A Dynamic Comparison of Organization Design Alternatives

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Abstract The purpose of this paper is to explain, in terms of a simple model, the structure of formal organizations, and to show how external events can affect their performance. The conceptual viewpoint used to describe the coordination occurring within organizations, is that of the decision-making theories of organization design, namely, that organizations are information processing systems with problem solving units connected by a communication network.

We begin by modeling a basic coordination structure (functional hierarchy), as a set of actors (processors and managers) who are connected together by communication lines. Then, queuing models are employed to analyze the execution of tasks by processors and the processing of results by managers. A production function is defined, which considers the average delay for both processors and managers. Then we introduce the concept of environmental uncertainty. We explain how it relates to structure, and how it can affect the organization's productivity.

In order to cope with this uncertainty, we have considered four alternative organizing strategies (Galbraith 1977): (1) creation of slack resources, (2) creation of self-contained tasks, (3) investment in information systems, and (4) creation of lateral relations. Each of these strategies is applied to the initial coordination structure, and for each case we define a production cost equation. In addition to production costs, we also analyze coordination and vulnerability costs. Then, based on these costs we make a comparison of the four strategies, pointing out the trade-offs between them.

In conclusion, since we consider management delay time in our model, we are able to explain in more detail the trade-offs between the alternative strategies.

1 INTRODUCTION

The main purpose of this paper is to explain, in terms of a simple mathematical model, the structure of formal organizations, and to show how external events can affect their efficiency. It is this loss of efficiency, that will force an organization to adopt one or more alternative structuring strategies that may improve its overall performance.

2 BACKGROUND RESEARCH

The model proposed in this paper is based on work by Malone (1987) and Malone and Smith (1988), and the alternative strategies we analyze are based on work done by Galbraith (1977). The perspective of organizations taken here, is that of the organizational decision-making theories (March and Simon 1958; Cyert and March 1963; Simon 1976).

Malone (1987) and Malone and Smith (1988) developed models for comparing the performance of coordination structures – various forms of markets and hierarchies. Their view highlights the importance of assigning tasks to processors as one of the fundamental components of coordination.

Then, drawing primarily on queuing models, they analyze and compare these structures in terms of three performance measures: production, coordination, and vulnerability costs.

The main difference with their work, is that, in addition to considering the assignment of tasks to processors as one of the components of coordination, we also include in our model the handling of exceptions occurring due to a dynamic and uncertain environment. This additional coordination necessary to cope with exceptions will not only increase the amount of information exchanged between actors in order to take decisions, but will also generate delay costs, which will affect the organization's productivity and vulnerability.

In contrast to Malone (1987) and Malone and Smith (1988), we extend our analyses to include the delay time incurred by management in making decisions. In our analyses we do not include market-like coordination structures. However, we do include in addition to hierarchical coordination structures, two more organizing strategies: investment in information systems, and creation of lateral relations. These two strategies, as well as the concept of task uncertainty were studied by Galbraith (1977), who explained why task uncertainty is associated with variations in organizing modes. Since we consider management delay time in our model, we are able to explain in more detail the trade-offs between the different strategies.

3 MODEL DEFINITION

3.1 *Uncertainty and Information Processing*

We begin by describing a coordination structure that models some of the information processing that takes place in organizations. Figure 1 shows the basic coordination structure we have considered: a functional hierarchy. While there are many other possible coordination structures, the functional hierarchy represents one of the structures which organizations usually adopt as they grow (Galbraith 1977; Mintzberg 1989).

In a functional hierarchy, a number of processors of similar types (P_i) are pooled in functional departments (FM_i) and shared among products [1]. This sharing of processors may reduce duplication of effort and may allow processing loads to be balanced over all products. Hence, under stable conditions (no competitive pressure), the functional hierarchy will generally have lower production costs in relation to a product hierarchy (Malone 1987; Malone and Smith 1988).

When an organization's environment is stable, much of its activity can be preplanned. On the other hand, if we consider a dynamic environment due to technological changes, product diversity, or increased competition, then during the actual processing of a task[2], exceptions[3] may occur, and will require decision-making in order to cope with them.

We have considered that these exceptions occur mainly at the processor level (see figure 1), and are communicated to the functional manager in charge of the department, which in turn, has to take a decision, and refer the problem one level higher in the hierarchy.

Based on these assumptions, we describe in detail our basic model of information processing in a functional hierarchy. The analysis of this model as well as that of the alternative strategies are presented in section 3.3.

[1] In this paper the word *product* has a much broader meaning than that of a tangible good. The word *product* will be used hereon to refer to any type of product or service, tangible or intangible.

[2] The word *task* refers to one part of the total job necessary to complete a *product*. For example, the task of designing a new product, the task of manufacturing it, the task of testing it; all these tasks will fit together to make a final product.

[3] An *exception* can be thought of as a situation or event that has not been anticipated in advance. Therefore, no behavior program appropriate for the situation yet exists.

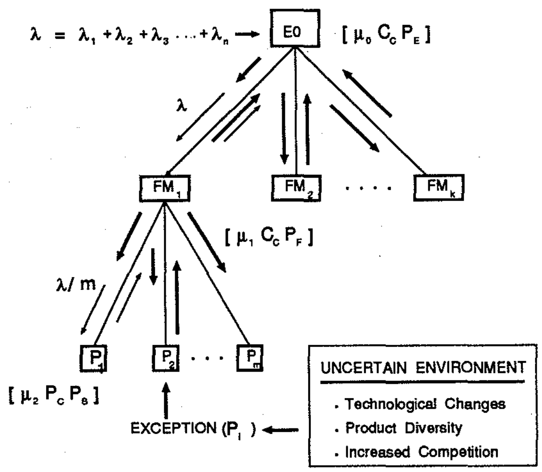

Figure 1: Coordination Structure (Functional Hierarchy)

3.2 *Functional Hierarchy*

The coordination structure shown in figure 1 can be thought, for example, as a manufacturing organization in which the functional departments represent the design, production, and sales department.

Whenever a task of a certain type needs to be done, the executive office (EO) delegates the task to the functional manager of the appropriate type, who in turn, assigns the task to one of the processors in the department.

Therefore, to assign a task four messages are required: One to delegate the task to the appropriate functional manager, one to assign it to a processor, and two to notify the functional manager and the executive office that the task is complete. In order to exchange these messages, the executive office must have a communication link to each functional manager, and each functional manager must have a link to the processors in their department.

In the normal process of assigning tasks to managers and processors, the executive office works as a coordinator between the different areas. His job is mainly that of planning and organizing. In contrast, the functional manager spends most of his time scheduling tasks to processors and making sure they are done (a control function). These activities will consume part of their decision-making and information-processing capacity.

When exceptions occur, we have assumed they will occur at the processor level of each functional department. The processor where the exception occurs, sends a message to the functional manager of the department, who after processing the message will in turn notify the executive office. The executive office will request the necessary information from the other functional managers in order to take a decision. This request of information will require two messages per functional manager. Once the decision is made, it will be informed throughout the entire organization. To realize this, the executive office will begin by informing the functional managers, and these will then proceed to inform the processors in their respective departments. The total number of messages required will be:

$$\text{Total Number of Messages} = \text{Number of Functional Managers} \times \text{Processors per Functional Department}$$

The process of informing the whole organization about exception-related decisions, corresponds to teaching the organization's employees about the job-related situations they may encounter, and the behavior appropriate to those situations. All organizations employ these behavior programs, call them rules or procedures. The use of procedures will eliminate the need for communication between actors for those situations anticipated in advance.

The decision taken by the executive office, as well as the processing of exceptions by the functional manager of the department were they occur, will both require time, and will consume decision-making capacity. Therefore, they will delay the processing of the task and hence generate a "delay cost".

We will further consider that the executive office, as well as the functional managers may fail in their decision-making processes. The reason for this, is that as their cognitive capacity becomes loaded, they will not be able to acquire and process all the information necessary for a decision. In contrast to Malone (1987), we assume that the probability of failure of these actors is not fixed, but rather a function of their processing capacity and load.

3.3 *Alternative Strategies*

Creation of Slack Resources As a first strategy to handle exceptions, the organization can simply reduce its level of performance. For example, the scheduled time for the design of some new product could be increased. This increase in time will represent an additional cost for the organization. We will apply this strategy to our basic organization a functional hierarchy (FH).

Creation of Self-contained Tasks The creation of self-contained tasks as a strategy to handle exceptions, will reduce the need for information processing, rather than increase the capacity to process information (Galbraith 1977). The main point in this strategy is to change from the functional hierarchy to one in which each group has all the resources it needs to perform its task. The resulting structure is often called a product hierarchy (PH).

Investment in Information Systems The use of Information Systems (IS) as a strategy to handle exceptions, reduces the time and cost of processing and communicating information. As a result of increasing the processors' capacity, these will have a higher total capacity cost. On the other hand, the average delay cost will be reduced. The delay cost due to exceptions will also decrease, because the managers' decision capacity has also been increased.

Creation of Lateral Relations The use of Lateral Relations (LR) as a strategy to handle exceptions, will increase the organization's capacity to process information. This is achieved by the use of lateral decision processes which cut across lines of authority. This mode moves the level of decision making down to where the information exists rather than bringing the information up to the points of decision. In few words: Delegation.

4 COMPARISONS

In order to compare the costs of the four exception-handling strategies explained above, we consider the following assumptions:

The initial scenario is that of an organization structured as a functional hierarchy. We also assume, that at the time of formation, the environment was stable and certain.

Initially, all actors in the organization (processors and managers) work under the same processing load. That is, for each actor the relation between arriving tasks (λ) and processing capacity (μ) is the same. In our model, this assumption means the following relation:

$$\rho = \frac{\lambda k}{\mu_0} = \frac{\lambda}{\mu_1} = \frac{\lambda}{m\mu_2} \tag{1}$$

From the above relation, it is clear that the executive office has a greater capacity than a functional manager ($\mu_0 > \mu_1$), and that a functional manager has a larger capacity than a processor.

These differences in processing capacity can be explained by the nature of the work of each of the actors.

The exception rate for all functional departments $(1, 2, \ldots, k)$ is the same and is equal to p. Therefore, in all cost equations the following simplification can be made:

$$\sum_{i=1}^{k} P_i \longrightarrow P \times k \tag{2}$$

Since $P = (1 + p)$, and p has a value in the range of $0 \leq p \leq 1$, P will vary between 1 (0% exception rate) and 2 (100% exception rate: all tasks generate exceptions).

Vulnerability costs are proportional to the costs of reassigning tasks and the costs of disrupting products due to the failures of task processors, product managers, functional managers or the executive office.

Processors and managers sometimes fail, and they do so at rates proportional to their processing load (ρ).

The cost of reassigning tasks from one processor to another (C_D) is less than the cost of disrupting a product (C_S). And the cost of disrupting all products (C_L) is at least n times as much as the cost of disrupting a single product (C_S). Put in a different way, $C_D < C_S < C_L$ and $nC_S \leq C_L$.

In comparing the production costs for the organizing strategies, we only made a comparison between the variable cost component (operating cost) of the production costs. The fixed cost component (capacity cost) is the same in all cases, except for the information systems strategy, in which it may differ considerable. However, the relation between the cost of information systems and human processors per task can be considered quite small ($\mu_2' P_C' / \mu_2 P_C < 1$ and $\mu_1' C_C' / \mu_1 C_C < 1$) (Scott Morton 1991). This comparison is done in section 4.1.

In order to calculate the production cost for the information systems strategy, it was necessary to find appropriate values for μ_0, μ_1, and μ_2. Lacking this type of information, we decided to use the computerization quotients given by Hussain and Hussain (1988), and shown in table 1.

Table 1: Calculation of the Computerization Coefficient for different levels of Management

Function	Percent susceptible to computerization	Top management: Percent of total job	Top management: Weighted value	Middle management: Percent of total job	Middle management: Weighted value	Operating management: Percent of total job	Operating management: Weighted value
Planning	30%	70%	21%	20%	6%	5%	1.5%
Organizing	15	10	1.5	10	1.5	5	1.0
Staffing	25	10	2.5	10	2.5	5	1.5
Direction	5	5	-	20	1	20	1.0
Control	80	5	4	40	32	70	56.0
Computerization quotient			29%		43%		61%

Source: Jerome Kanter, Management-Oriented Management Information Systems (Englewood Cliffs, NJ: Prentice-Hall, 1982).

4.1 *Production Costs*

With the previous assumptions in mind, we may now transform the production cost equations for all strategies to those shown in table 2.

Table 2: Production Costs

STRATEGY	FIXED COST	OPERATING COST
FH	$km\mu_2 P_C$	$D_C[k(E_{LL} + m\rho) + \frac{P\rho(k+1)}{1-P\rho}]$
PH	$kn\mu_2 P_C$	$D_C[\frac{nk\rho}{1-\rho} + \frac{P\rho}{1-P\rho/n}]$
IS	$km[\mu_2 P_C + \mu_2' P_C']$	$D_C[k(E_{LL}' + \frac{m\rho}{1.61}) + \frac{Pk\rho}{1.43-P\rho} + \frac{P\rho}{1.29-P\rho}]$
LR	$km\mu_2 P_C$	$D_C[k(E_{LL} + m\rho) + \frac{Pk\rho}{1-P\rho} + \frac{P\rho(1-d)}{1-P\rho(1-d)}]$

If we look at the operating cost component of the production cost for the functional hierarchy (FH), we can observe that while no exceptions occur ($P = 1$), the organization will have its processing load uniformly distributed over all actors. However, as the exception rate increases, the organization will lose its balance, and management's load will begin to increase while the processors remain idle.

The use of information systems (IS) does not redistribute the load, but rather copes with uncertainty by increasing the processing capacity of the organization's actors. An increase in capacity will mean a decrease in the average delay time.

Delegation of decision making is a way to distribute the extra load to lower levels in the organization. This can be done, for example, by using lateral relations in many parts of the organization. In our model, lateral relations (LR) have only been applied to the functional manager level. The factor $(1 - d)$ in the operating cost component of the LR strategy equation, effectively unloads the executive office. Since functional managers take d% of the executive office decisions for her, and they do it in parallel, there is no increase in the production cost. However, as we mentioned before, all strategies have a cost. The cost of creating lateral relations, is not reflected in the production costs, but rather appears as an increase of the coordination costs.

From the above equations, it can be shown that:

$$PC_{IS} < PC_{LR} < PC_{FH} \tag{3}$$

The relative ranking for the product hierarchy strategy (PH) will depend on the number of products (n), the organization load (ρ), and the exception rate (p). Nevertheless, certain relations can be logically inferred. For example, if we consider two products (the minimum for a product hierarchy), three functional departments ($k = 3$), and a 75% decision delegation for the task force, we can graph the resulting production costs for different organization loads ($0\% < \rho < 50\%$). We are considering a benign environment, that is, $p = 0\%$.

According to the results of our calculations, the PH strategy has a larger cost than the IS strategy, but a smaller cost than the other strategies. Now, if we increase the number of products (and hence the number of processors), the curve for the PH strategy will slowly rise above those for the other two strategies. For the case of four products ($n = 4$), the PH strategy reveals the highest costs among them. The reason for this increase, is that as the number of processors increase, the economies of scale due to processor sharing within the functional hierarchy become larger, and outperform the economies obtained by the product hierarchy for having a smaller load.

In summary, in a stable environment the product hierarchy will normally have higher production costs than a functional hierarchy (Malone 1987).

However, we want to know what happens when the environment is no longer stable, that is, when exceptions arise. To answer this, we will analyze separately the two components of the production operating costs: processor delay and management delay.

It is not possible to differentiate between the processor delay for the functional hierarchy and that for the lateral relations strategy. Both have the same value, since lateral relations were only applied to the functional manager level. However the product hierarchy has the highest average delay time, since it does not share processors among its product lines. On the other hand, if we analyze the management component of the production costs, we will notice the exact opposite. Product hierarchies have lower management costs, since product managers only attend the tasks related to one product.

Now, when exceptions arise, organizations begin to lose their balance, and while processors can be working under a 50% load, for example, managers may be working at higher loads. When this happens, the self-contained tasks strategy begins to show its advantage with respect to the other strategies. Depending on the organization load and the level of uncertainty, the product hierarchy can outperform the functional hierarchy and lateral relations strategies.

4.2 *Coordination Costs*

In order to compare the coordination costs of the alternative strategies, we first separate and simplify the cost equations as shown in table 3.

Table 3: Coordination Costs

STRATEGY	FIXED COST	OPERATING COST
FH	$(k+1)\mu_1 C_C$	$kC_M\lambda[4+pk(3+m)]$
PH	$n\mu_1 C_C$	$kC_M\lambda[2+pk(3-1/k)]$
IS	$(k+1)[\mu_1 C_C+\mu_1' C_C']$	$kC_M\lambda[2+pk(1+\frac{1}{k}+m)]$
LR	$(k+1)\mu_1 C_C$	$kC_M\lambda[4+pk(3+m+d(k-4+\frac{2}{k}))]$

Since m (number of processors) can be assumed to be greater than one ($m>1$), the operating cost component of the above equations can be ranked in the following order:

$$CC_{PH} < CC_{IS} < CC_{FH} \quad (4)$$

For values of k smaller than four ($k<4$), the lateral relations strategy would have a smaller operating cost than the functional hierarchy ($CC_{LR} < CC_{FH}$), but larger than the other strategies. For values of k greater than, or equal to four ($k \geq 4$), the following relation between the strategies' coordination costs will take place:

$$CC_{PH} < CC_{IS} < CC_{FH} < CC_{LR} \quad (5)$$

4.3 *Vulnerability Costs*

In order to compare the vulnerability costs for the alternative strategies, we first separate them in two component costs (processor failure cost and management failure cost) as shown in table 4.

Since the cost of disrupting a single product (C_S), the cost of disrupting all products (C_L), and that of reassigning a task to a different processor (C_D) are all unknown, we will try to homogenize the processor failure cost in order to allow the comparison only between the management failure costs. First of all, we know that $nC_S \leq C_L$, and for our specific case, that $n=m$. Also, it has been assumed that $C_D < C_S < C_L$. With these considerations in mind, it is possible to change the vulnerability cost equation for the Self-contained task strategy from (6) to (7):

$$V_C = knP_SC_S + nC_S[P_P(\frac{Pk\lambda}{n\mu_1})] \quad (6)$$

$$V_C = kmP_SC_S + C_L[P_P(P\rho/n)] \quad (7)$$

Table 4: Vulnerability Costs

STRATEGY	PROCESSOR FAILURE COST	MANAGEMENT FAILURE COST
FH	kmP_SC_D	$C_L[kP_F(\frac{P\lambda}{\mu_1}) + P_E(\frac{Pk\lambda}{\mu_0})]$
PH	knP_SC_S	$nC_S[P_P(\frac{Pk\lambda}{n\mu_1})]$
IS	kmP_SC_D	$C_L[kP_F(\frac{P\lambda}{\mu_1+\mu_1'}) + P_E(\frac{Pk\lambda}{\mu_0+\mu_0'})]$
LR	kmP_SC_D	$C_L[kP_F(\frac{P\lambda}{\mu_1}) + (1-a)P_E(\frac{Pk\lambda}{\mu_0})]$

As stated above $C_D < C_S < C_L$. What is not known, is the quantitative relation between C_D and C_S. However, it is possible to infer a certain relation. If C_D and C_S would have approximately the same value (which is not very logical, because that would imply that the reassignment of a task to a different processor would have the same cost as the disruption of a complete product line), then C_S could be replaced by C_D, with the result that the left hand side of the vulnerability cost equations would become the same, allowing us to compare only the right-hand side of the equations. If this were the case, the vulnerability cost for the self-contained task (PH) strategy would be the lowest among the four strategies, and could be represented by the following equation:

$$V_C = kmP_SC_D + C_L[P_P(P\rho/n)] \tag{8}$$

On the other hand, it is more reasonable to think of $C_D << C_S$ (C_S much greater than C_D). If this were the case, the vulnerability cost equation for the PH strategy could be transformed in the following way:

$$V_C = kmP_S(C_D + C_S) + C_L[P_P(P\rho/n)] \tag{9}$$

$$V_C = kmP_SC_D + kmP_SC_S + C_L[P_P(P\rho/n)] \tag{10}$$

$$V_C = kmP_SC_D + kP_SC_L + C_L[P_P(P\rho/n)] \tag{11}$$

P_S is the probability of failure of a processor, and according to our model, this probability would be proportional to ρ. Many different types of functions can be considered. However, we will consider a linear relation between ρ and the probability of failure.[4] Further, for the sake of simplicity, we will also consider that $P_S(\rho) = \rho$. Therefore, our final equation would become the following:

$$V_C = kmP_SC_D + C_L[P_P(P\rho/n) + k\rho] \tag{12}$$

Now, the vulnerability cost equations for all strategies can be rewritten as shown in table 5.

We must remember that P_E, P_F, P_P, and P_S are the probabilities of failure of each of the organization's actors. As mentioned above, we are considering them (probabilities of failure) as linear functions of their arguments, and for our particular case we will consider these linear functions to have the same value as their arguments. That is:

$$P_E(x) = P_F(x) = P_P(x) = x \tag{13}$$

With this in mind, the following relation between the vulnerability costs of the four alternative strategies can be easily deduced from the above equations:

[4]It is more reasonable to think of the probability of failure of an actor as a non-linear function of its load. This, because as the average delay time of a task grows larger the external pressure on the actor would also increase, increasing its probability of failure.

Table 5: Vulnerability Costs

STRATEGY	PROCESSOR FAILURE COST	MANAGEMENT FAILURE COST
FH	kmP_SC_D	$C_L[kP_F(P\rho) + P_E(P\rho)]$
PH	kmP_SC_D	$C_L[P_P(P\rho/n) + k\rho]$
IS	kmP_SC_D	$C_L[kP_F(\frac{P\rho}{1.43}) + P_E(\frac{P\rho}{1.29})]$
LR	kmP_SC_D	$C_L[kP_F(P\rho) + (1-d)P_E(P\rho)]$

$$VC_{FH} > VC_{PH}, VC_{IS}, VC_{LR} \text{ for } n, k > 1 \tag{14}$$

This relation is valid for $n > 1$ (more than one product line), and for values of $k > 1$ (at least two functional departments are expected). The relative ranking among the other three strategies cannot be determined unless we have more information about the exception rate (p), and the degree of decision decentralization (d). However, for $k \geq 3$, the following relations can be determined by analyzing the vulnerability costs for certain ranges of the exception rate:

Strategy	$0\% \leq p < 20\%$	$20\% \leq p < 43\%$	$p \geq 43\%$
FH	H	H	H
PH	M$'$	L$'$	L$^-$
IS	M$^-$	L$^+$	L$^+$
LR	M$^+$	M	M

L = Low costs("Good")
M = Medium costs
H = High costs("Bad")

5 SUMMARY

In this paper we presented a model of an organization as an information processing system. Using this model we showed the negative effects of uncertainty on the organization's performance. In order to improve the organization's performance we evaluated four alternative design strategies on the basis of production, coordination and vulnerability costs.

The results obtained show that investment in information systems (IS) is potentially the best alternative. However, when product and market diversity increase beyond a certain point, the creation of self-contained tasks will become a preferred alternative. The use of information systems and lateral relations in a product hierarchy can improve even further the performance of an organization.

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A Variable Definitions

Variable	Definition
λ_i	Number of tasks per time unit for product "i"
k	Number of functions
n	Number of products
m	Number of processors of a given type
d	Degree of decision delegation
μ_0	Processing capacity of the Executive office
μ'_0	Processing capacity of IS for the Executive office
μ_1	Processing capacity of one functional/product manager
μ'_1	Processing capacity of IS for a functional/product manager
μ_2	Processing capacity of one processor
μ'_2	Processing capacity of IS for a processor
E_{LL}	Average number of tasks waiting to be processed by a processor
E'_{LL}	Average number of tasks waiting to be processed by a processor when IS are used

Costs	Definition
P_C	Cost of processor capacity per task, per time unit
P'_C	Cost of processor IS capacity per task, per time unit
C_C	Cost of management capacity per task, per time unit
C'_C	Cost of management IS capacity per task, per time unit
D_C	Cost of delay of 1 task per time unit
C_M	Cost of sending a message
C_S	Cost of disrupting production of 1 product
C_L	Cost of disrupting production of all products
C_D	Cost of reassigning 1 task to a different processor

Probabilities	Definition
P_i	Exception rate for function "i" per time unit
P_E	Probability of failure of the executive office
P_F	Probability of failure of a functional manager
P_P	Probability of failure of a product manager
P_S	Probability of failure of a processor