

# **A Formal Model of Organizational Structure and Its Use in Predicting Effects of Information Technology**

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WP# 1849-86

August 1986

Sloan School of Management Working Paper #1849-86  
Massachusetts Institute of Technology

## Abstract

There are three parts of this paper. The first part describes a highly simplified model of organizational structures that focuses on the information processing involved in coordination. This model distinguishes several generic organizational structures (various kinds of markets and hierarchies) and identifies tradeoffs among them in terms of production costs, coordination costs, and vulnerability costs. The model is unusual in that it includes formal definitions of these structures and mathematical derivations of the comparisons among them.

In the second part of the paper, the model is tested for consistency with two kinds of empirical observations: generalizations from previous work on organizational design and major changes in the structures of American businesses over the last century. The simplified model is found to be consistent with a surprising range of these empirical observations.

Finally, the model is used to predict how the widespread use of information technology may affect organizational structures. The primary prediction is that, by reducing coordination costs, information technology will lead organizations to retrace the evolutionary path their structures have taken in the last century.

## A Formal Model of Organizational Structure and Its Use in Predicting Effects of Information Technology

Human organizations are possibly the most complex entities on our planet. Their complexity can be viewed from many different perspectives, each emphasizing some factors and neglecting others. This paper emphasizes one perspective: analyzing organizational structures in terms of the information processing involved in coordination. This perspective appears particularly promising for predicting how information technology affects organizational structure because coordination processes are critical in determining organizational structure, and because they are among the processes most likely to be directly affected by information technology.

We first develop formal definitions of several common structures for coordinating human activity--various forms of markets and hierarchies. These definitions are based on micro-level assumptions about how tasks are selected and assigned. Then we analyze these structures in terms of macro-level characteristics such as production costs and coordination costs. These models represent a kind of idealized "frictionless plane" in which many factors known to be present in the real world are temporarily ignored. Therefore, we next test the results of the models for consistency with two kinds of empirical observations: (1) the generalizations developed in several decades of research on organizational design and (2) the major changes that have occurred in the structure of American businesses during the last century. These tests demonstrate that the highly simplified formal models are consistent with a surprising range of empirical behavior. Even though the models are known to be incomplete, they appear to capture important qualitative relationships between organizational structure, efficiency, and flexibility. The qualitative results of the models can therefore be viewed, in part, as a way of integrating and formalizing some of the previous empirical work on organizational design. Finally, with this basis for believing that the models have some validity, we use the models to make speculative predictions about the possible consequences that the widespread use of information technology may have for organizational structures.

In order to simplify the flow of the paper, the main line of the argument is included in the body of the paper, and all the formal details are in appendices. The formal models developed in the appendices draw heavily on previous work by Baligh and Richartz (1967), Baligh and Damon (1980), and Baligh and Burton (1981, 1984). The models also draw implicitly on analogies between the information processing done by people and the information processing done by computers (see Malone & Smith, 1984; Malone, in press [b]). While people and computers differ in many ways, this "cognitive"

approach has been useful in many of the social sciences (e.g., March & Simon, 1958; Norman, 1981) and appears to have unrealized potential for analyzing human organizations.

## BACKGROUND

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. 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.

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, much 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 goals of this paper is to take a small step toward integrating and formalizing some of the knowledge in this area. In order to do this, we will next review a number of formal mathematical 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 and parameter values that can be used within Marschak and Radner's general framework leads to a multitude of highly conditional results. Almost all the Marschak and Radner theorems 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 can be represented in this manner 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 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 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. Much of our formal modeling is based on their work. Kochen and Deutsch (1980) take a somewhat similar approach to analyzing the desirability of various kinds of decentralization in service organizations. Mackenzie (1986a,b) describes a detailed set of models and methodologies for studying and representing the tasks, structures, and coordination methods of specific organizations. For instance, he shows how a sequence of tasks can be represented as a process and how tasks and coordinating processes can be analyzed at a series of different levels of abstraction.

## MODEL

This section presents a simple model that emphasizes some of the basic processes involved in coordination. The highly simplified assumptions described here are not intended to be complete descriptions of the detailed processes in any real organization. By simplifying different structures down to their "barest bones," however, some of their essential differences are highlighted.

*Organizational structures.* To begin our modeling, we define an organizational structure as consisting of (1) a set of *goals* to be achieved, (2) a set of *tasks* performed (or "processed") in order to achieve the goals, (3) a set of *actors* (or "processors") who process the tasks, (4) an *assignment* of (or method of assigning) tasks to actors, and (5) a way of communicating information between actors, which we will call *messages* (c.f., Baligh & Damon, 1980; Baligh & Burton, 1981). For example, an automobile manufacturing company like General Motors<sup>1</sup> might 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 perform the tasks necessary for achieving those goals (e.g., the people and machines specialized for doing engineering, manufacturing, sales, etc.).

*Goals.* As the automobile manufacturing example illustrates, one common kind of goal is a product to be produced, and we will use the terms "goal" and "product" interchangeably. Other interpretations are possible, however. For instance, in universities, goals might be educating students with different majors, and tasks might be teaching courses in different subjects; in hospitals, goals might be caring for patients with different kinds of diseases, and tasks might involve supplying medication, nursing care, and surgery. It is also possible to interpret goals and tasks in different ways for different purposes. For instance, what is regarded as an elementary task at one level of analysis may be, at another level of analysis, regarded as a goal with its own subtasks (see March & Simon, 1958, pp. 31-32). For example, designing a car is a subtask for the goal of producing cars, but designing a car is itself a goal with subtasks such as designing the engine, designing the body, and so forth. Mackenzie (1986) shows how elaborate descriptions of these task/subtask relationships can be constructed for specific organizations.

Both these examples of interpreting goals illustrate how, in general, our formal models are abstract descriptions of coordination patterns that can be interpreted in different ways for different purposes. Our interpretations here emphasize macro-level organizational structures, but the same patterns also occur at many other levels (e.g., assigning typists to individual authors or to word processing pools).

*Organizational boundaries.* Similarly, our definition of organizational structure is quite abstract. We use the term "organization" to mean any structure for coordinating human activity, including both hierarchical firms and markets. (For examples of previous work that treats coordination in a similarly general way--though not using the same terms--see Coase [1937], Williamson [1979], and Baligh [in press]). Since our models are primarily concerned with how task processing is coordinated,

they are relatively insensitive to where the legal boundaries of organizations are drawn (see Baligh & Burton, 1982; Baligh, in press; and Mackenzie, 1986a, for extended discussions of this issue).

*Coordination.* In order to focus on the information processing involved in coordination, we divide tasks 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 (e.g., see Jonscher, 1982, 1983). 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. For instance, much of the work done by managers at all levels can be thought of as coordination. 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).

We will sometimes refer to production tasks simply as "tasks" and to coordination tasks as "decisions". We analyze production tasks only in terms of their "type" (i.e., the type of processor that can process them) and their processing time (see Appendix C). We focus our primary attention on two types of coordination tasks: (1) *product decisions* - deciding which tasks should be done to achieve the goals, and (2) *functional decisions* - deciding which processor should do each task. These two decisions represent simple, but fundamental, aspects of coordination. They seem essential, for instance, to what Mackenzie (1986a, 1986b) calls "directing, coordinating, and controlling task process laws."

Appendix A describes detailed assumptions about how these decisions concerning task processing are made and about the consequences for task processing of processor failures. The highly simplified assumptions implicitly include only two kinds of interactions between tasks: (1) The selection of new tasks to be done depends only on the previous tasks for the same product (Thompson's "sequential interdependence"); and (2) The decision about where to do a task depends on other tasks only to the extent that they share the same processors (Thompson's [1967] "pooled interdependence"). In other words, we model sequential interdependence within a product and pooled interdependence between products.

The assumptions in Appendix A depend primarily on alternatives for who makes product and functional decisions. We consider two alternatives for who makes product decisions: (1) *decentralized product decisions*, in which a separate "product manager" for each goal chooses the tasks to be done, and (2) *centralized product decisions*, in which a single "product manager" for the entire organization



(e.g., a "chief executive") chooses tasks to be done. Similarly, we consider three alternatives for how functional decisions are made: (1) *dedicated processors*, in which each task processor is "dedicated" to a goal and processes tasks only for that goal, (2) *decentralized functional decisions*, in which task processors are shared among goals, but decisions about which processor should perform a task are made by the "product managers" for the goals, and (3) *centralized functional decisions*, in which task processors are shared among goals and decisions about which processor should perform a task of a given type are made by a separate "functional manager" who supervises all processors of that type.

*Comparing organizational structures.* Appendix A shows how the different combinations of alternatives for product and functional decisions give rise to different organizational structures. Figure 1 shows four of these formally defined structures that resemble structures commonly found in human organizations. The lines and symbols in the figure summarize the detailed patterns of decision-making and communication described in the appendix. These "pure" organizational structures serve as the building blocks for much more complex organizations. In the next section we describe these different organizational forms and give examples of their use in human organizations.

We will compare the different organizational forms in terms of their *production costs*, their *coordination costs*, and their *vulnerability costs*. Production and coordination costs are the costs for performing production and coordination tasks, respectively. The third factor, vulnerability costs, reflects the unavoidable costs of a changed situation that are incurred before the organization can adapt to a new situation. 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. The assumptions in Appendix A 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 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*

In a product hierarchy, 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, in the "pure" form of this structure, 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 this "pure" form, 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 the operational coordination involved in task assignment and processing 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.

### *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, General Motors 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, as we have defined it, 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 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 car allocations 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 market coordination structures, 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 the "pure form" of a decentralized market, 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 "requests 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.

### **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." The formal derivations of these comparisons require extended analysis and are relegated to Appendix C. For readers who would like a summary of the derivations before proceeding, informal justifications for the comparisons are presented in Appendix B.

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 characteristics of 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.

*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 organization, 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 C. 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.

## TESTS OF THE MODEL

We will consider two kinds of tests of the model just presented: (1) Is it consistent with previous, empirically based, principles of organizational design? and (2) Are its implications consistent with the major historical changes that have been observed in American business structures in the last century?

### Consistency with previous organizational design principles

As noted above, the qualitative comparisons shown in the table do not begin to include all the factors discussed by organizational design theorists (e.g., Mintzberg, 1979; Galbraith, 1977; March & Simon, 1958; Gulick & Urwick, 1937; and Hax & Majluf, 1981). In the cases where our model addresses issues considered previously, however, the comparisons in the table do appear to be consistent with previous work. Thus, our model not only summarizes certain previous results but also places them in a more comprehensive framework. In some cases, as the examples below show, our model also extends or suggests limitations of previous principles.

*Tradeoffs between production costs and coordination costs.* March and Simon (1958, p. 29) summarize the problem of departmentalization as 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. . ."<sup>2</sup> 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 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 reflects this and goes on to suggest an important distinction between two kinds of flexibility that must be used to qualify the 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, our models suggest that 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).

Table 1 suggests, however, that 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. We can interpret this comparison in terms of our model 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.

### **Historical changes in American business structures**

Figure 2 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 and adds to these earlier explanations.

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 2). 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. For instance in a sample documented by Rumelt (1974), the approximate percentage of firms structured as functional hierarchies dropped precipitously from between 1950 and 1970 (from about 60% to about 10%) and the proportion of firms structured as product hierarchies increased just as dramatically (from about 20% to about 75%). 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 (see Table 1).

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.

**APPLICATION:  
PREDICTING THE EFFECT ON ORGANIZATIONAL STRUCTURE  
OF WIDESPREAD USE OF INFORMATION TECHNOLOGY**

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.

In contrast to these approaches, the model presented here attempts to provide a basis for making long-term predictions based on fundamental considerations about information processing and coordination. This approach is certainly not without its own dangers, and our predictions should be viewed as theory-based speculation. However, the ability of our model to provide plausible explanations for the historical changes that led organizations to have the forms they do today gives us some additional confidence in its validity.

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, several large multi-divisional companies have recently moved back toward a single centralized sales force (e.g., Kneale, 1984; IBM, 1981).<sup>3</sup> 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).

In some cases, information technology may be able to not only reduce the overall coordination costs of an organization, but also to increase the maximum "decision load" (see Appendix A) a single individual can handle. If this occurs, our analyses in Appendices A and C suggest that organizations may move toward an organizational form that is now quite unusual. We call this form a "fully centralized hierarchy", and in its "pure" version, one manager (or "executive office") makes all the decisions in the organization. We speculate that this form may be rare now in large organizations, in part, because of the limits on "decision loads" that any single individual or "executive office" can handle. Changing these limits, however, might make possible more fully centralized decision making.

*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 (see Malone, Yates, & Benjamin, 1986). 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 entrepreneurial 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

This paper has presented a model that helps integrate and formalize severalize previous results 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.

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 (see also Malone, Yates, & Benjamin, 1986). 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 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.



### Acknowledgements

This research was supported, in part, by the Center for Information Systems Research at the Massachusetts Institute of Technology; Citibank, N.A.; the Management in the Nineties Research Program at the Massachusetts Institute of Technology; the Xerox Corporation Palo Alto Research Center; and National Science Foundation Grant No. SES-8213169.

The author would especially like to thank John Little, Michael Cohen, and three anonymous referees of a previous paper for helpful comments.

## Appendix A

### Definitions of Organizational Forms

This appendix sketches out how a set of formally defined organizational structures can be derived from assumptions about several alternative policies for the decision-making and information processing involved in task assignment. The formal representation of organizational structures in terms of messages and decisions is adapted from that used by Baligh & Damon (1980) and Baligh & Burton (1981, 1984). We generalize their notion of decision to include tasks of all types, and we omit explicit consideration of rewards for decision makers and of parameters set by the environment.

*Definitions.* First, we assume the definitions given in the main text for (D1) organizational structure, (D2) product decisions, (D3) functional decisions, (D4) decentralized product decisions, (D5) centralized product decisions, (D6) dedicated processors, (D7) decentralized functional decisions, and (D8) centralized functional decisions.

*Axioms.* In order to generate specific organizational structures for each of the alternatives for product and functional decisions, we make some further assumptions about the way these decisions are made:

- (A1) Task processors require descriptions of the tasks they are to process and notification that a task has been assigned to them. They produce a description of the completed task.
- (A2) Product decisions require a description of a task that has been completed and produce a description of a new task to be done.
- (A3) The status of task processors changes depending on their previous status and on the tasks they have been assigned.
- (A4) Functional decisions require information about the task that needs to be done and the status of the processors. These decisions are made in one of three ways:
  - (a) With *dedicated processors*, only one processor of each type is ever available for each product and no current information about its status is necessary or useful. Tasks are simply assigned to the dedicated processor of the appropriate type. (We assume that the level of aggregation used for counting processors is chosen such that only one of each type is dedicated to each product.)
  - (b) With *shared processors and non-overlapping decisions* (i.e., when only one manager makes functional decisions for all the processors of a given type), the managers keep track of which processors are available by remembering (i) to which processors they have assigned tasks and (ii) from which processors they have received reports of task completion. The managers use this information to assign the task to the "best" available processor. The "best" available processor is defined as the one that optimizes a measure of the "goodness" of assigning the task to that processor. The

"goodness" measure for each processor depends on the task description and the processor status. It may reflect, for example, estimated completion time or cost.

- (c) With *shared processors and overlapping decisions* (i.e., when several managers all make functional decisions for the same processors), the task processors keep track of their own status and the product managers poll all the processors of the appropriate type to find the "best" available processor.

We also make several additional assumptions to reduce the number of variations considered:

- (A5) Each goal requires at least some tasks of each type.
- (A6) The same actor cannot play more than one of the following roles: task processor, functional manager, or product manager. (Note, however, that product managers can make functional decisions by D7).
- (A7) Messages are exchanged, communication paths are established, and managers are included in organizations only when required by the definitions and assumptions listed above. A detailed statement of rules implied by this assumption of "technological efficiency of structures" is given by Baligh and Burton (1984, pp. 19-20). We list three specific examples here:
  - (a) Messages are not used to communicate information to the same actor who produces it.
  - (b) Messages are sent through intermediaries when this avoids the need for an extra communication path.
  - (c) Multiple pieces of information with the same source and destination are combined in the same message.

*Notation.* To express these assumptions more formally, we first let  $t_i$  represent a description of task  $i$  before it has been processed and  $t_i'$  be a description of the task after processing. (We do not specify the form of these descriptions. They may, for example, be lists of attribute-value pairs, and  $t_i'$  may include the results of the task processing.) We let  $s_j$  be a description of the status of processor  $j$ . Again the form of this description is not specified, but it must at least include some representation of whether the processor is available. We let  $a_i$  be the assignment of task  $i$ , with  $a_i = j$  iff task  $i$  is assigned to processor  $j$ , and  $g_{ij}$  is the "goodness" measure for assigning task  $i$  to processor  $j$ . All these variables may change over time, but we omit a time subscript in order to simplify our notation. In cases where confusion might result, we use a prime (as in  $t_i'$ ) to indicate a different time. The function  $\tau(t_i)$  returns the "type" of task  $i$ ,  $\pi(j)$  returns the "type" of processor  $j$ ,  $\beta(t_i)$  returns the product for which task  $t_i$  is performed, and  $\gamma(j)$  returns the product to which processor  $j$  is dedicated (if any). We use the label  $TP_j$  for the  $j$ th production task processor,  $PM_j$  for the product manager for product  $j$ , and  $FM_j$  for the functional manager for task processors of type  $j$ . In cases where no confusion will result, these subscripts will be omitted. All this notation is summarized in Table 3.

With this notation, we can restate our first four axioms more formally as follows:

- (A1)  $t_i' = f_1(t_i, a_i)$ .
- (A2)  $t_i = f_2(t_{i_0}')$  where  $i > i_0$ .
- (A3)  $s_j' = f_3(T^*, A^*, s_j)$  where  $T^* = \{t_i | a_i = j\}$  and  $A^* = \{a_i | a_i = j\}$ .
- (A4) (a)  $a_i = f_4(t_i) = j^*$  where  $j^*$  is chosen such that  $\pi(j^*) = \tau(t_i)$ , and  $\gamma(j) = \beta(t_i)$ .
- (b)  $a_i = f_5(t_i, S^*) = j^*$  where  $S^* = \{s_j | j \in J\}$ ;  $J = \{j | \pi(j) = \tau(t_i)\}$ ; and where  $j^*$  is chosen such that  $g_{ij} = g_j(t_i, s_{j^*}) = \min_{j \in J} g_j(t_i, s_j)$ .
- (c)  $a_i = f_5(t_i, S^*)$  as defined in (b).

*Implications for decisions, information flows, and messages.* Table 4 shows the assignments of decisions to actors implied by these assumptions and the information needed and produced by each decision. Table 5 summarizes the information flows needed to make the decisions. Each row in Table 5 corresponds to a message in Table 6 except where, according to assumption A7, messages or communication paths can be avoided.

*Alternative organizational forms.* The alternatives for product and functional decisions we have considered give rise to six possible combinations, each of which represents a possible organizational form. These possibilities are listed in Table 7 along with the numbers of product managers, functional managers, communication paths, and messages implied by the above assumptions. A sample of the reasoning by which this table was constructed is included in the final section of this appendix.

We have attempted to label the possibilities defined in this way with the names of common organizational structures they resemble. In four of the cases (product hierarchies, functional hierarchies, decentralized markets, and centralized markets), the formally defined structures do, indeed, seem to resemble common ways of organizing human activity. We describe and analyze these structures in much more detail in the text and the other appendices.

*Unusual organizational forms.* Two of the cases (over-centralized product hierarchies and fully centralized hierarchies) do not seem to occur frequently in the human organizations we have considered. Therefore, though we include them in the formal analyses of Appendix C, we do not describe and analyze them in the main body of the text. One intriguing question raised by our taxonomy of structures is why these two structures are less common than the others. A clue is provided by the observation that, in both these organizational forms, all decisions (both product and functional) are made by a single manager. It seems plausible to hypothesize that in organizations of

more than a few people, this decision load may quickly exceed the "bounded rationality" (Simon, 1981) of individual managers and their staffs.

To formalize this conjecture, we make the following assumption:

- (A8) The decision load on an actor is proportional to the number of product decisions and the number of functional decisions made by that actor per time unit.

We let  $p$  and  $f$  be the cost (or perhaps "mental load") of a product decision and a functional decision respectively. Then we analyze, for each organizational form, the maximum number of decisions made by any actor. To do this, we let  $n_{tp}$  be the number of tasks generated per time unit of type  $t$  for product  $p$ . Then we let  $N_T$  be the number of tasks of the most frequent type ( $N_T = \max_t (\sum_p n_{tp})$ ),  $N_P$  be the number of tasks for the product with the heaviest task load ( $N_P = \max_p (\sum_t n_{tp})$ ), and  $N$  be the total number of tasks ( $N = \sum_{t,p} n_{tp}$ ). Table 8 shows the resulting decision loads for each organizational form. It is clear from the table that the two unusual forms do, indeed, have a greater maximum decision load than any of the other forms. This may explain, in part, why these two forms are not commonly used.

*Assumptions about processor failure.* In order to complete our formal definitions of the properties of the different organizational forms, we make the following assumptions about the consequences of an actor failing to function correctly:

- (A9) When a task processor fails:
- (a) if there are other task processors to perform the task, the task is reassigned to another processor.
  - (b) If there are no other processors to perform the task, production of the product involved is disrupted until the processor performs correctly again.
- (A10) When a manager fails, production of the products processed by that manager are disrupted until the manager is functioning correctly again.

Table 7 shows the consequences of these two assumptions for the different combinations considered.

*Derivation of organizational descriptions.* In this section, we illustrate the derivation of the values included in Table 7 by examining one case--the case labeled "centralized market". The arguments for the other cases are similar.

First, we let  $k$  be the number of types of task processors,  $m$  be the total number of task processors, and  $n$  be the number of products. The product decisions are decentralized in this case, so by D4, and A7, there must be  $n$  product managers. The functional decisions are centralized, so by D8 and A7 there must be a functional manager for this type.

Next we trace the path of messages needed to assign a task. First a product manager decides that a task needs to be done (D4). Since functional decisions are centralized, a functional manager must be notified that the task needs to be done (D8, A4). The functional manager will know which is the best processor (A4c) and will notify that processor (A1). When the task is completed, the functional manager must be notified (A4c), and so must the product manager (A2). These steps require a total of 4 messages. In order for all the messages of these types to be exchanged, each product manager must be able to communicate with the functional manager of this type (A5) and each processor must be able to communicate with the functional manager for its type (D8). No other connections or messages are necessary (A7). This leads to a total of  $n + m$  links. Note that direct links between task processors and product managers are not necessary because the functional managers can be used as intermediaries (A7b).

Since no processors are dedicated, if a task processor fails, other processors are available and the task can be reassigned (A9a). Since all products use each functional manager (D8, A5), the failure of any functional manager disrupts all products (A10). Since each product manager is involved with only one product (D4), the failure of a product manager disrupts only one product (A10).

## **Appendix B**

### **Informal Justifications for Organizational Form Comparisons**

This appendix gives intuitive justifications of the qualitative comparisons in Table 1. Formal proofs are included in Appendix C. The key assumptions about the alternative organizational forms are summarized in Table 7.

#### **Production costs**

Our primary assumption about production costs is that they are proportional to the amount of processing 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.

#### **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 7 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 the functional managers (or brokers) must be connected not only to the processors they supervise, but also to the product 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.

### **Vulnerability Costs**

Our primary assumption about vulnerability costs is that they are proportional to the expected costs due to failures of task processors and managers. We assume that both processors and managers 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 7. 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 functional manager or broker 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

*Production costs.* 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. They 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.* Appendix C 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 C 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.* 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 C

#### Formal justifications for organizational form comparisons

The bases for the qualitative comparisons of organizational forms in Tables 1 and 2 are summarized in Tables 9, 10, and 11 and explained below. Table 9 lists the variables used in this appendix and Table 10 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, DM for decentralized market, OPH for overcentralized product hierarchy, and FCH for fully centralized hierarchy. We let  $m$  be the number of processors of the functional type being analyzed,  $n$  be the number of products, and  $k$  be the number of functions. In all cases, we assume that

- (C0) Costs not explicitly modeled are the same in all organizational forms.

#### Production costs

For all organizational forms, we make the following assumptions:

- (C1) Tasks of a given type are generated randomly according to a Poisson process that is the same for each product and has arrival rate  $m\lambda$  for the system as a whole.
- (C2) Individual tasks are assigned to the first available processor of the appropriate type and are processed, in the order of arrival, at a rate  $\mu$  on each processor. The processing times are exponentially distributed.
- (C3) Production costs are proportional to the amount of processing capacity in the organization and the amount of time that tasks are delayed.
- (C4) The processing capacity  $\mu$  of each processor is chosen to minimize total production costs.

We let  $c_c$  be the cost of a unit of processing capacity (measured in dollars per time unit per unit of processing capacity; where a unit of processing capacity can process one task per time unit). We also let  $c_D$  be the cost of delay for tasks that have been generated but not yet completed (measured in dollars per task per unit of time task remains uncompleted). With these assumptions, the total production costs per unit of time are

$$P = m\mu c_c + A c_D$$

where  $A$  is the average number of uncompleted tasks in the system at any given time. In this and the other cost expressions, we are concerned only with relative costs of different organizational forms, so

by assumption C0, we may omit all other (constant) costs. Baligh and Richartz (1967, pp. 113-118) show that the capacity that minimizes this cost 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  $\lambda$  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 10: 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 (A8): 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 10, it is clear that

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

as reflected in Table 1.

### Coordination costs

*Assumptions.* We make the following assumption about coordination costs:

- (C5) Coordination costs are proportional to the number of communication paths (or links) between actors and the number of messages sent over these links.

We let  $c_L$  be the cost per time unit of maintaining a link and  $c_M$  be the cost of sending a message.

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.

*Comparisons.* Using assumption C5 and the values given in Table 7 for the number of messages and links in the different organizational forms, it is a simple matter to calculate the costs shown in Table 10. If  $n > 1$  and  $m \geq 1$ , then the following inequalities for coordination costs,  $C$ , follow immediately:

$$C_{PH} = C_{OPH} = C_{FCH} < C_{FH} < C_{CM} < C_{DM}$$

*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 10 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 10 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  $c_C$ , 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 10 also 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  $C_{PH} = C_{FCH} = C_{OPH} < C_{FH} < C_{CM}$ , 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 make the following assumptions about vulnerability costs:

- (C6) Vulnerability costs are proportional to the costs of reassigning tasks and the costs of disrupting products due to the failures of processors or managers.
- (C7) Processors and managers sometimes fail (i.e., with probability greater than 0), and they do so independently at constant rates according to a Poisson process.
- (C8) Product managers that manage more than one product (i.e., with centralized product decisions) fail at least as often as other product and functional managers.
- (C9) The cost of reassigning the tasks from one processor to another processor is less than the cost of disrupting a product.
- (C10) The cost of disrupting one product is less than the cost of disrupting all products.

We let  $p_T$ ,  $p_F$ , and  $p_p$  be the failure rates of task processors, functional managers, and product managers, respectively, and we let  $p_e$  be the failure rate for centralized product managers ("executive offices"). According to assumptions C7 and C8,  $p_T, p_F, p_p > 0$ , and  $p_e \geq p_F, p_p$ . We let  $c_T$  be the expected cost of reassigning the tasks from a failed processor to another processor,  $c_p$  be the expected

cost of having the production of one product disrupted, and  $c_A$  be the expected cost of having all the products disrupted. From assumptions C8 and C9, we know that  $c_T < c_P < c_A$ .

*Comparisons.* Given these assumptions, the expressions for failure costs  $F$  in Table 10, and the following inequalities all follow immediately:  $F_{DM} < F_{CM} < F_{FCH} < F_{FH}$ , and  $F_{DM} < F_{PH} < F_{OPH}$ .

### Size of the organization

Finally, we assume that

- (C11) 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 11 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 11.

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### Footnotes

<sup>1</sup> 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 is an attractive choice for illustration 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.)

<sup>2</sup> We have substituted "functional" and "product" for the terms used in the original: "process" and "purpose," respectively.

<sup>3</sup> This argument is being developed in more detail with Robert Benjamin and JoAnne Yates.

**Table 1**  
**Tradeoffs Among Alternative Organizational Forms**

<i>Organizational Form</i>	<i>Evaluation Criteria</i>		
	<i>Efficiency</i>	<i>Flexibility</i>	
	<i>Production Costs</i>	<i>Coordination Costs</i>	<i>Vulnerability Costs</i>
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 Costs as Size of Organization Increases**

	<i>Production Costs</i>	<i>Coordination Costs</i>	<i>Vulnerability Costs</i>
Product hierarchy	+	+	+ + +
Functional hierarchy	+	+ +	+
Centralized market	+	+ + +	+ +
Decentralized market	+	+ + + +	+ +

**Note:** Different numbers of pluses indicate relative rates of change (more pluses mean faster change).

**Table 3**  
**Symbol Table for Appendix A**

$t_i$	= description of task i
$t_i'$	= description of task i (after processing)
$s_j$	= status of processor j
$a_i$	= assignment of task i
$\tau(t_i)$	= type of task i
$\pi(j)$	= type of processor j
$g_{ij}$	= "goodness" measure for assignment of task i to processor j
$TP_j$	= task processor j
$PM_j$	= product manager
$FM_j$	= functional manager



**Table 4**  
**Decision and Action Locations**

<i>Condition</i>	<i>Decision or action (Information produced)</i>	<i>Location</i>	<i>Information needed</i>
Dedicated processors	$t_i$	PM	$t_i'$
	$a_i$	PM	
	$t_i'$	TP	$t_i, a_i$
Centralized functional decisions	$t_i$	PM	$t_i'$
	$a_i$	FM	$t_i, s_j$
	$s_j$	FM	$t_i, t_i', a_i, s_j$
	$t_i'$	TP	$t_i, a_i$
Decentralized functional decisions, decentralized product decisions	$t_i$	PM	$t_i'$
	$a_i$	PM	$g_{ij}$
	$g_{ij}$	TP	$t_i, s_j$
	$s_j$	TP	$t_i, a_j, s_j$
	$t_i'$	TP	$t_i, a_i$
Decentralized functional decisions, centralized product decisions	$t_i$	PM	$t_i'$
	$a_i$	PM	$t_i, s_j$
	$s_j$	PM	$t_i, t_i', a_i, s_j$
	$t_i'$	TP	$t_i, a_i$

**Table 5**  
**Information Flows Needed**

<i>Condition</i>	<i>Variable</i>	<i>Where produced</i>	<i>Where needed</i>	<i>Message number used<sup>a</sup></i>
Dedicated processors	$t_i$	PM	TP	1
	$a_i$	PM	TP	1
	$t_i'$	TP	PM	2
Centralized functional decisions	$t_i$	PM	TP	3, 4
	$t_i$	PM	FM	3
	$a_i$	FM	TP	4
	$a_i$	FM	FM	-
	$s_j$	FM	FM	-
	$t_i'$	TP	FM	5
	$t_i'$	TP	PM	5, 6
Decentralized functional decisions, decentralized product decisions	$t_i$	PM	TP	7
	$a_i$	PM	TP	9
	$g_{ij}$	TP	PM	8
	$s_j$	TP	TP	-
	$t_i'$	TP	PM	10
Decentralized functional decisions, centralized product decisions	$t_i$	PM	TP	11
	$t_i$	PM	PM	-
	$a_i$	PM	TP	11
	$a_i$	PM	PM	-
	$s_j$	PM	PM	-
	$t_i'$	TP	PM	12

<sup>a</sup> See Table 6

**Table 6**  
**Message Sequences, Contents, and Paths**

<i>Condition</i>	<i>Message Number</i>	<i>Message Type</i>	<i>Contents</i>	<i>Source</i>	<i>Destination</i>
Dedicated processors	1	task assignment	$t_i, a_i$	PM	TP
	2	task complete	$t_i'$	TP	PM
Centralized functional decisions	3	task available	$t_i$	PM	FM
	4	task assignment	$t_i, a_i$	FM	TP
	5	task complete	$t_i'$	TP	FM
	6	task complete	$t_i'$	FM	PM
Decentralized functional decisions, decentralized product decisions	7	"goodness" query ("request for bids")	$t_i$	PM	TP, j, c, d
	8	"goodness" reply ("bid")	$g_{ij}$	TP, j, c, d	PM
	9	task assignment	$a_i$	PM	TP
	10	task complete	$t_i'$	TP	PM
Decentralized functional decisions, centralized product decision	11	task assignment	$t_i, a_i$	PM	TP
	12	task complete	$t_i'$	TP	PM

**Table 7**  
**Definition of Alternative Organizational Forms**

<i>Product Decisions</i>	<i>Functional Decisions</i>	<i>Organizational Form</i>	<i>No. of Product Managers<sup>a</sup></i>	<i>No. of Functional Managers<sup>b</sup></i>	<i>No. of Connections required between actors<sup>a,b</sup></i>	<i>No. of Messages required to assign a task<sup>a</sup></i>	<i>Task processor</i>	<i>Functional manager</i>	<i>Product manager</i>	<i>Results of failure of</i>
decentralized	dedicated	product hierarchy	n	0	m	2	1 product disrupted	--	1 product disrupted	1 product disrupted
decentralized	decentralized	decentralized market	n	0	mn	2m + 2	task reassigned	--	1 product disrupted	1 product disrupted
decentralized	centralized	centralized market	n	1	m + n	4	task reassigned	all products disrupted	1 product disrupted	1 product disrupted
centralized	dedicated	overcentralized product hierarchy	1	0	m	2	1 product disrupted	--	all products disrupted	all products disrupted
centralized	decentralized	fully centralized hierarchy	1	0	m	2	task reassigned	--	all products disrupted	all products disrupted
centralized	centralized	functional hierarchy	1	1	m	4	task reassigned	all products disrupted	all products disrupted	all products disrupted

<sup>a</sup> m = Number of task processors of functional type being analyzed, n = number of products.

<sup>b</sup> Number required per functional type.

**Table 8**

**Maximum Decision Load on a Single Actor**

<i>Organizational Form</i>	<i>Maximum Functional Decisions per Actor</i>	<i>Maximum Product Decisions per Actor</i>	<i>Maximum Total Decision Load per Actor</i>
Product hierarchy	$N_p$	$N_p$	$(f+p) N_p$
Decentralized market	$N_p$	$N_p$	$(f+p) N_p$
Dentralized market	$N_T$	$N_p$	$\max(f N_T, p N_p)$
Overcentralized Product Hierarchy	$N$	$N$	$(f+p) N$
Fully Centralized Hierarchy	$N$	$N$	$(f+p) N$
Functional Hierarchy	$N_T$	$N$	$\max(f N_T, p N)$

**Table 9**  
**Symbol Table for Appendix C**

<b>Variable</b>	<b>Definition</b>
<i>Total Costs</i>	
$P_{PH}, P_{FH}, P_{CM}, P_{DM}$	= 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
<i>Component Costs</i>	
$c_C$	= 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)
<i>Probabilities</i>	
$p_T$	= 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)
<i>Other quantities</i>	
$m$	= number of processors of this type for all products combined
$n$	= number of products
$k$	= number of functions
$\lambda$	= number of tasks per time unit of this type for each product $\mu$
$\mu$	= average processing rate of each processor

Table 10

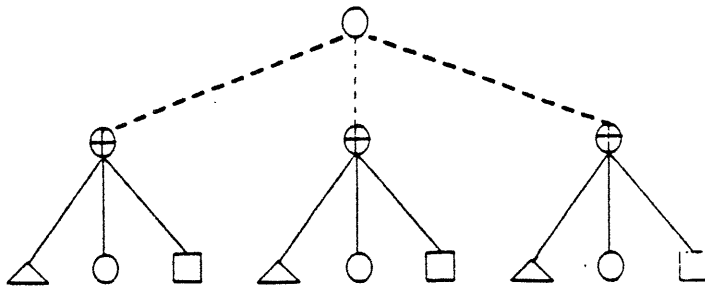
Evaluation Criteria for Alternative Organizational Forms

Organizational forms	Production Costs	Coordination Costs (w/o fixed costs of managers)	Coordination costs (with fixed costs of managers)	Vulnerability costs
Product hierarchy	$2m(c_{DEC} \lambda)^{\frac{1}{2}} + m\lambda c_C$	$m c_L + 2m\lambda c_M$	$m c_L + 2m\lambda c_M + n c_R$	$m P_{TCp} + n P_{TCp}$
Functional hierarchy	$2m(c_{DEC} \lambda)^{\frac{1}{2}}$	$(m+1)c_L + 4m\lambda c_M$	$(m+1)c_L + 4m\lambda c_M + c_F + c_E$	$m P_{TCt} + P_{ECA} + P_{ECA}$
Centralized market	$2m(c_{DEC} \lambda)^{\frac{1}{2}}$	$(m+n)c_L + 4m\lambda c_M$	$(m+n)c_L + 4m\lambda c_M + c_B + n c_I$	$m P_{TCt} + P_{ECA} + n P_{TCp}$
Decentralized market	$2m(c_{DEC} \lambda)^{\frac{1}{2}}$	$m n c_L + (2m+2)m\lambda c_M$	$m n c_L + (2m+2)m\lambda c_M + n c_I$	$m P_{TCt} + n P_{TCp}$
<i>Unusual forms:</i>				
Overcentralized product hierarchy	$2m(c_{DEC} \lambda)^{\frac{1}{2}} + m\lambda c_C$	$m c_L + 2m\lambda c_M$	$m c_L + 2m\lambda c_M + c_E$	$m P_{TCp} + P_{ECA}$
Fully centralized hierarchy	$2m(c_{DEC} \lambda)^{\frac{1}{2}} + m\lambda c_C$	$m c_L + 2m\lambda c_M$	$m c_L + 2m\lambda c_M + c_E$	$m P_{TCt} + P_{ECA}$

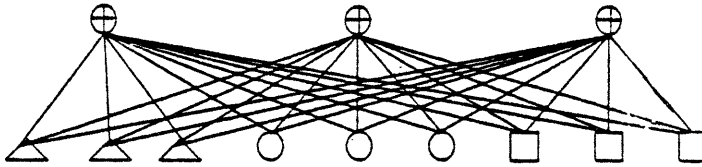
**Table 11**  
**Rates of Change of Evaluation Criteria as Size of Economy Increases**

<i>Organizational forms</i>	<i>Production Costs</i>		<i>Coordination Costs</i>		<i>Vulnerability Costs</i>	
	$\frac{\delta}{\delta m}$	$\frac{\delta}{\delta n}$	$\frac{\delta}{\delta m}$	$\frac{\delta}{\delta n}$	$\frac{\delta}{\delta m}$	$\frac{\delta}{\delta n}$
Product hierarchy	$2(c_{DCC})\frac{1}{2} + \lambda c_C$	0	$c_L + 2\lambda c_M$	0	$p_{TCp}$	$p_{PCp}$
Functional hierarchy	$2(c_{DCC})\frac{1}{2}$	0	$c_L + 4\lambda c_M$	0	$p_{TCr}$	0
Centralized market	$2(c_{DCC})\frac{1}{2}$	0	$c_L + 4\lambda c_M$	$c_L$	$p_{TCr}$	$p_{PCp}$
Decentralized market	$2(c_{DCC})\frac{1}{2}$	0	$nc_L + 2\lambda c_M(2m + 1)$	$mc_L$	$p_{TCr}$	$p_{PCp}$
<i>Unusual forms:</i>						
Overcentralized product hierarchy	$2(c_{DCC})\frac{1}{2} + \lambda c_C$	0	$c_L + 2\lambda c_M$	0	$p_{TCp}$	0
Fully centralized hierarchy	$2(c_{DCC})\frac{1}{2}$	0	$c_L + 2\lambda c_M$	0	$p_{TCr}$	0

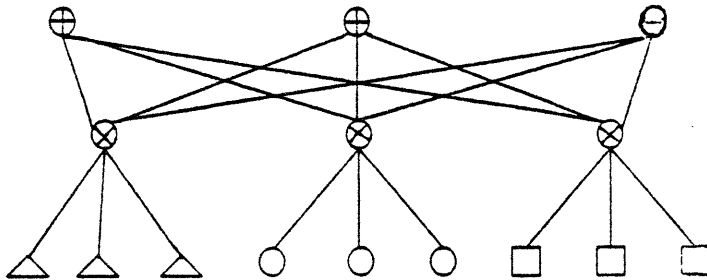




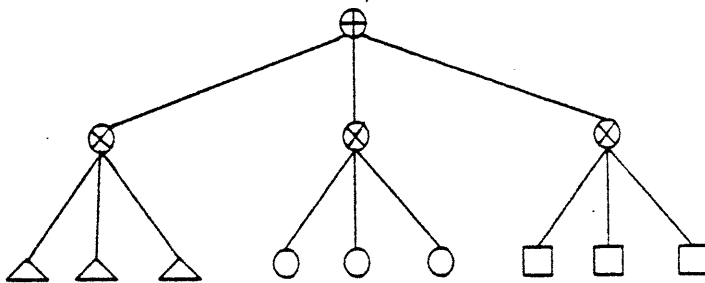
**Product hierarchy**



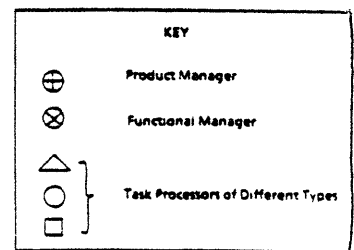
**Decentralized market**



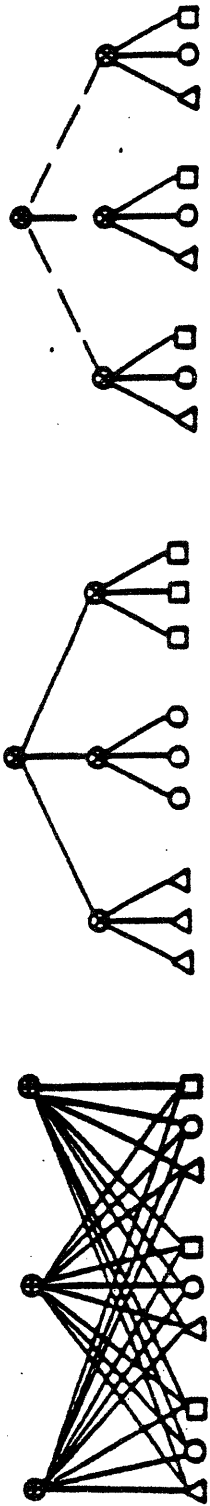
**Centralized market**



**Functional hierarchy**



**Figure 1**  
**Alternative Organizational Forms**



DECENTRALIZED → FUNCTIONAL → PRODUCT → ?  
 MARKETS            HIERARCHIES    HIERARCHIES

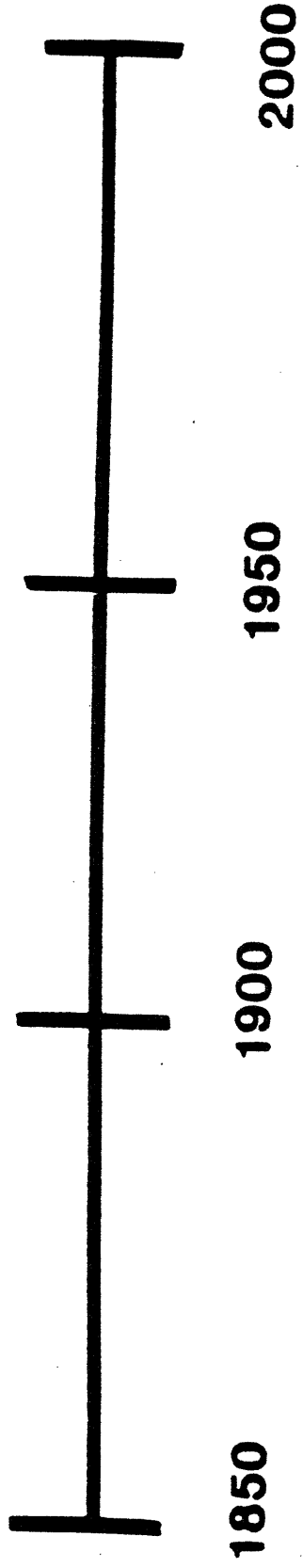


Figure 2

**CHANGES OF DOMINANT ORGANIZATIONAL STRUCTURES  
 IN AMERICAN BUSINESS**