Organizational Structure and Information Technology: Elements of a Formal Theory

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Abstract

There are three parts of this paper. The first part (1) discusses the kinds of theories needed to understand the consequences of information technology for organizational structure and (2) reviews a number of previous models of organizational design.

In the second part of the paper, a new model is presented that helps integrate and formalize some of the previous work. This model distinguishes several generic organizational structures and identifies tradeoffs between them in terms of coordination costs, productivity, and adaptability. The model is unusual in that it includes mathematical derivations of qualitative results that summarize several important principles from previous research on organizational design.

In the last section of the paper, the model is used to help explain several major historical changes in the structure of American businesses and to help predict changes that may occur in the future with the widespread use of information technology.

Organizational Structure and Information Technology: Elements of a Formal Theory

This paper has two goals. The first is to take a small step toward developing powerful theories about the use of information technology in organizations. We are particularly interested in the relationships between information technology and organizational structure. We would like, for example, to have some basis for predicting whether certain existing organizational structures are likely to become more desirable as information technology becomes more widespread or whether new organizational forms that are now impractical will become, for the first time, feasible and desirable.

In order to help answer these questions in a principled way, the second goal of this paper is to take a step toward summarizing and formalizing the existing knowledge about organizational design. There is already a large body of literature on this topic, and this article does not begin to encompass it all. The formal model presented here, however, does appear to capture a number of important qualitative relationships between organizational structure and coordination cost, productivity, and adaptability. The final section of the paper illustrates how this model can be used to explain several major changes that have occurred in the structure of American businesses over the last century and to help predict changes that may occur in the future with the widespread use of information technology.

A model similar to the one presented here was described by Malone and Smith (1984). This paper integrates the earlier model with a number of other models of organizational design and emphasizes applications of the model to questions about organizational structure and information technology.

Information technology and organizational structure

For almost as long as computers have been used in human organizations, people have speculated about the effects these computers would have on organizational structures. The predicted effects have included the elimination of middle management (Leavitt and Whisler, 1958), greater centralization (Stone, 1978) and greater decentralization (Anshen, 1960; Burlingame, 1961). In a few cases, observers have documented changes that have already resulted from the early uses of computers for data processing and management support (e.g., Robey, 1981, 1983; Walton & Vittori, 1983; Kling, 1980). Using this approach as the basis for predicting long term trends is somewhat problematic, however. As Huber (1984) points out, these analyses may be extrapolating recent trends of a transition period far beyond the range where such extrapolation is valid. In particular, it is difficult to use the early effects of our first systems as the basis for predicting the ultimate effects of systems that, in some cases, have not even been developed yet.

When anything changes by several orders of magnitude--as the costs and capabilities of information technology have in the past three decades--it is not unreasonable to expect radical changes in other parts of the systems in which the factor that has changed is embedded. In other words we should not expect people and organizations to just continue doing the same old things a little faster or less expensively using new technology. Instead we should expect, in some cases at least, to find people doing very different things or doing the same old things in very different ways (e.g., Rockart & Scott Morton, 1984).

In order to help us understand these fundamental changes affecting organizational structures, our models must represent factors that are at least as fundamental. To analyze the ramifications of the dramatic changes in the costs and capabilities of information technology, it is useful to regard the tasks that are performed by people (and machines) in organizations as falling into two categories:

1) *Production tasks*, i.e. the physical or other primary processes necessary to create the central products of the organization, and

2) *Coordination tasks*, the information processes necessary to coordinate the work of the people and machines that perform the primary processes.

The classification of a specific task into one of these two categories depends on the level and purpose of analysis, but at an intuitive level, the distinction is clear.

In some industries, such as banking, insurance, and publishing, the core "production" activities are primarily information processing. In these industries we should expect radical changes accompanying the increasing use of information technology, but the nature of the changes should depend strongly on the specific kinds of information processing in the different industries.

In all industries, however, a great deal of information must be processed to coordinate different people's activities. Much of the work done by managers at all levels falls within this category as does the work of many kinds of staff specialists in functions such as finance, accounting, law, and strategic planning. Salespeople, purchasing agents, brokers, and others who help establish market transactions are also, in essence, coordinating the "production" activities of people in the respective buying and selling firms (e.g., see Williamson, 1975: Coase, 1937). These different kinds of coordination costs include approximately 80% of all "information workers" and account for nearly 40% of all economic activity in the U.S. (e.g., see Jonscher, 1983). The basic nature of these coordination activities appears to be surprisingly homogenous across all industries (Jonscher, 1982)

Our best hope of developing powerful and general theories about the use of information technology in organizations, therefore, appears to lie in the direction of developing theories about the information processing involved in coordination.

In order to help develop such theories, we will review briefly a series of informal and formal models of organizational design and organizational structure. Then, a new model will be presented that helps integrate and formalize a small subset of the principles embodied in the earlier work.

Scope of this paper

In this paper, we will focus on three factors that affect the desirability of different organizational structures. By "organizational structure," we mean the relatively stable aspects of how people are grouped and tasks are assigned. Since the radical decreases in costs of information technology are likely to lead to large decreases in the cost of information processing for coordination, the first factor included in these models is simply the *cost of coordination*. The second factor the models emphasize is the overall cost for producing a given level of output. This factor can also be thought of as the level of output that can be produced for a given cost, or the *productivity* of the organization. The final factor, which many theorists believe is becoming increasingly important in the rapidly changing environment faced by many organizations, is the ability to adapt rapidly to these changes (Toffler, 1970; Huber, 1984; Naisbitt, 1982). Clearly an important part of this *adaptability* depends on the coordination required to "re-coordinate" in new environments. The models also emphasize another part of adaptability that is quite important but seldom analyzed--the vulnerability of an organization to unexpected changes. By vulnerability costs, we mean the unavoidable costs that are incurred before the organization adapts to the new environment. For example, when one of a company's major suppliers goes out of business, the company may have a number of costs associated with finding a new supplier, renegotiating a contract, and so forth.

In focusing on the relationships among organizational structure, coordination costs, productivity, and adaptability, our concern will be in some ways more general and in some ways more restricted than the treatments by previous theorists.

The most important way in which the treatment in this paper is more general than most previous work is that we include within the same framework the coordination of activities by hierarchical structures within a single firm and by market structures between firms. (For examples of previous work that makes this same generalization see Coase [1937], Williamson [1979]). Restricting our consideration to either of these two kinds of coordination structures alone would seriously hamper our ability to understand the fundamental changes that may occur with the widespread use of information technology.

The treatment in this paper is more restricted than some previous work because, as with any model, we must leave some things out. For example, the models presented here are relatively insensitive to where the legal boundaries of organizations are drawn (e.g., see Baligh & Burton, 1982). Instead, they are concerned primarily with the information processing necessary to coordinate activities. We will mostly ignore questions about individual human motivations, opportunistic or dishonest behavior (e.g., see Williamson, 1975), conflicts of interest between people in organizations (e.g., Cyert and March, 1963; Ross, 1973; Grossman & Hart, 1973) and power and authority in decision-making (e.g., see Pfeffer, 1981).

This lack of emphasis does not, of course, reflect a belief that these factors are unimportant any more than an aircraft designer's decision to model passengers for some purposes as inert masses would reflect a belief that the passengers never move or have no feelings. The first, and most important, reason for this choice of emphasis is simply that by neglecting some factors we are able to greatly simplify our analysis and thus see the effects of other factors much more clearly. The second reason is that the factors emphasized here are those that appear most likely to change with the widespread use of information technology. The factors we neglect, while they are always important, appear to be changing much less rapidly than those we will emphasize.

Informal models

There is a large body of literature about organizational design, and since there are a number of integrative summaries (e.g., Mintzberg, 1979; Galbraith, 1977; Hax & Majluf, 1981), we will only briefly review here several of the most important schools of thought in this work. Much of the *classical theory* in this area (e.g., Weber, 1947; Fayol, 1949; Taylor, 1911; Gulick & Urwick, 1937) was based on the idea that there are certain universal principles that must be followed for an organization to be successful. For example, Fayol's "unity of command" principle says that each person should have one and only one boss.

Largely as a reaction to this approach, three important schools of thought emerged in the middle of this century. The *human relations* school (e.g., Mayo, 1933; Roethlisberger & Dickson, 1939; Likert, 1967a,b) emphasized the importance of informal relationships among people and of individual needs, motivations, and attitudes. The *organizational decision-making* school (e.g., Simon, 1976; March & Simon, 1958; Cyert & March, 1963) emphasized the information processing that occurs when individuals with "bounded rationality" make decisions in a context of organizational goals, conflicts of interest, and standard procedures. Finally the *contingency theory* school emphasized the conditions under which different organizational structures are appropriate. The conditions investigated included the nature of the production technology (e.g., mass production, batch production, or process production [Woodward, 1965]), the nature of the interdependencies among production tasks (e.g., pooled, sequential, or reciprocal [Thompson, 1967]), and the nature of the environment (e.g., stable or turbulent [Lawrence & Lorsch, 1967]).

The work by Galbraith (1973, 1977) begins to integrate the latter two schools by using an information processing model to analyze alternative organizational coordination strategies such as teams, task forces, and vertical information systems.

Finally, the *transaction cost* approach (e.g., Coase, 1937; Williamson, 1979) analyzes alternative organizational structures based on their costs for the transactions necessary to coordinate activities. As noted above, this approach explicitly considers coordination between firms through markets as well as coordination within a single firm.

We will see below how a number of the specific principles articulated by these theorists are included or extended by the model presented here.

Critique of informal models

These informal models are extremely useful in highlighting important issues and basic qualitative results. As a number of commentators (e.g., Hax & Majluf, 1981) have remarked, however, most of the work in this field is still relatively "soft" and thus it is often easy, in trying to apply this knowledge, to unwittingly introduce inconsistencies or leave out important factors. As Mintzberg (1979, p. 12) says, ". . .the research on the structuring of organizations has come of age, but the literature has not: there is the need to. . .synthesize it into manageable theory." One of the secondary goals of this paper is to take a small step toward synthesizing and making more precise the knowledge in this area. In order to do this, we will next review a number of formal models that bear on the questions with which we are concerned.

Formal models

Our central problem was formulated in very general mathematical terms by Marschak and Radner (1972). In their formulation of "team theory," each member of a group of actors has some (possibly null) initial information about the world and some (possibly null) ability to control certain actions in the world. A team also has some shared *payoff function* that determines, for a given state of the world, the value team members attach to the results of the different possible actions. Since, in general, the team members who must take actions do not possess all the relevant information about the world, there must be some *information structure* that determines how members perceive and communicate information, and there must also be some *decision function* that determines how members decide what actions to take based on the information they receive. The goal of an organizational designer may be thought of as choosing an information structure and a decision function that maximize the *net payoff* to the team members, i.e., the gross payoff less the cost of communicating and deciding.

Assuming that decision-makers will make "optimal" decisions based on the information they have, Marschak and Radner prove a number of theorems about the consequences of various information structures. For example, they analyze the effects of no information exchange, complete information exchange, "exception reporting," and "emergency conferences."

Unfortunately for our purposes, the range of possible formal assumptions that can be used within Marschak and Radner's general framework leads to a multitude of different and sometimes conflicting results. Almost all the theorems that Marschak and Radner prove themselves depend on the assumption that the payoffs are determined by a quadratic function of the action variables. While this is, of course, a very general mathematical formulation, it is not at all clear what substantive processes in the real world it should be used to model or how to interpret the results.

Other theorists have used somewhat more easily interpretable models of the relationship between payoffs and coordination. For example, Jonscher (1982) and Beckman (1982) model the efficiency of production processes as simple functions of the amount of coordination resources applied to them. Burton and Obel (1984) assume that the coordination process in organizations is in some ways similar to iteratively approximating the solution of an optimization problem. Accordingly, they formulate linear programming problems and iterative solution methods that correspond to various organizational forms (e.g., grouping by product or function) and various control mechanisms (e.g., budgets vs. internal prices). Then they use the solutions that would result from a few iteration steps to model the efficiency of the different organizational structures.

In contrast to these approaches, the modeling approach we will explore in most detail here focuses directly on the activities that must be coordinated. We will view each activity as a task that must be performed by some processor (either a person or a machine) and the performance of which requires some amount of time. This view, therefore, highlights the importance of assigning tasks to processors as one of the fundamental components of coordination and it highlights delay time and processing capacity as important components of overall output or cost.

Several previous theorists have analyzed aspects of organizational coordination from this general point of view. For example, Baligh and Richartz (1967) present a very detailed and comprehensive analysis of the costs for factors such as processor capacity, queuing delays, and communication in markets with and without various kinds of brokers and middlemen. Some of their results are used and extended in our analysis below. Kochen and Deutsch (1980) take a somewhat similar approach to analyzing the desirability of various kinds of decentralization in service organizations.

A previous paper (Malone & Smith, 1984), described a model that is very similar to the one presented here. The previous paper emphasizes the analogies between human organizations and computer systems and shows how the same general results can be applied to both kinds of "organizations." For example, it shows how the same model that helps explain historical changes in human organizations can also help analyze design tradeoffs in distributed computer networks. The previous paper makes several different detailed assumptions from those made here and we will note these differences below.

AN INTEGRATING MODEL

As we have seen, there are a number of previous models--both formal and informal--of organizational coordination structures. This section will present a simple model that is a step toward integrating and formalizing some of the previous work. The highly simplified assumptions described here are not intended to be accurate descriptions of the detailed processes in any real organization. By simplifying the different structures down to their "barest bones," however, some of their essential differences are highlighted.

To begin with, we can think of any organization as having (1) a set of *goals* to be achieved and (2) a set of *processors* that can perform the *tasks* (i.e., achieve the subgoals) necessary to reach these overall goals. For example, an automobile manufacturing company like General Motors can be thought of as having a set of goals (e.g., producing several different lines of automobiles--Chevrolet, Pontiac, Oldsmobile, etc.) and a set of processors to achieve those goals (e.g., the people and machines specialized for doing engineering, manufacturing, sales, etc.) (Note: For concreteness in our exposition we will use "an automobile company like General Motors" as a source of examples throughout this section. Except where specifically noted, these examples are hypothetical illustrations only. Readers who have any direct knowledge about General Motors will quickly realize that our examples are not based on any specific information about General Motors. General Motors was chosen for illustrative purposes because of the pioneering role it has played in developing innovative organizational forms (e.g., Sloan, 1963; Chandler, 1962) and because the names of its product divisions are household words for most American readers.)

We will be concerned here with the answers to two basic questions about how these goals and processors are organized:

(1) Are the processors shared among goals or dedicated to single goals?

(2) Is the decision-making about which processors perform which tasks, centralized or decentralized?

There are four possible combinations of answers to these two questions, and Figure 1 shows the organizational structures that result from each combination. These generic organizational structures serve as the building blocks for much more complex organizations.

We will compare the different organizational forms in terms of their *production costs*, their *coordination costs*, and their *vulnerability costs*. Production costs are the costs of performing the basic tasks necessary to achieve the organization's goals--for example the basic manufacturing, marketing, and engineering tasks necessary to produce automobiles. Coordination costs include all the "overhead" associated with deciding which tasks will be performed by which processors. In hierarchies, much of what managers do can be considered coordination costs. In markets, the equivalent coordination costs include costs for the seller (e.g., advertising and sales) and the "search costs" for the buyer (e.g., the costs of talking to many different salespeople). The third factor, vulnerability costs, reflects the unavoidable costs of a changed situation that are incurred before the organization can adapt to the new situation.

In order to compare the different organizational forms on these dimensions, each form will be described in terms of a set of highly simplified assumptions about (1) which processors perform which tasks, (2) the method for assigning tasks to processors, and (3) the consequences of processor failures. These assumptions allow us to measure: (1) production costs in terms of the amount of processing capacity required and the delay in processing tasks, (2) coordination costs in terms of the minimum number of communication links and communication instances, or "messages" necessary to assign tasks to processors, and (3) vulnerability costs in terms of the expected costs of failures of processors.

In order to make "fair" comparisons among the different forms, we will assume that the forms are equivalent in all respects that do not follow from these basic differences. For example, we assume that the different forms are identical in terms of: (1) the "products" that must be produced to achieve the organizational goals, (2) the tasks that must be performed to produce these products, (3) the cost of operating the processors, and (4) the difficulty of deciding what tasks need to be done and what kind of processor can do them.

Alternative organizational forms

Product hierarchy

When processors are not shared among products and decision making is decentralized the resulting organizational structure is a product hierarchy. In this structure there is a separate division for each product or major product line. We use the term "product hierarchy" here, even though the groupings are sometimes made along other "mission-oriented" lines such as geographical regions or market segments. Each division has a "product manager" and its own separate departments for different functions such as marketing, manufacturing, and engineering. General Motors was one of the earliest and best known examples of this form with its separate divisions for Chevrolet, Pontiac, Cadillac, and other product lines (see Chandler, 1962).

In this form, the "executive office" may set long-range strategic directions, but it is not ordinarily involved in the operational coordination of tasks and processors. The lack of connection with the executive office for operational purposes is indicated by dotted lines in Figure 1. (This form is sometimes called the "multi-divisional" form [Chandler, 1962] or the "M-form" [Williamson, 1975].)

The solution to the task assignment problem that is implied by this "pure" form is simple: Whenever a task of a certain type needs to be done, the product manager assigns the task to the department that specializes in that type of task. For example, the general manager of the Chevrolet division would ordinarily expect all new Chevrolet models to be designed by the engineering department in the Chevrolet division. In the "pure" form of a product hierarchy, there is only one department (or one processor) for each type of task, so the assignment decision is trivial.

When a processor fails in a product hierarchy, the product division in which the failure occurs is disrupted, but the other divisions are not necessarily affected. For example, a major mechanical failure at a factory that produced only Chevrolets would not have any direct effect on the other divisions. A failure by the Cadillac marketing department to correctly predict what their customers would want in next year's models, would not necessarily affect the other divisions, either.

Our formal model involves only operational coordination so it does not include any interactions between the divisions of a product hierarchy. From the point of view of this model, therefore, a product hierarchy is equivalent to a holding company or, indeed, to a set of separate companies that do not share any resources.

Overcentralized product hierarchy. When processors are not shared among products, but decision-making about task assignment is centralized, the second structure shown in Figure 1 results. The fact that the executive office performs all the operational coordination of tasks in all the divisions is indicated by the solid lines connecting the executive office to the divisions. This structure, which might be called an "overcentralized product hierarchy" is not labeled in the figure since it is inferior to the simple product hierarchy in terms of the factors we are considering. It requires more coordination than the simple product hierarchy (since there is an extra layer of management involved in all decisions) but it has no greater efficiency or flexibility. Though such cases of "non-optimal" overcentralization certainly occur in human organizations, they will be ignored in our further analysis of "pure" organizational forms.

Functional hierarchy

In a functional hierarchy, as shown at the bottom of Figure 1, processors of a similar type are pooled in functional departments and shared among products. This sharing reduces duplication of effort and allows processing loads to be balanced over all products. For example, a company might need less manufacturing capacity if instead of having to provide enough capacity in each division to meet peak demands it could balance heavy demands for one product against ordinary demands for other products that share the same manufacturing facility. As another example, having a single research department in a company instead of separate research departments in each division might reduce the need to duplicate expensive facilities and may allow a few people with specialized expertise to be shared among all products instead of having to hire separate specialists for each division. (The functional hierarchy is also sometimes called the "unitary" form or "U-form" (Williamson, 1975).)

In a pure functional hierarchy, the "executive office" must coordinate the operational processing for all products. The task assignment method implied by the "pure" form of this organizational structure is somewhat more complicated than for the product hierarchy, because an extra layer of management is involved: Whenever a task of a certain type needs to be done, the executive office delegates it to the functional manager of the appropriate type who, in turn, assigns it to one of the processors in that department. In order to make this assignment intelligently, the functional manager needs to keep track of not only the priorities of the tasks, but also the loads and capabilities of the processors in the department. For example, if General Motors were a "pure" functional hierarchy a central manufacturing department would contain all the manufacturing plants. The vice-president of manufacturing and his or her staff would be responsible for coordinating the sharing of these facilities to produce all the different kinds of cars for all the different product lines. This overall coordination requires significantly more information and interactions than does the simple product hierarchy.

When an individual processor fails in a functional hierarchy, the tasks it would have performed are delayed until they can be reassigned to another processor. For example, if General Motors had a single centralized sales and distribution department for all its products, it would be relatively easy to shift sales volume from poorly performing dealerships to more successful ones. If GM had a pure product hierarchy, on the other hand, it would be very difficult to shift sales volume of Cadillacs into dealerships that handled only Chevrolets. There is another kind of failure however, in which the functional hierarchy is much more vulnerable. When a functional manager fails instead of just an individual task processor, the processing of the entire organization may be disrupted. For instance if the vice-president in charge of all manufacturing performed very poorly, the manufacturing of all products could be excessively costly or delayed and these effects would be felt throughout the organization.

Markets

So far we have considered two hierarchical structures for coordinating task assignments. One of the important insights from the literature of organizational theory and economics (e.g., see Williamson, 1975) is that the same tasks can, in principle, be coordinated by either a market or a hierarchy. For example, General Motors does not need to make all the components that go into its finished products. Instead of manufacturing its own tires, for instance, it can purchase tires from other suppliers. When it does this, it is using a market to coordinate the same activities (i.e., tire production) that would otherwise have been coordinated by hierarchical management structures within General Motors.

In the "pure" form of this coordination structure, all the task processors (e.g., all the factories, engineering units, distribution organizations, and dealerships) are independent subcontractors and the coordination is provided by separate general contractors for each product. For instance, if General Motors used the extreme form of this coordination structure, then the vice president in charge of the Chevrolet division would have only a small staff and all the basic tasks of product design, manufacturing, and sales would be performed by outside subcontractors. This form of subcontracting as a coordination structure is already common in some industries (e.g., construction) and has recently been used to an unexpected degree in others (e.g., IBM's extensive use of software and hardware from other vendors in its Personal Computer product [see Toong & Gupta, 1985; Business Week, 1985]).

Decentralized market

We distinguish here between two kinds of markets: decentralized and centralized. In a decentralized market, processors are shared among goals, but the decision-making about task assignment is decentralized. In the pure form, this means that all buyers are in contact with all possible sellers and they each make their own decisions about which transactions to accept. If each division of General Motors contacted each of the potential subcontractors directly about every task, with no intermediary brokers, then this would be a decentralized market. As another example, the consumer market for automobiles is largely a decentralized market in the sense that each potential buyer ordinarily communicates with many different potential sellers in order to select a car.

We can model this process as one in which buyers send some form of "request for bids" to sellers of the appropriate type and then select a seller from among the bids received. In this framework, advertising can be considered a special kind of implicitly requested "bid." In either case, a large number of "messages" must be exchanged in a decentralized market in order for buyers and sellers to select each other. When a processor fails in a decentralized market, the task it was to have performed can often be reassigned to another processor. For example, if one independent distributor for General Motors cars failed to achieve a satisfactory sales volume, that distributor's contract could be terminated and another distributor selected.

Centralized market

In a centralized market, buyers do not need to contact all possible sellers because a broker is already in contact with the possible sellers. This centralization of decision-making means that substantially fewer connections and messages are required compared to a decentralized market. One of the best known examples of a centralized market is the stock market. People who want to buy a particular stock do not need to contact all the owners of shares of that stock; they only need to contact a broker who is also in contact with people who want to sell the stock. In our hypothetical example with General Motors as a general contractor, if there were brokers for each of the kinds of subcontractors (e.g., a broker for all the engineering subcontractors, another one for all the factories, and so forth), then the coordination structure would be more like a centralized market.

From a task assignment point of view, a centralized market is similar to a functional hierarchy. Instead of having a functional manager as a central scheduler for each type of task, the centralized market has a broker. We can model the coordination process as one in which the broker keeps track of the prices, capabilities, and availability of all the subcontractors. Then when buyers send "requests for bids" to the broker, the broker can respond by identifying the best available subcontractor.

The centralized market and the functional hierarchy are also similar in their responses to failures of processors. Both can often reassign tasks when a task processor fails, and in both cases, the production of all products is disrupted when one of the central schedulers fails. The difference between the two structures is that in the centralized market, one of the general contractors can fail without disrupting the production of the other products, but in the functional hierarchy, if the executive office fails, the production of all products is disrupted.

Other organizational forms

As mentioned above, these four "pure" organizational forms serve as building blocks for the much more complex organizations we observe. For example, as Figure 2 shows, a "matrix" organization is a hybrid form in which a functional hierarchy is augmented by separate product managers for each product who have direct links to specialized processors in each functional division. From a task assignment point of view, this might imply that specialized processors give priority to tasks from the product manager to which they are linked but that all specialized processors in a department are available to help with each others' overflow tasks.

Other examples of composite organizational forms include (1) product hierarchies in which each product division is organized as a small functional hierarchy with multiple small scale processors in each department, (2) decentralized markets in which contractors are internally organized as functional hierarchies, (3) organizations in which a formal product hierarchy is supplemented by informal communications and load-sharing patterns that resemble a decentralized market, and (4) regulated markets in which a hierarchical structure (for example, a functional hierarchy) is superimposed on a decentralized market.

Tradeoffs among organizational structures

Now that we have distinguished among these generic organizational forms, one of the most important questions we can ask is what are the relative advantages of each. In particular, we will focus on the tradeoffs between *efficiency* and *flexibility* in the different structures. We will view efficiency as being composed of two elements *production costs* and *coordination costs*. Coordination costs are also a component of flexibility, since the amount of re-coordination necessary to adapt to new situations helps determine how flexible a structure is. The other component of flexibility we will consider is *vulnerability costs,* or the unavoidable costs of a changed situation that are incurred before the organization can adapt to the new situation.

Comparisons. As shown in Table 1, it is now possible to compare the different organizational structures on the dimensions of production costs, coordination costs, and vulnerability costs. All the dimensions shown in the chart are represented as costs, so in every column low is "good" and high is "bad". The comparisons apply only within columns, not between rows. Primes are used to indicate indeterminate comparisons. For example, H' is more than L, but it may be either more or less than H+ or H-. The characteristics of the hybrid forms, such as matrix organizations, can be expected to be between the values for the same dimensions in the respective "pure" forms.

Justification of comparisons. The comparisons summarized in Table 1 have two different kinds of support. First, as we will see in the next section, many of the comparisons represent empirically based generalizations about organizational design. Second, they can all be derived mathematically, using queuing theory and probability theory, from a fairly straightforward set of assumptions about the definitions of different organizational forms. Thus these comparisons represent a set of assertions about organizational design that are, in some sense, "derivable from first principles." Informal justifications for the comparisons are presented in Appendix 1, and more detailed formal justifications are in Appendix 2.

Two common problems with formal models of organizational structure are that either (1) they are very general (e.g., Marshak & Radner, 1972) in which case the large number of more specific assumptions that are possible leads to a multitude of conflicting results, or (2) they are very specific (e.g., Kochen & Deutsch, 1980), in which case the reader is often left with a feeling that the assumptions are overly *ad hoc* and that the results are therefore not widely valid.

By focusing our analysis on the set of basic inequalities shown in Table 1, rather than on specific equations, we are able to see some of the essential unity in these models without the clutter of excessive detail. In the appendices, we consider a number of specific alternative assumptions. In some cases, these different assumptions make it impossible to discriminate between alternatives for which inequalities are shown here. In most cases, however, the different assumptions all lead to the same basic inequalities.

Summary of previous organizational design principles

The qualitative comparisons shown in the table provide a concise summary of many of the generalizations about organization design that have been made by previous theorists (e.g., Galbraith, 1977; March & Simon, 1958; Gulick and Urwick, 1937). In all these cases, our model not only summarizes previous results but also places them in a more comprehensive framework. In some cases, as the examples below suggest, our model also extends or shows limitations of previous principles.

Tradeoffs between production costs and coordination costs. March and Simon (1958, p. 29) summarize the problem of departmentalization as centering on a tradeoff between self-containment and skill specialization: "[Functional] departmentalization generally takes greater advantage of the potentialities for economy through specialization than does [product] departmentalization; [product] departmentalization leads to greater self-containment and lower coordination costs. . ."[1] Table 1 reflects this tradeoff with the "economies of specialization" in functional hierarchies being represented as lower production costs, and the advantages of self-containment in product hierarchies being represented as lower coordination costs.

Galbraith (1977), extends this view by pointing out that the advantages of coordination can be obtained by either investment in a vertical information system (as in a functional hierarchy in Table 1), or by the creation of lateral relations (as in a decentralized market in Table 1). He also points out that coordination costs can be reduced by either creating self-contained tasks (as in a product hierarchy) or by having slack resources. One of the insights from the detailed justification of our model (see appendices) is that creating self-contained tasks may often itself cause slack resources. For example, the time that dedicated processors in a product hierarchy remain idle when, in the other organizational forms they could be processing tasks for other products, is an important kind of slack resource.

Organizational structure and flexibility. It is commonly claimed that product hierarchies are more flexible in rapidly changing environments than functional hierarchies (e.g., Galbraith, 1973, pp. 113-116; Mintzberg, 1979. p. 415; Ansoff & Brandenburg, 1971, p. 722). Our model, however, suggests an important distinction between two kinds of flexibility that must be used to qualify this claim. According to our model, product hierarchies are indeed more *adaptable*, in the sense that their coordination costs for re-coordinating in new environments are less than for functional hierarchies.

But, contrary to what some theorists claim, product hierarchies are not necessarily less *vulnerable*, in the sense of the losses suffered when unexpected changes occur. For example, Mintzberg, quoting Weick, observes that: ". . .the [product hierarchy] spreads its risk. '. . .if there is a breakdown in one portion of a loosely coupled system then this breakdown is sealed off and does not affect other portions of the organization' (Weick, 1976, p. 7). In contrast, one broken link in the operating chain of the functional structure brings the entire system to a grinding halt" (Mintzberg, 1979, p. 415).

As Table 1 shows, however, the overall vulnerabilities of the product and functional hierarchies are not necessarily different. Examining the justifications in the appendices shows why. While a failure in one product division may, indeed, be limited in its effect to that division, the failure of a single processor may bring the entire division to a halt. The failure of an equivalent processor in a functional hierarchy, on the other hand, might be less costly since other processors of the same type are pooled in a central department and shifting tasks between them is presumably much easier than shifting tasks between product divisions. The real vulnerability of the functional hierarchy is to failures of the functional managers themselves, because a failure there does indeed disrupt the entire organization. Without more information about the relative frequency and costs of these two kinds of failures, however, we cannot say *a priori* whether the product or functional hierarchy is more vulnerable.

Comparison between markets and hierarchies. There is a growing body of literature concerned with the relative advantages of markets and hierarchies as coordination structures (e.g., Coase, 1937; Williamson, 1975, 1979, 1980, 1981a, 1981b). As Williamson (1981a, p. 558) summarizes, ". . . trade-offs between production cost economies (in which the market may be presumed to enjoy certain advantages) and governance cost economies (in which the advantages may shift to internal organization) need to be recognized." At a general level, Table 1 reflects this result: markets have lower production costs than hierarchies (with one exception to be discussed below) and markets have higher coordination costs. A more detailed comparison leads to several additional insights, however.

First of all, one of the production cost advantages of markets described by Williamson (1981a, p. 558) is that ". . . markets can also aggregate uncorrelated demands thereby realizing risk-pooling benefits." This observation stems from the fact that when a group of firms subcontracts some activity instead of each performing the activity internally, the pool of processors from which each firm can choose is larger. For example, if a group of automobile companies buys tires instead of making them, the pool of tire manufacturing plants from which a given automobile company can choose is ordinarily larger. The best way of interpreting this comparison in terms of our model is as a comparison between product hierarchies and either of the two kinds of markets. Companies that manufacture their own tires would be like separate divisions of a product hierarchy; those that buy tires elsewhere would be like buyers in either a centralized or decentralized market. As Table 1 shows, both forms of markets include the production cost benefits of load sharing. (This load sharing benefit could also, in theory, be realized by merging all the automobile companies into a single large functional hierarchy with a centralized tire manufacturing department. The advantage of the market as a coordination mechanism is that it allows load sharing among otherwise unrelated clients.)

Williamson goes on to point out one of the factors not included in our model. The load sharing advantages of markets hold only when--as we assumed--the assets (or processors) can be used interchangeably by many different buyers. When assets are highly specific to a particular buyer, other factors, such as the possibilities of opportunistic behavior by the buyers and suppliers, increase the costs of market coordination and--in some cases--make hierarchies more desirable.

Curiously, however, Williamson does not seem to recognize the simple coordination cost advantages shown in Table 1 that hierarchies have all along. Since market coordination usually requires more connections between different actors and more communication to assign tasks appropriately (e.g., to find the right supplier of a service), markets should involve somewhat higher coordination costs, even in the absence of opportunistic behavior by buyers and suppliers.

Size of the organization

The tradeoffs shown above in Table 1 assume that the size of the organization being modeled is fixed, that is, that the number of processors, the number of products, and the total number of managers generating tasks are all constant. As the number of processors increases, the relative rankings of the alternative organizational forms do not change on any of the evaluation criteria. However, the values change much faster for some organizational forms and criteria than for others. Thus simply changing the size of the economy, even without changing any other parameter values, may change the relative importance of different criteria and therefore change the "optimal" organizational form. The relative rates of change for the different criteria are summarized in Table 2 and justified in Appendix 2. The different numbers of pluses in the table represent the different rates of change. For example as the size of an organization increases, vulnerability costs increase more rapidly for product hierarchies than for the other forms, and coordination costs increase most rapidly for decentralized markets.

APPLICATIONS

In this section, we will see how the analysis just presented can be applied to a wide variety of organizational design issues. In particular, we will see how the model can be used to help understand historical changes in the structure of American businesses and to predict changes that may occur with the widespread use of information technology in organizations.

Historical changes in American business structures

Figure 3 summarizes, in simplified form, the changes in the dominant organizational structures used by American businesses as described by Chandler (1962, 1977) and other business historians. From about 1850 to 1910, numerous small businesses coordinated by decentralized markets began to be superseded by functionally organized hierarchies. These hierarchies continued to grow in size until, in the early and middle parts of this century, they were in turn replaced by the multi-divisional product hierarchies that are prevalent today. In the next section, we will discuss how the widespread use of computers in organizations may again change the dominant organizational structures. Before doing that, however, we will show how the observed historical changes can be explained using the model already presented. Williamson (1981b) and Chandler (1962, 1977) have also proposed explanations of these same changes and our explanation both draws on these earlier explanations and illuminates their incompleteness.

We assume, first of all, that organizations move toward the structure that is best suited to their current situation. (For our purposes here, we do not care whether this motion results from conscious adaptation on the part of managers or from "blind" evolutionary forces favoring one kind of organization over another [see, e.g., Alchian, 1950; Nelson and Winter, 1981; Hannan & Freeman, 1977].) In our explanations, we will insist that, for each structural change, we be able to say what underlying parameters changed in the old structure and why this change caused the new structure to become the most desirable of the alternatives.

Decentralized markets to functional hierarchies

The first change to be explained is the change from separate small companies to large scale functional hierarchies. Williamson (1981b) and Chandler (1977) both explain the change in size as the result of changing economies of scale so that large scale processors became much more economical than small ones. They also argue that the increasing scale of manufacturing led to an intense pressure to increase the scale of distribution and the size of markets. In order to keep the large scale factories busy, it was necessary to use railroads and other transportation systems to develop a large scale distribution network and a mass market (see also Piore and Sabel, 1984). Elsewhere, Malone and Smith (1984) have shown how the model presented here can be augmented to include the effects of processor scale and how these effects can explain the observed changes. There is another explanation, however, based only on the model presented here that is quite intriguing: One of the effects of improved transportation and communication systems such as railroads was to dramatically increase the size of potential markets. As decentralized markets grow in size, their coordination costs increase much more rapidly than the coordination costs for the equivalent functional hierarchies (see Table 1). Thus as markets grow, more of their activity should be transferred into functional hierarchies in order to economize on coordination costs. In other words, instead of larger scale manufacturing leading to larger markets, it may be that larger markets led to larger firms (structured as functional hierarchies) and that these larger firms, in turn, enabled larger scale manufacturing.

Functional hierarchies to product hierarchies

The next change to be explained is the change from functional hierarchies to product hierarchies. This change is nicely documented by Rumelt (1974) as shown in Figure 4. Williamson and Chandler explain this change, in part, by saying that as functional hierarchies grow larger their executive offices become increasingly overloaded by the demands of coordinating all the different projects across all the different functional departments. In a product hierarchy, the operational and tactical components of these coordination problems are delegated to the division managers, leaving the top executive officers free to concentrate on strategic questions.

This seems to be a plausible description of an advantage product hierarchies have over large functional hierarchies, but it leaves an essential question unanswered: Why did the functional hierarchies grow larger in the first place? Why didn't companies just grow until they exhausted the economies of scale and then let further demand be met by other companies of a similar size coordinated by a market? Williamson gives reasons for why hierarchies are sometimes superior to markets, but not for why they should become even better during the period in question.

Our model allows us to answer this question quite simply using the same argument about market size that we used to explain the appearance of functional hierarchies in the first place. As markets grow, more of their activity should be transferred into functional hierarchies in order to economize on coordination costs. Thus the functional hierarchies continued to grow, as the marketplaces in which they operated grew, even after the underlying scale economies were exhausted.

We have still not explained, however, why these large functional hierarchies would change to product hierarchies. If functional hierarchies were superior to product hierarchies at the beginning of the period, why didn't they remain so at the end? Williamson's and Chandler's arguments rest on the assumption that the information processing capacity of a top management team is limited, no matter how many people are added to the team. If we don't make this assumption, however, Table 2 shows that there is no increasing advantage of functional hierarchies over product hierarchies as size increases.

There is an alternative explanation for the change, however, which is historically quite plausible. The argument is as follows: At the same time that functional hierarchies were getting larger, the relative importance of production costs and coordination costs was also changing. As production processes became more and more efficient, they constituted a smaller and smaller proportion of the total cost of products. Meanwhile, there were fewer improvements in the efficiency of coordination processes, so coordination costs constituted an increasing proportion of the total costs of products. Thus, product hierarchies, which economized on coordination costs at the expense of production costs, became increasingly attractive.

There is some strong empirical evidence to support this explanation. For example, we may take the proportion of the workforce engaged in handling information (rather than physical goods) as a rough measure of the proportion of total product costs due to coordination costs. Jonscher (1983) shows that the proportion of "information workers" in the workforce increased from about 25% in 1920 to almost 50% in 1960. During the same period, the economic productivity of "production workers" increased almost fourfold, while the productivity of information workers grew much more slowly. Taken together these results suggest that the relative importance of production and coordination costs did, indeed, change between 1920 and 1960, and that this might have contributed to the shift toward a less coordination-intensive organizational structure.

Effect on organizational structure of widespread use of information technology

In order to use our model to analyze structural changes accompanying information technology, we need to make some assumptions about which of the parameters in our model is directly affected by information technology. It seems plausible to hypothesize that the widespread use of computers in organizations may substantially decrease the "unit costs" of coordination--both the transmission and processing of information. This assumption is of course, an empirically testable hypothesis, and there are at least some suggestive data that support it (e.g., Crawford, 1982). If coordination costs decrease, then coordination mechanisms that would previously have been prohibitively expensive will, in some situations, become affordable.

The implications of this change according to our model are quite intriguing. Since each of the historical changes described above can be explained by a need to reduce coordination costs, the result of lowering coordination costs in the future should be to allow us to retrace our steps along the previous evolutionary path. In particular, there could be at least two possible consequences for companies presently organized as product hierarchies (see Table 1):

Product hierarchies to functional hierarchies. In some industries or firms, economizing on production costs is the most important strategic consideration. In these cases, our model suggests that product hierarchies should shift toward functional hierarchies in order to take advantage of the lower production costs in functional hierarchies. For example, a number of large multi-divisional companies have recently moved back toward a single centralized sales force (Kneale, 1984; DEC, 1983; IBM, 1981).[2] In some cases, this may be due to lower costs of internal communication between the sales force and other departments. For instance, simple innovations like inexpensive long distance telephone calls as well as more advanced technologies like electronic mail can make it easier for a single salesperson to sell products from a number of different divisions. In other cases, direct electronic links with customers may be used to reduce coordination costs and enable a recentralization of the sales force. For example, the use of remote order entry terminals on customer premises, appears to have already facilitated the consolidation of several divisional sales forces and the emergence of a corporate marketing and sales organization in one company that pioneered this technology (Doerhoefer, 1985).

Product hierarchies to decentralized markets. For many industries and companies, it appears that retaining maximum flexibility may be an even more important strategic consideration (e.g., see Piore & Sabel, 1984; Huber 1984) than reducing production costs. Our model suggests that these industries should shift even further and become more like decentralized markets. The higher coordination requirements of these market-like structures will now be more affordable, and markets provide the additional flexibility of being less vulnerable to sudden situational changes such as in supplies and demands.

In general, information technology should lower the transaction costs (e.g., see Williamson, 1975) of market coordination, thus making markets more efficient and therefore more desirable as coordination mechanisms. For example, information technology can lower the costs of market-like transactions with innovations such as remote order entry terminals on customer premises, "electronic yellow pages," and on-line credit networks (see Ives & Learmonth, 1984, for examples of these and a number of related innovations already in use).

There are two ways market-like structures can be used for coordination. The most obvious way is with actual buying and selling between different companies. To make greater use of this mechanism for increasing flexibility our economy will increasingly use products from numerous small firms whose activities are coordinated by decentralized markets rather than products from a few large hierarchies. The increasing importance of small entrepeneurial companies in many rapidly changing high technology markets--particularly in the computer industry--provides an early indication of this trend (e.g., Rogers & Larsen, 1984).

Another, and perhaps more likely, possibility is that coordination mechanisms like those in a market will come to be used more and more inside large firms. For example, the widespread use of electronic mail, computer conferencing, and electronic markets (e.g., Hiltz & Turoff, 1978; Johansen, 1984; Turoff, 1984) can facilitate what some observers (e.g., Mintzberg, 1979; Toffler, 1970) have called "adhocracies," that is, rapidly changing organizations with many shifting project teams composed of people with different skills and knowledge. These organizations can rely heavily on networks of lateral relations at all levels of the organization rather than relying solely on the hierarchical relations of traditional bureaucracies to coordinate people's work (e.g., Rogers, 1984; Naisbitt, 1983).

CONCLUSION:
TOWARD AN "ORGANIZATIONAL SCIENCE"

This paper, has presented a model that helps integrate and formalize a number of previous principles about organizational design. This work can be viewed as a contribution to an emerging interdisciplinary area that might be called "organizational science." This field will include a body of theory--like that we have begun to develop here--about the *information processing necessary to coordinate the activities of separate actors*, whether the actors are people, computers, or--possibly even--neurons in a brain. Parts of this theory will apply to designing "organizations" of computer processors as well as to designing human organizations. Other parts of the theory will be specific to one kind of organization or another.

By viewing problems in this way, we are able to see commonalities in questions that have previously been considered separately in fields such as organization theory, economics, management information systems, and computer science. Just as the interdisciplinary field of cognitive science (e.g., Norman, 1983) appears to have provided important leverage to investigators studying problems previously considered separately in psychology, linguistics, and computer science, it appears likely that a similar kind of leverage will result from identifying a common level of analysis for problems of organizational coordination.

As Figure 5 illustrates, there appear to be at least three important application areas for this body of theory. The first, and the one emphasized in this paper, is in developing more precise theories of organizational design for human organizations. In addition to the mathematical tools used here, the intellectual tools for analyzing information processing that have been developed in computer science in the last few decades appear to have much more potential for analyzing coordination in human organizations than has heretofore been exploited. Concepts from the field of artificial intelligence, in particular, seem to be especially fruitful tools for theorizing about organizational coordination (e.g., Cohen, 1984; Barber, 1984).

The second application area for organizational science is in the design of distributed and parallel computer systems. There are already a number of examples of computer systems being designed based on analogies and insights from human organizations (Goldberg & Robson, 1983; Hewitt, 1977, Erman et al, 1980; Smith & Davis, 1981; Kornfeld & Hewitt, 1981; Malone, Fikes, and Howard, 1983). Elsewhere Malone and Smith (1984) provided one example of how an organizational science theory like that developed here can go beyond simple analogies and provide strong quantitative implications for computer system design.

The third, and in some ways most interesting, application area for organizational science is in the "hybrid" case of organizations that include both people and computers. Malone (1985, in press) has discussed in more detail elsewhere, how theories like the one presented here can aid in designing computer systems that help support and coordinate the activities of people in groups and organizations.

These three applications are already increasingly important research areas. The prospects for cross-fertilization of intellectual tools and results between them appear to be quite exciting.

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Appendix 1

Informal Justifications for Organizational Form Comparisons

This appendix gives intuitive justifications of the qualitative comparisons in Table 1. Formal proofs are included in Appendix 2. The key assumptions about the alternative organizational forms are summarized in Table 3.

Production costs

Our primary assumption about production costs is that they are proportional to the amount of procesing capacity in the organization and the average delay in processing tasks. We assume that tasks of a given type arrive at random times and that processing each task takes a random amount of time. We also assume that processing capacity for a given organizational form is chosen to minimize the total costs of capacity and delay time.

The product hierarchy has the highest average delay in processing tasks because it uses processors that are not shared. The decentralized market, centralized market, and functional hierarchy all have a somewhat lower average delay time because they are able to take advantage of the "load leveling" that occurs when tasks are shared among a number of similar processors. For example, processors that would otherwise be idle can take on "overflow" tasks from busy processors thus reducing the overall average delay.

Alternative assumptions. Malone and Smith (1984) examine the consequences of removing the assumption that in all organizational forms, processing capacity is optimally chosen to minimize total production costs. Here we assume instead that all organizational forms have the same processing capacity. This alternative assumption does not change our results.

Malone and Smith (1984) also analyzed alternative forms of functional hierarchies and centralized markets that include one large scale processor for a function instead of several small scale processors. The large scale organizational forms have lower production costs, but higher vulnerability costs, than their small scale counterparts.

Coordination costs

Our primary assumption about coordination costs is that they are proportional to the number of connections between agents and the number of messages necessary to assign tasks. Table 3 summarizes our assumptions about the number of connections and messages required.

The product hierarchy requires the least number of connections since each processor must only be connected to its division manager. This form also requires the least number of messages for task assignment since each task is simply assigned to the processor of the appropriate type in the division in which the task originates.

The centralized market and functional hierarchy require more connections since each broker or functional manager must be connected not only to the processors they supervise, but also to the managers or clients who originate tasks. These two forms also require more scheduling messages since an extra layer of management is involved in assigning tasks to the proper processor.

The decentralized market requires the most connections of all because it requires each buyer to be connected to all possible suppliers. This form also requires the most messages since assigning each task requires sending "requests for bids" to all possible processors of the appropriate type and then receiving bids in return.

Alternative assumptions. Appendix 2 considers several alternative sets of assumptions about coordination costs. The most important of these alternatives involves the role of prices in the decentralized market. In its "pure" form, this structure requires connections and messages between all possible buyers and all possible suppliers. One might argue, however, that in a market with a functioning price mechanism, buyers would only need to contact a few potential suppliers, since most suppliers would have approximately the same price anyway. Appendix 2 shows, however, that as long as the number of suppliers contacted by buyers is, on the average, at least two, this organizational form still has the highest coordination costs of all the forms considered.

Vulnerability Costs

Our primary assumption about vulnerability costs is that they are proportional to the expected costs due to failures of task processors and coordinators. We assume that both processors and coordinators sometimes fail (i.e., with probabilities greater than 0). Our assumptions about the consequences of different kinds of failures in different organizational forms are summarized in Table 3. We assume that when a task processor fails in a market or in a functional hierarchy, the task can be reassigned to another processor of the same type. When a task processor fails in a product hierarchy, however, there is no other processor of the same type available, so the entire production of the product in question is disrupted. The entire production of a product is also disrupted if the product manager fails, or in the case of the market, if the client who supervises that product fails. Finally, the production of all products is disrupted if a centralized market broker, or a functional manager, or an executive office fails.

We assume that the cost of delaying a task in order to reassign it is less than the cost of disrupting all the production for a given type of product and that this cost is, in turn, less than the cost of disrupting the production of all products.

Given these assumptions, the decentralized market is the least vulnerable to component failure since if one processor fails, the task is only delayed until it can be transferred to another processor. The centralized market and functional hierarchy are more vulnerable since not only can tasks be delayed by the failure of individual processors, but also the entire system will be disrupted if a centralized scheduling manager fails. The functional hierarchy is somewhat more vulnerable than the centralized market because the functional hierarchy can also be completely disrupted if the executive office fails. The product hierarchy is more vulnerable than the decentralized market because when a processor fails, tasks cannot be easily transferred to another similar processor. Whether the product hierarchy is more or less vulnerable than the functional hierarchy and the centralized market cannot be determined from our assumptions alone. It depends on the relative sizes of costs and probabilities for failures of product managers and functional managers.

Alternative assumptions. Elsewhere, Malone and Smith (1984) ignore the possibility of failures of "product coordinators" (e..g, product managers) and the "executive office." When these possibilities are ignored, we cannot distinguish between functional hierarchies and centralized markets in terms of vulnerability costs.

Appendix 2
Formal justifications for organizational form comparisons

The bases for the qualitative comparisons of organizational forms in Tables 1 and 2 are summarized in Tables 4, 5, 6, and 7 and explained below. Table 4 lists the variables used in this appendix and Table 5 shows the values for production costs, coordination costs, and vulnerability costs in the different organizational forms. The following abbreviations are used: PH for product hierarchy, FH for functional hierarchy, CM for centralized market, and DM for decentralized market. We assume that there are m processors of the functional type being analyzed and that there are n products and k functions.

Production costs

Processing time assumptions. For all organizational forms, it is assumed that tasks of a given type arrive randomly according to a Poisson process with arrival rate $m\lambda$ in the system as a whole. Individual tasks are processed at a rate μ on each processor. In some cases, processing times will be assumed to be exponentially distributed in order to obtain closed form expressions for the queue length statistics. This is usually a pessimistic assumption as far as performance is concerned, since the exponential has a mean to standard deviation ratio that is relatively high. When general service times are used, the variance of the service time will be denoted by σ^2.

Processing capacity assumptions. We assume that there is a cost c_c for processing capacity (measured in dollars per unit of processing capacity). A unit of processing capacity can process one task per time unit. We also assume that there is a waiting cost c_w for tasks that have been generated but not yet completed (measured in dollars per task per unit of time task remains uncompleted). The total production costs per unit of time are therefore

$$P = m\mu c_c + Ac_D$$

where A is the average number of uncompleted tasks in the system at any given time. Our primary results are based on the assumption that the processing capacity μ of each processor is chosen so as to minimize P. Baligh and Richartz (1967, pp. 113-118) show that under this assumption, the optimal capacity is

$$\mu^* = (c_D\lambda / c_C)^{\frac{1}{2}} + \lambda$$

and the total production costs are

$$P = 2m\,(\lambda\, c_D\, c_C)^{\frac{1}{2}} + m\lambda c_C.$$

when tasks are not shared among processors, and λ is the arrival rate of tasks at each processor.

When tasks are shared among the processors, Baligh and Richartz (1967, pp. 123-125) show that the optimal capacity is

$$\mu^* = (c_D\lambda / c_C)^{\frac{1}{2}}$$

and the total production costs are

$$P = 2m\,(\lambda\, c_D\, c_C.)^{\frac{1}{2}}$$

The latter result holds exactly only in the limit as m becomes large.

These two production cost results are the basis for the production cost expressions in Table 5: Product hierarchies have processors with separate streams of tasks; the other organizational forms are able to share tasks among processors.

Note that our model makes different assumptions about task assignment than the model developed by Baligh and Richartz. They assume that buyers in a decentralized market send tasks randomly to suppliers. The model presented here uses what appears to be a more plausible assumption: that buyers send their tasks to the best supplier at a given time (i.e., the one that is available soonest to process the task). With this assumption, tasks are processed in exactly the same way in the decentralized market as in the centralized market and the functional hierarchy. All three cases behave as if the processors were m servers for the overall queue of tasks.

Comparisons. Using the expressions for production costs P shown in Table 5, it is clear that

$$P_{PH} > P_{FH} = P_{CM} = P_{DM}$$

as reflected in Table 1.

Coordination costs

Assumptions. We assume that the costs of maintaining a connection (or communication link) between two people is c_L and that the cost of sending a message is c_M. The analysis of coordination costs presented here is similar in spirit to that of Baligh and Richartz (1964; 1967, Ch. 2, especially p. 35), but it modifies and extends their analysis in several ways. First, as noted below, their assumptions about the number of messages exchanged in markets have been modified to ones that seem more plausible. Second, the same type of analysis has been extended to include the two hierarchical forms: product hierarchies and functional hierarchies.

It is quite straightforward to determine the number of connections required for each organizational form by looking at Figure 1. Our assumptions about the minimum number of messages required for task assignment in each form require slightly more explanation. In the case of the product hierarchy, we assume that a minimum of two messages are required for task assignment: one for the product manager to notify the task processor that a new task has arrived and one for the task processor to notify the manager that the task is completed. In the functional hierarchy, a minimum of four messages are required: one for the executive office to notify the functional manager that the task has arrived, one to notify the processor that will actually perform the task, and then one each to notify the functional manager and the executive office that the task is complete.

In the centralized market, we asume that four similar mesages are required for task assignment: one for the buyer to notify the broker that the task needs to be done, one for the broker to notify the seller that will perform the task, and one each to notify the broker and the buyer when the task is complete. Note that we could have included an additional message for the broker to notify the buyer which seller was selected. Including this additional message for centralized markets would not change any of the results.

Finally, in the pure case of a decentralized market with m suppliers, 2m messages are required for a buyer to send out "requests for bids" to all m potential suppliers and receive m bids in return. An additional 2 messages are required for the buyer to notify the winning bidder and then for the supplier to notify the client when the task is complete.

Comparisons. With these assumptions, it is a simple matter to calculate the costs shown in Table 5, and then the following inequalities for coordination costs, C, follow immediately:

$$C_{PH} < C_{FH} < C_{CM} < C_{DM}.$$

Alternative assumptions: Baligh and Richartz. The assumptions used here about the centralized market are substantially different from the corresponding assumptions by Baligh and Richartz (1967, p. 35). They assumed that the broker would pass along to all of the buyers the prices offered by each of the sellers and to all of the sellers the prices offered by each the buyers. Thus, in their model, $C_{CM} = (m + n)\, c_L + [\, n(m + 1) + m(n + 1)\,]\, c_M$. Our assumption, in contrast to theirs, is equivalent to saying that the broker receives a request from a buyer and, instead of passing along prices for all the possible sellers, passes on the best one available.

The assumptions used here for the decentralized market are also somewhat different from those of Baligh and Richartz. They focused on the number of messages per processor and assumed (p. 35) that all buyers would exchange prices with all suppliers. Thus, in their model, $C_{DM} = mnc_L + 2mnc_M$. We focused, instead, on the number of messages per task and assumed that a buyer would solicit prices from all suppliers for each task.

In both these cases, even though their assumptions are substantially different from the assumptions made here, both sets of assumptions lead to the same results in terms of rankings of the different organizational forms on the dimension of coordination costs.

Baligh and Richartz also consider a number of other factors, such as rebates strategies, inventory carrying costs, and multiple middlemen, that we ignore here. They show, for example, that the centralized market with exactly one broker (or "middleman") is the market structure that minimizes the coordination costs we consider here.

Alternative assumptions: Neglecting costs of connections. Elsewhere Malone and Smith (1984) consider only the message processing costs of coordination and ignore the costs of communication links. With this assumption, functional hierarchies cannot be distinguished from centralized markets in terms of coordination costs.

Alternative assumptions: Consequences of an efficient price mechanism. In a decentralized market with a functioning price mechanism, buyers might assume that most contractors would have approximately the same price, and therefore buyers would only need to contact a few potential contractors. In this case, the coordination costs shown for a decentralized market in Table 5 might be substantially reduced. To determine whether this would change the qualitative results in Table 1, we want to know the conditions under which $C_{DM} > C_{CM}$. Substituting the values in Table 5 and simplifying we obtain

$$(mn - m - n)\, c_L + [(2m - 4)\,\lambda + 2]\, c_M > 0$$

which is true if $n > 2$ and $m \geq 2$. In other words, as long as there are more than two clients in the marketplace, and each client contacts at least two possible contractors, the decentralized market still has higher coordination costs than the alternatives.

Alternative assumptions: Including fixed costs of coordinating processors. The last set of alternative assumptions we consider involves the fixed costs of keeping a coordinating processor (i.e., a manager, broker, or client) in the system. These fixed costs are defined as the costs that occur regardless of the number of messages processed or the number of communication connections maintained. We can model these costs with the following variables: c_R, the fixed cost of a product manager; c_F, the fixed cost of a functional manager, c_E; the fixed cost of an executive office; c_B, the fixed cost of a broker; and c_I, the fixed cost of a client. We interpret these variables as the part of total costs that are apportioned to the function being analyzed. Table 6 shows the revised expressions for coordination costs that include these fixed costs.

If we make the fairly restrictive assumptions that $c_R = c_F = c_B = c_I$, and $c_E = nc_R$, it is straightforward to show that $C_{PH} < C_{FH} < C_{CM}$, and $C_{PH} < C_{DM}$, but we cannot show that $C_{FH} < C_{DM}$ or $C_{CM} < C_{DM}$. With less restrictive assumptions about the costs we are able to prove even less about the relative coordination costs. For example, if we assume that the two kinds of product coordinators have the same costs, $c_I = c_R$, as do the two kinds of functional coordinators $c_F = c_B$, then we can still show that $C_{PH} < C_{DM}$, but, depending on the values of c_F and c_E, C_{FH} and C_{CM} can be anywhere with respect to each other and the other two costs.

In summary, introducing fixed costs of coordinating processors into the model does not lead to results that directly contradict the main results in Table 1, but it does render some of the comparisons indeterminate. It seems plausible to assume that, in the long run, the number of messages to be processed will be the major determiner of the number of coordinating processors needed. Accordingly, the main results presented here ignore the fixed costs of coordinating processors and focus on the costs of maintaining communication links and the variable costs of processing messages.

Vulnerability costs

Assumptions. We assume that processors fail according to Poisson processes at constant rates. The rates are p_T for task processors, p_F for processors that coordinate tasks of the same functional type (i.e., functional managers and brokers), p_P for processors that coordinate all tasks necessary to produce a given product (i.e., product managers and clients), and p_E for executive office processors that coordinate all tasks for a number of products. We assume that p_T, p_F, $p_P > 0$, and $p_E \geq p_F, p_P$. The failure of one processor is assumed to be independent of the operational status of all other processors.

We assume that the expected cost of having the tasks on a processor delayed because the processor fails and they are sent elsewhere is c_T. The expected cost of having all the production of one product disrupted is c_P, and the expected cost of having all the products disrupted is c_A, with $c_T < c_P < c_A$.

Comparisons. Given these assumptions, the expressions for failure costs F in Table 5, and the following inequalities all follow immediately: $F_{DM} < F_{CM} < F_{FH}$, and $F_{DM} < F_{PH}$.

Size of the organization

We assume that as the size of the organization increases, the number of products and the number of processors increase. To determine the effect of these increases on the different kinds of costs, we examine the partial derivatives with respect to m and n. Table 7 shows these partial derivatives. The assignment of varying numbers of pluses for the values in Table 2 all follow immediately from the relative sizes of the partial derivatives in Table 9.

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Footnotes

1 We have substituted "functional" and "product" for the terms used in the original: "process" and "purpose," respectively.

2 This argument is being developed in more detail with Robert Benjamin and JoAnne Yates.

Table 1
Tradeoffs Among Alternative Organizational Forms

Organizational Form	*Evaluation Criteria*		
	Efficiency		***Flexibility***
	Production Costs	*Coordination Costs*	*Vulnerability Costs*
Product hierarchy	H	L	H
Functional hierarchy	L	M −	H +
Centralized market	L	M +	H −
Decentralized market	L	H	L

Note: L = Low costs ("good")
M = Medium costs
H = High costs ("bad").
Comparisons apply only within columns, not between rows.

Table 2
Changes in Evaluation Criteria as Size of Economy Increases

	Production Costs	*Coordination Costs*	*Vulnerability Costs*
Product hierarchy	+	+	+ + +
Functional hierarchy	+	+	+
Centralized market	+	+ +	+ +
Decentralized market	+	+ + +	+ +

Table 3

Assumptions about Alternative Organizational Forms

	No. of connections required between actors	*Minimum no. of msgs. to assign task to best processor*	*Result of task processor failure*	*Result of functional manager failure*	*Result of product manager failure*	*Result of executive office failure*
Product hierarchy	m	2	1 product disrupted	--	1 product disrupted	--
Functional hierarchy	m + 1	4	task reassigned	all products disrupted	--	all products disrupted
Centralized market	m + n	4	task reassigned	all products disrupted	1 product disrupted	--
Decentralized market	mn	2m + 2	task reassigned	--	1 product disrupted	--

Note: m is the number of processors and n is the number of products in the organization

Table 4
Symbol Table

Variable		Definition
Total Costs		
$P_{PH}, P_{FH}, P_{CM}, P_{DM}$	=	production costs per task for the various organizational forms
$C_{PH}, C_{FH}, C_{CM}, C_{DM}$	=	coordination costs per task for the various organizational forms
$V_{PH}, V_{FH}, V_{CM}, V_{DM}$	=	vulnerability costs per task for the various organizational forms
Component Costs		
c_C	=	cost of production capacity (cost per unit of processing capacity capable of processing 1 task per time unit)
c_D	=	cost of delay (or waiting) for tasks to be processed (cost of delay of 1 task for 1 time unit)
c_L	=	cost of maintaining a connection (or link) between processors (cost per time unit)
c_M	=	cost of sending a message (cost per message)
c_T	=	cost of reassigning a task to another processor (average cost attributed to this function per reassignment)
c_P	=	cost of disrupting production of 1 product (average cost per disruption)
c_A	=	cost of disrupting production of all products (average cost per disruption)
Probabilities		
p_T	=	probability of task processor failure (per time unit)
p_F	=	probability of failure of a functional manager or broker (per time unit)
p_P	=	probability of failure of a product manager or buyer (per time unit)
p_E	=	probability of failure of an executive office (per time unit)
Other quantities		
m	=	number of processors of this type for all products combined
n	=	number of products
k	=	number of functions
λ	=	number of tasks per time unit of this type for each product
μ	=	average processing rate of each processor

Table 5
Evaluation Criteria for Alternative Organizational Forms

	Production Costs	*CoordinationCosts*	*Vulnerability Costs*
Product hierarchy	$2m(c_D c_C \lambda)^{\frac{1}{2}} + m\lambda c_C$	$mc_L + 2\lambda c_M$	$mp_T c_P + np_P c_P$
Functional hierarchy	$2m(c_D c_C \lambda)^{\frac{1}{2}}$	$(m+1)c_L + 4\lambda c_M$	$mp_T c_T + p_F c_A + p_E c_A$
Centralized market	$2m(c_D c_C \lambda)^{\frac{1}{2}}$	$(m+n)c_L + 4\lambda c_M$	$mp_T c_T + p_F c_A + np_P c_P$
Decentralized market	$2m(c_D c_C \lambda)^{\frac{1}{2}}$	$mnc_L + (2\lambda m + 2)c_M$	$mp_T c_T + np_P c_P$

Table 6
Coordination Costs Including Fixed Costs of Coordinating processors

Organizational form	*Coordination costs*
Product hierarchy	$mc_L + 2\lambda c_M + nc_R$
Functional hierarchy	$(m+1)c_L + 4\lambda c_M + c_F + c_E$
Centralized market	$(m+n)c_L + 4\lambda c_M + c_B + nc_I$
Decentralized market	$mnc_L + (2\lambda m + 2)c_M + nc_I$

Table 7
Rates of Change of Evaluation Criteria as Size of Economy Increases

	Production Costs		*Coordination Costs*		*Vulnerability Costs*	
	$\frac{\delta}{\delta m}$	$\frac{\delta}{\delta n}$	$\frac{\delta}{\delta m}$	$\frac{\delta}{\delta n}$	$\frac{\delta}{\delta m}$	$\frac{\delta}{\delta n}$
Product hierarchy	$2(c_D c_C)^{\frac{1}{2}} + \lambda c_C$	0	c_L	0	$p_T c_P$	$p_P c_P$
Functional hierarchy	$2(c_D c_C)^{\frac{1}{2}}$	0	c_L	0	$p_T c_T$	0
Centralized market	$2(c_D c_C)^{\frac{1}{2}}$	0	c_L	c_L	$p_T c_T$	$p_P c_P$
Decentralized market	$2(c_D c_C)^{\frac{1}{2}}$	0	$nc_L + 2\lambda c_M$	mc_L	$p_T c_T$	$p_P c_P$

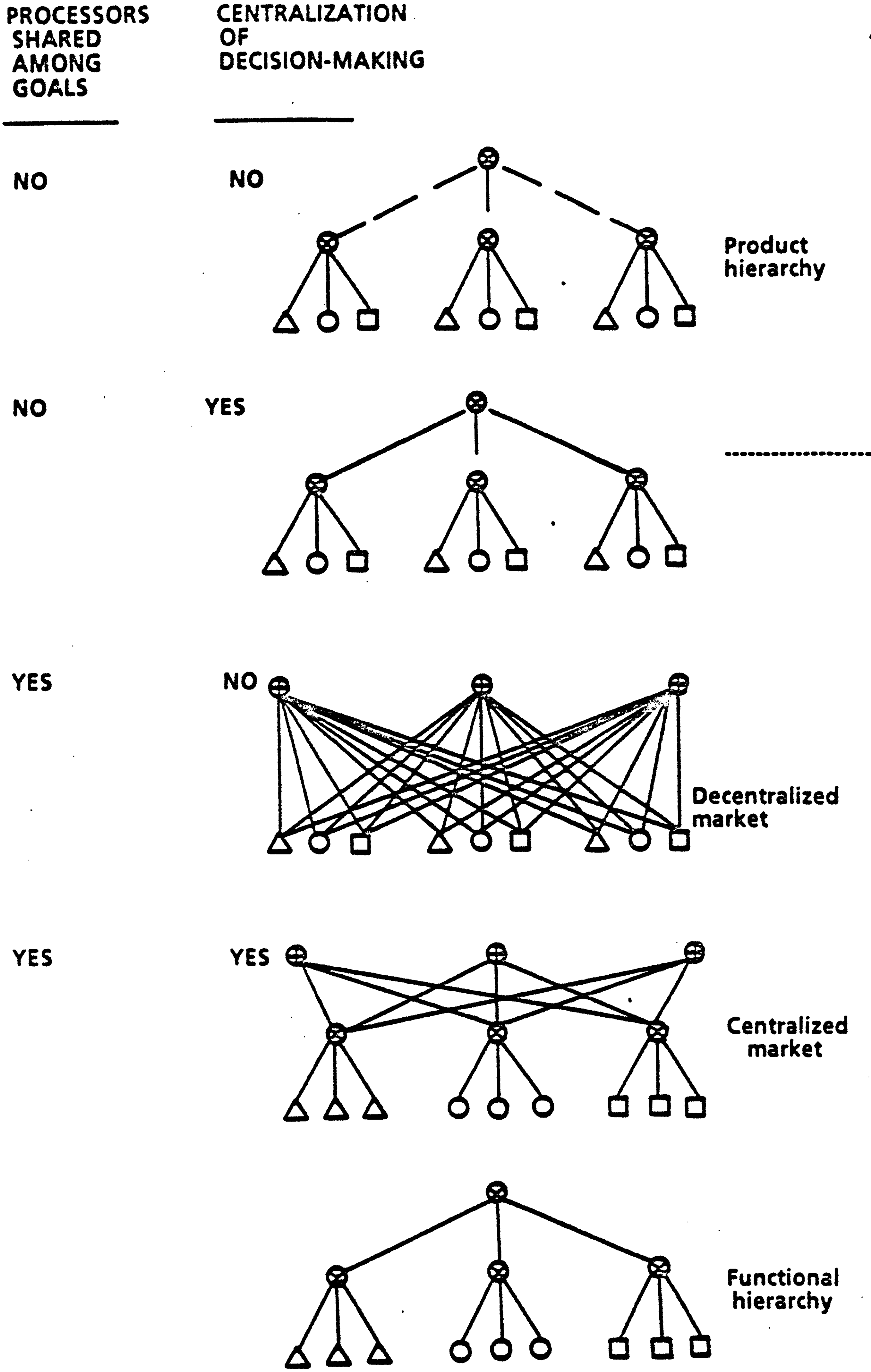
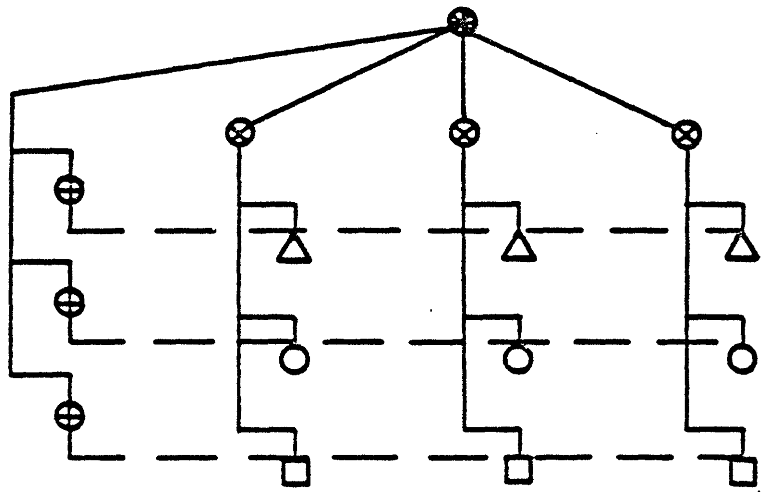


Figure 1
Alternative Organizational Forms



Key:

⊕ Functional manager
⊗ Product manager
⊛ Executive office

△ ⎧ Different
○ ⎨ processor
□ ⎩ types

Figure 2
Matrix Organization

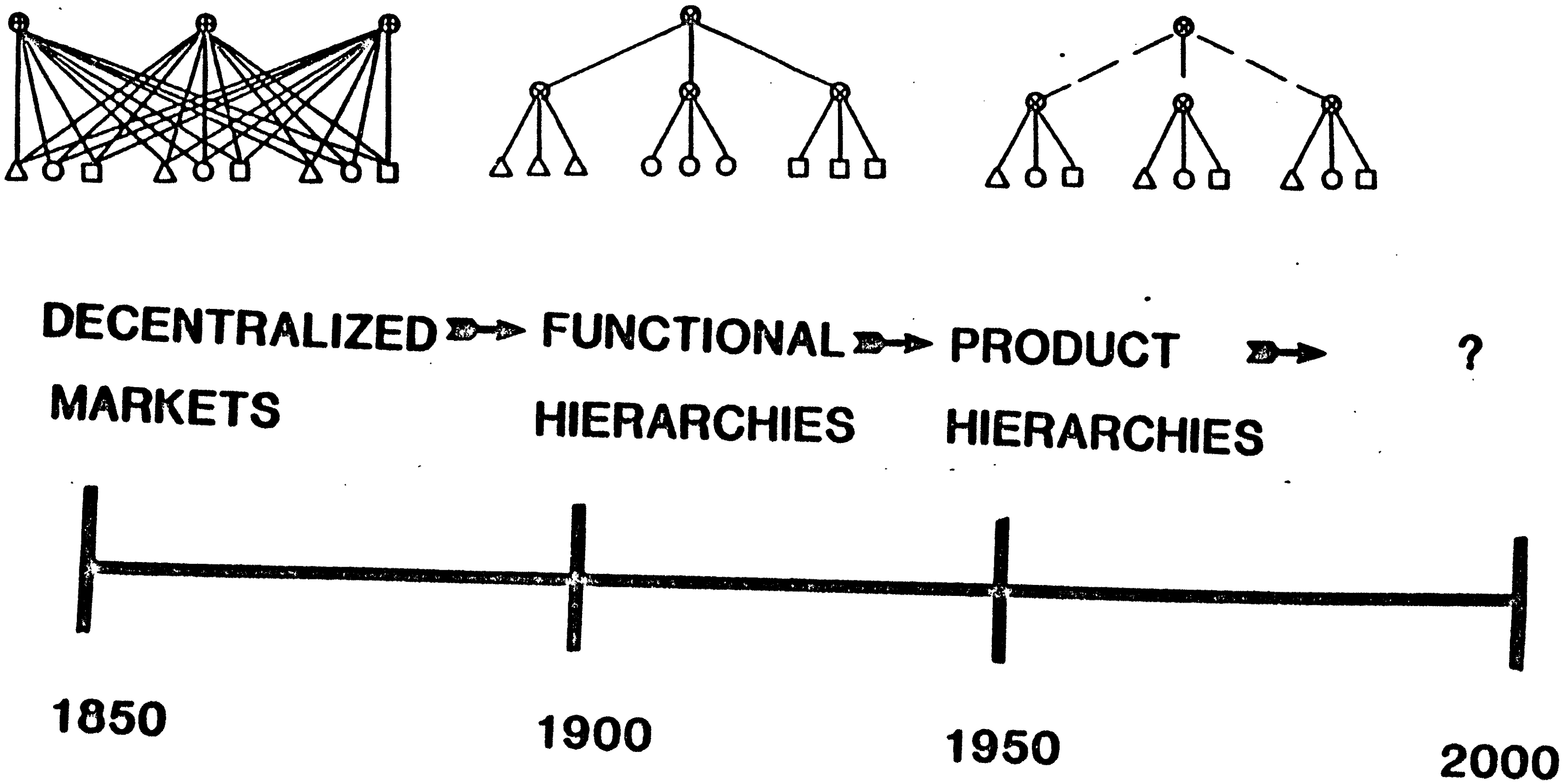


Figure 3

CHANGES OF DOMINANT ORGANIZATIONAL STRUCTURES IN AMERICAN BUSINESS

Figure 4
Estimated Percentage of Firms in Each Organizational Class
1949-1969

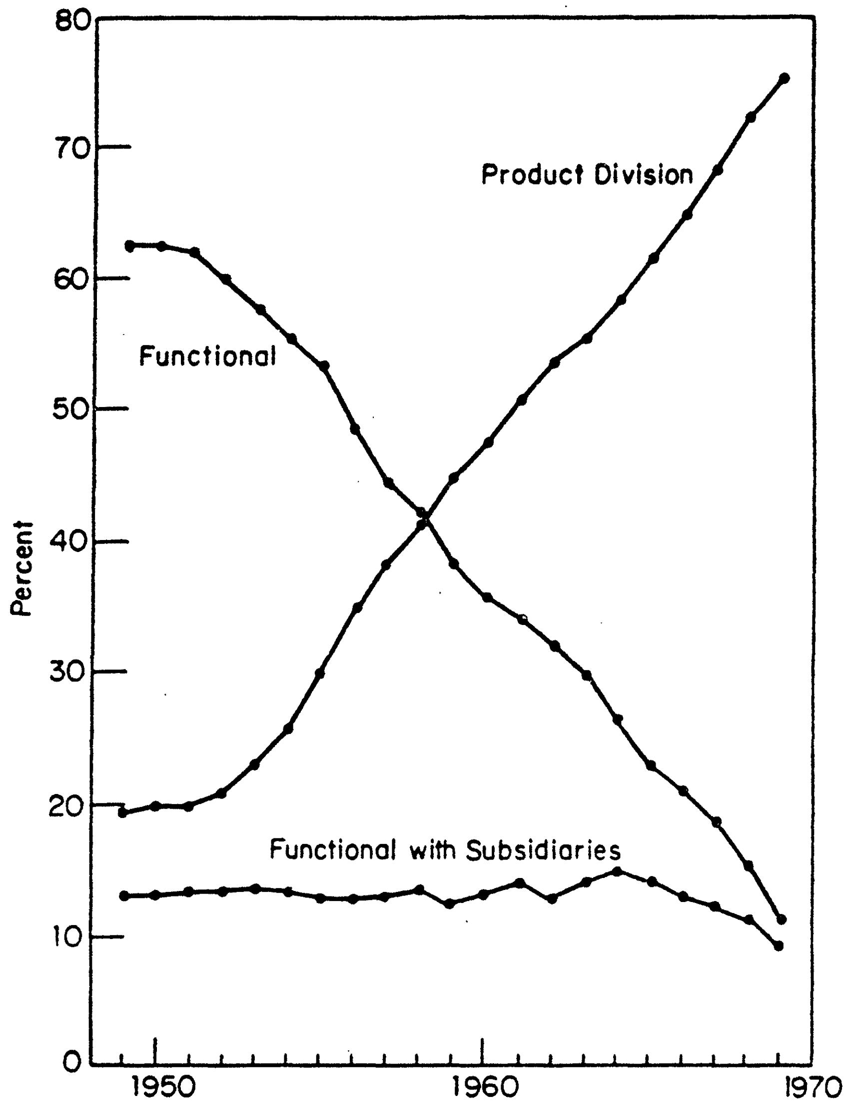


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Figure 5

Organizational Science: Theory and Applications