central feature will be the decision making processes by which organizations direct their resources.

In this paper two contrasting modelling approaches are described. The basic philosophy underlying each approach is explained and the circumstances in which the approach is likely to be valid are assessed. This in turn leads to different views on the likely impact of new information technologies.

THE C^3 MODEL

C^3 Systems

C^3—Command, Control and Communication--systems have attracted considerable scientific interest recently (see for example IEEE 1980). However, the context of the discussion of their application is mostly military. That is, the focus has been on how the battle commander acquires information about the battle situation and controls the dispositions and actions of his forces in response to the actions and threats of the enemy. Actual implementations of C^3 systems appear to be characterized by a very high degree of sophistication in their use of information technology.

The analysis of C^3 systems has led to the formulation of some challenging scientific problems and to the development of sophisticated models. For example, consideration of the command and decision making issues when it is necessary to anticipate opponent reaction to alternative actions has led to sophisticated gaming models. Another aspect of decision making, coping with a number of tasks and the relevant information when the time available for performance of each task is limited, has led to complex combinatorial scheduling problems (Tulga and Sheridan 1980, Pattipatti et al. 1980). Another category of problems arises from the vulnerability of the communication links, making it necessary for the central command to assign appropriate local objectives to the local commander so that he will, in spite of limited information, pursue actions which support the overall objectives (Loparo 1980).

There are a number of issues considered in the C^3 literature which have relevance to issues discussed in the literature on organizational design. Further, the background of most scientists working on C^3 systems--control engineering and applied mathematics--is such that the C^3 literature is characterized by the widespread use of formal mathematical models, some of which appear to have been validated in experimental situations.

Drenick's Model

The C^3 system model which appears to be most relevant to our interest in information technology effects is that due to Drenick (Drenick

1980). He views the organization as being concerned with the acquisition of inputs and their processing to give various outputs.

The basic framework is as follows:

The set of inputs $x_i, i=1,2,\ldots,n$, is such that every Δ time units an input arrives with probability $p(x_i)$. The set of outputs is denoted by y_k and the organization must respond to each input within time Δ. If the output is y_k for input x_i there is a reward ψ_{ik}.

The organizational design problem is to choose the interconnections between members of the organization and prescribe their activities so that

$$E(\psi) = \sum_{i,k} \psi_{i,k} p(x_i) p(y_k \mid x_i)$$

is maximized, subject to the constraints which ensure that the organization responds within the required time Δ. The constraints on organizational response are formulated as constraints on the response of individuals. Each individual has a finite processing capacity and it takes a finite time t_{ik} for him to produce an output v_k if his input is u_i. Thus the way in which the processing capacity constraint will be met is through the individual choosing actions which are less desirable but which take a shorter processing time. That is, instead of producing v_k with desired probability $\bar{p}(v_k \mid u_i)$ it will be chosen with probability $p(v_k \mid u_i)$ so that

$$\sum_{i,k} t_{ik} p(u_i) p(v_k \mid u_i) \leq \Delta$$

where $p(u_i)$ is the probability the individual receives input u_i. Drenick calls the $\bar{p}(v_k \mid u_i)$ the "protocols."

To apply the model it is necessary to identify the basic functions of the organization. Drenick views simple organizations as consisting of three linked segments, "staff" who process incoming inputs, "executive" who take the preprocessed information from the staff and produce instructions and "line" who convert the instructions to action. He also postulates a Control Branch which monitors the performance of the different activities (see Figure 1) but his formal models do not seem to actually include the Control Branch.

If all paths from input to output pass through the "executive" (i.e., a centralized organization) then the model seems to have a fairly clear formulation and structure. However, in decentralized systems it may require rather careful prescription of the protocols to assure that there are no significant inconsistencies and maintain the separation of line and staff functions. In real decentralized organizations an individual can have both a staff and a line function so more complex processing capacity constraints may be required.

Note that the "staff" essentially preprocess inputs to prevent overload of the "executive" by enabling him to deal with issues more quickly. It is of interest that the model indicates that the "executive" can become the captive of his "staff" through the "staff" feeding him inputs to assure their desired outputs.

Possible Extensions

Drenick's model can obviously be easily adapted to investigate the effect of improved information processing (lowering the t_{ik} or modifying

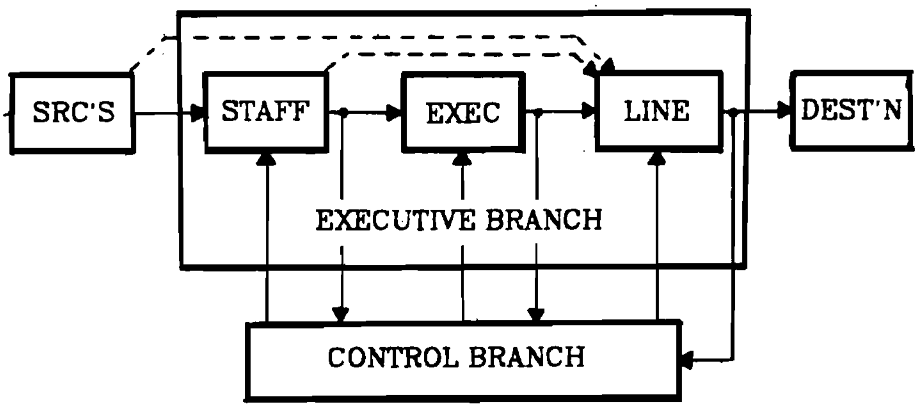

Figure 1. C^3 Organizational Structure (from Drenick 1980)

the $\bar{p}(v_k | u_i)$). It would also be possible to add to the objective function of the organizational design problem a term representing the organization costs (costs relating to the internal transactions).

An alternative model having the same underlying concepts could be developed by assuming that the organizational inputs arrive at random. This would result in queues forming at some locations within the organization. Models of queueing networks with multiclass jobs (Baskett et al. 1975), now extensively used to model computer systems and manufacturing systems, could then be used to analyze the performance of the organization with the $P_{is,jt}$, the probability that a job of class s at server i becoming a job of class t at server j, being used to define the protocols, (i.e., the action of the individual is the choice of class and destination). The organizational design problem is to select the protocols to maximize the overall performance measure $E(\psi)$ subject to constraints which ensure that no individual is, as a server in the queue network, overloaded.

The queueing network model of the organization would enable other types of performance measure to be considered, for example, measures relating to the speed of organizational response. Obviously, the major problem in applying the formal conceptual model to real organization is defining the set of feasible protocols for each organizational member. However, in C^3 systems and other organizations with clearly defined performance goals and well defined inputs and outputs, a reasonable set of protocols can probably be identified.

It should be noted that there would be no exact closed form solution to the queueing model in which associated with each $(i,s)\rightarrow(j,t)$ transition there is a processing rate $\mu(is,jt)$ which depends on s,j and t. Closed form solutions require that μ depend only on i and they are also restricted in the range of possible service discipline. Nevertheless, there is evidence that very good approximate results can be developed even when there are priorities (Buzacott and Shanthikumar 1981).

THE GARBAGE CAN MODEL

Organizations as Garbage Cans

The garbage can model views organizations as organized anarchies with no

> clear or consistent notions about what it is they are trying to do ... how it is they are supposed to do it ... or who it is that should make the decisions (Padgett 1980).

The organization is viewed as having problems, solutions, choice opportunities and participants all being tossed into and churning about in a garbage can. Action only occurs if simultaneously a problem, a solution, a choice opportunity and the relevant participants intersect (Huber 1980).

Garbage can models seem particularly appropriate for organizations in high stress or confronting unique situations. For example, Fisher's description of the behavioral responses at the Bravo and TMI accidents seem to indicate many features of garbage can behavior (Fisher 1981).

Padgett's Model

The only formal garbage can model in the literature seems to be that due to Padgett (Padgett 1980). However, his model has some rather specialized and unique features. He considers a bureaucratic organization with a hierarchical structure in which information and program recommendations flow from the base to the apex. His focus is on the decision making at the apex (Presidential level) and the recommendations at the level below (Secretarial level) in the case where there are distortions or bias introduced as the information and recommendations flow from the base to the apex but where it is to some extent open to the President through choice of appropriate Secretary to modify the general direction or extent of the bias.

It is of interest to note that the author concludes from his model that the correct strategy of the President is to choose Secretaries in such a way that he never has to make any decisions himself.

Although the development seems completely unrelated, there are a number of general similarities between Drenick's C^3 model and Padgett's garbage can model. That is, the garbage can element in Padgett's model enters because of the inherent unreliability, bias and general probabilistic behavior of individuals in the organization. Because Drenick assumes probabilistic behavior it is possible that the C^3 model might behave like Padgett's model. However, it should be noted that Drenick assumes that individual behavior can be created by specification of a protocol while Padgett assumes that behavior is inherent in the individual so must be created by selecting appropriate individuals.

An Alternative Garbage Can Model

Other aspects of the garbage can model, in particular the process of "solutions" finding "problems," seem also to be appropriate for formal modelling.

Conceive the organization as having the basic structure shown in Figure 2. The President is located at the center, surrounded by successive layers of managers who insulate him from the environment. Furthermore, suppose that there is some sort of managerial specialization by function, product line or market region. The organization could have the hierarchical structure of Figure 3.

Our assumption will be that "solutions" arise in the environment. They will appear as signals denoting such events as new inventions, market place actions by competitors, government information releases or even rumour generation on the stock exchange. The events will be assumed to

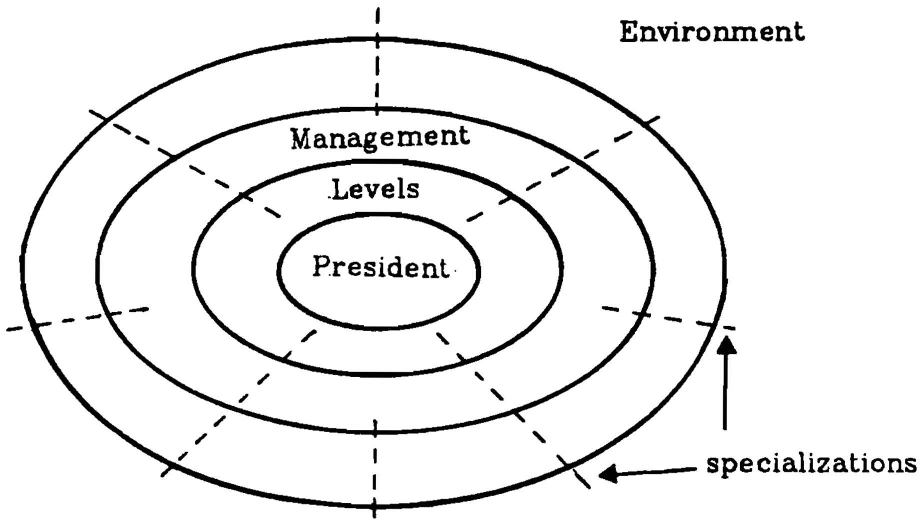

Figure 2. Basic Structure of Organization

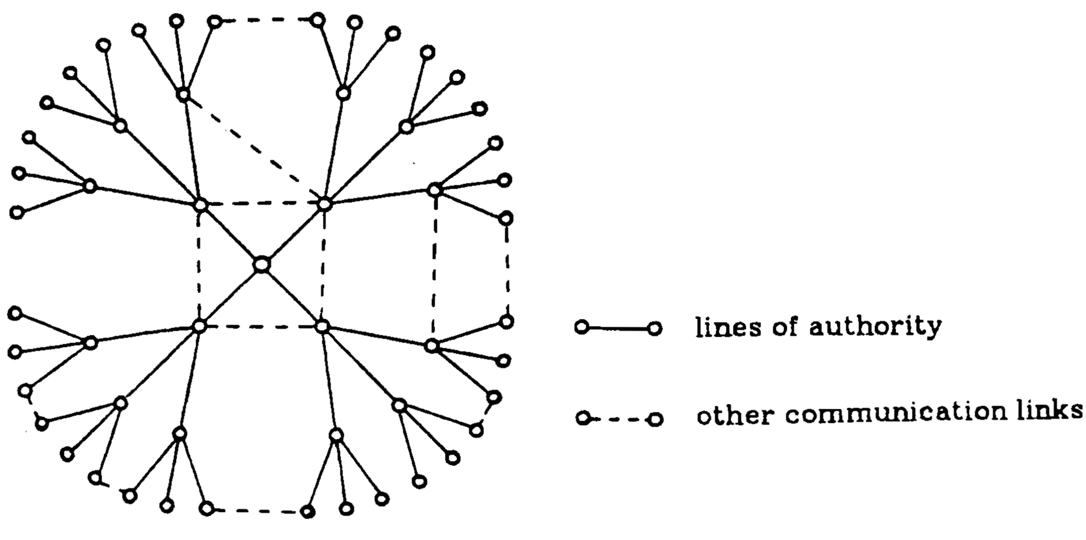

Figure 3. Garbage can Organizational Network
(Each member has also links to environment)

be surprises so there is a finite probability that an event will not be noticed by anybody in the organization.

On the other hand, it will be assumed that "problems" are defined by the President. His role is to formulate goals for the organization and identify issues or problems for which solutions are required. Very often the problems will appear most relevant to some management specialization.

At this point there seem to be two alternative modelling approaches a "connectivity" model or a "message communication" model. Each is described briefly.

Connectivity Model

Assuming certain probabilities of perceiving environmental events and of passing on this perception to other organization members it would be possible to determine p_{is}, the probability organization member i is aware of environmental event s. Existing algorithms for finding graph connection probability measures can be used (Buzacott 1980). Using a similar approach it would also be possible to determine r_{it}, the probability that organization member i is aware of President's goal t.

Then the probability that the problem will be solved by organization member i is given by

$$P_{it} = r_{it} \prod_{S(t)} p_{is}$$

where $S(t)$ is the set of environmental events which together define the solution to the problem defined by goal t. It would also be possible to develop an algorithm to find the probability that some member of the organization finds the solution to the problem (note--this is not given by $\sum_i P_{it}$ because events i finding the solution and j finding the solution are not mutually exclusive).

The use of the connectivity model requires that the probabilities of message flow along arcs and through nodes be given. Huber (1980b) has proposed a number of hypotheses on the way in which these probabilities depend on various aspects of the organizational structure. Laing (1980) also describes some experimental results on the communication of messages and draws some conclusions on the way in which the structure of the organization will be constrained as a result of these error probabilities.

Message Communication Model

There are two significant limitations to the connectivity model. It ignores "forgetting," that is a signal may be perceived but it is forgotten by the time some other relevant signal occurs. To some extent this can be allowed for in the connectivity model by associating a time with the occurrence of each event $s \varepsilon S(t)$ and requiring the events to occur within a certain time range but the forgetting process is probably more complex than this.

The other limitation of the connectivity model is that it ignores time delays in the propagation of information through the network. While a queueing network model could capture some elements of the process of propagation of information through the network if it is augmented to allow such erroneous actions by servers as directing a job to leave the system instead of forwarding it up the hierarchy (or vice-versa), such a model disregards one property of the type of information being considered. One piece of information can split into many equal and equivalent pieces, each of which can follow different paths, but if two equivalent pieces should meet (and are recognized as being equivalent) then they merge into one piece again. This splitting and merging is not captured by existing queueing network models.

An approach which does represent aspects of splitting and merging is the description of information flow and processing by Petri nets (see Ellis, Gibbons and Morris 1980 for an application to describe an office procedure). However, methods of analysis of unreliable Petri nets seem to be still at a primitive level (see Joller 1980 for some preliminary ideas). Thus it seems that it is not yet possible to model information flow as an unreliable Petri net and so for the moment no adequate message communication model is available.

Some Comments

It is apparent from the connectivity model that the fewer the barriers and the stronger the connections, between the President and the environment the more likely it is that problems will find solutions. Furthermore, the ideal network structure is probably to maximize connections across specializations subject to some constraint limiting the degree of each node. This constraint is required because the probability of node failure would increase with the number of connections, and probably quite rapidly beyond some value.

Of course, in reality, even though a problem has found a solution resources would also be required in order to implement the solution. Thus it may be necessary to carry out a further analysis and multiply the probability that organization member i is aware of both problem and solution (P_{it}) by the probability that organization member i has the resources or status to get the solution implemented. This would no doubt depend on his position in the formal organizational hierarchy.

CONCLUSIONS

Contrast in Perspectives of the Models

The key distinction between the two models is that in C^3 systems there are clear goals with information acquisition being directly linked to the achievement of these goals. In garbage can systems goals are more diffuse and random and information "happens" rather than being focussed on acieving goals.

Thus, it would seem that C^3 systems are likely to be good descriptions of the way in which organizations meet the well defined short run goals. On the other hand, garbage can systems probably describe the way in which organizations meet the vaguer and more diffuse long run goals.

It is interesting that the C^3 model (and Padgett's garbage can model) suggest that to a large extent it is possible to bypass the Executive or Presidential function while our connectivity garbage can model makes the Presidential function central and recommends as few barriers as possible between him and the environment. That is, between them the models support the theory that Presidents or Executives should devote their attention to long term objectives once they have selected staff who can look after the short term objectives.

Effect of Information Technology

The two approaches also lead to differing conclusions as to the potential impact of information technology. In C^3 systems information technology, with its ability to speed up the flow of information and increase the sophistication of decision making, should have a very significant impact. On the other hand, garbage can systems do not seem to be likely to be much influenced by information technology changes. Although conferencing systems might help increase contact between different parts of the organization, moving people around the organization might be a better way of increasing awareness of the nature of organizational goals as it is not clear that existing information technology is particularly effective in transmitting vague notions. Environmental perceptions might be enhanced by using techniques developed for artificial intelligence but it would seem that significant research is still required. Thus it can be hypothesized that the technology per se will not have a significant impact although in the long run the more abstract computer science methodologies might result in considerable improvements when implemented by the organization.

Research Needs

Further research is required on numerous aspects of the approaches outlined in this paper, ranging from mathematical model refinement to collection of data on probabilities of message transmisson in organizations. However, while a close watch should be kept on developments in the methodology for analyzing C^3 systems, it is unlikely that any institution without links to the military and their resources can hope to make significant contributions. The garbage can approach, because it is so contradictory to the military mind in its basic philosophy, warrants much more intensive research, particularly with its focus on the way organizations cope with surprises and meet long term goals. Furthermore, it seems to be much less clear as to what, if any, will be the impact of information technology and hence there is a need for a larger research effort by other individuals and institutions.

REFERENCES

Baskett, F., K.M. Chandy, R.R. Muntz and F.C. Palacios. 1975. Open, Closed and Mixed Networks of Queues with Different Classes of Customers. Journal of the Association for Computing Machinery. 22(2):248-260.

Buzacott, J.A. 1980. A Recursive Algorithm for Finding Reliability Measures related to the Connection of Nodes in a Graph. Networks. 10:311-327.

Buzacott, J.A. and J.G. Shanthikumar. 1981. Approximate Queueing Models of Job Shops. Paper to be presented at ORSA/TIMS meeting, Toronto, May 1981.

Drenick, R.E. 1980. A Mathematical Approach to Decision Theory. Proceedings of 19th IEEE Conference on Decision and Control. pp.613-624.

Ellis, C., R. Gibbons and P. Morris. 1980. Office Streamlining. Paper presented at ORSA/TIMS conference, Washington, May 1980. Office Research Group, Xerox Palo Alto Research Center.

Fisher, D.W. 1981. Organizing for Large-Scale Accidents: Experiences from the Bravo and Three Mile Island Accidents, in J. Lathrop (ed.), Procedural and Organizational Measures for Accident Management: Nuclear Reactors. Oxford: Pergamon.

Huber, G.P. 1980a. Organizational Science Contributions to the Design of Decision Support Systems. In: G. Fick and R.H. Sprague, Jr. ed., Decision Support Systems: Issues and Challenges. pp.45-55. Oxford: Pergamon.

Huber, G.P. 1980b. Organizational Information Processing Systems: Logistical Determinants of Performance and Behaviors. Working Paper, Graduate School of Business, University of Wisconsin, Madison.

IEEE. 1980. Proceedings of 19th IEEE Conference on Decision and Control, Albuquerque, N.M. December 1980. New York: Institution of Electronic and Electrical Engineers.

Joller, J.M. 1980. Reliability Block Diagrams and "Petri" Nets. Microelectronics and Reliability. vol.20:613-624.

Laing, G.J. 1980. Communication and its Constraints on the Structure of Organizations. Omega. 8(3):287-301.

Loparo. 1980. Overlapping Control Structures and Security in Large Scale Systems. Proceedings of 19th IEEE Conference on Decision and Control. pp214-218.

Padgett, J.F. 1980. Managing Garbage Can Hierarchies. Administrative Science Quarterly. 4:583-602.

Pattipatti, K.R., D.L. Kleinman and A.R. Ephrath. 1980. A Model for Real-Time Human Decision Making in a Multi-Task Environment. Proceedings of 19th IEEE Conference on Decision and Control. pp.415-421.

Tulga, M.K. and T.B. Sheridan. 1980. Dynamic Decisions and Work Load in Multitask Supervisory Control. IEEE Transactions on Systems Man and Cybernetics. SMC-10(5):217-232.