DESIGN OF ORGANIZATIONS AND STATISTICAL DECISIONS

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ABSTRACT

Organization design has been discussed by many authors in management and organization theory. They have obtained intuitive and prescriptive propositions appealing that the best organization design is contingent on the environmental conditions. But their studies, called contingency theory, are mostly based on the empirical researches. Most of the "propositions" are drawn as only inferences from the results of them. On the other hand, decision theoretic models of "organizations" in stochastic environment have been studied by some economists and management scientists independently of contingency theory, and a decision theoretic approach to organization design problems had little literature ever published in management and organization theory.

But an important aspect of organization design problems can be formulated as a statistical decision problem in the framework of management and oraganization theory. This research attempts to analyze such a decision problem and to test the results through the empirical research on Japanese firms.

To attain these objectives, this paper consists of five chapters. Chapter 1 is a general introduction, and Chapters 2 through 4 consider a design problem of an organization whose choice process of the task is formulated as the sequential statistical decision process in the conceptual framework of

management and organization theory. In this paper, the organization design is represented by a combination of an organization structure and a management system, where the organization structure is defined as the system of task assignment, and the management system is defined as the communication system of the observation process on the stochastic environment.

The organization design is incorporated in the sequential decision model formulated in Chapter 2, and Chapter 3 obtains the propositions that have the following managerial implications: The traditional pyramid organization structure (strictly speaking, a line and staff organization) and the centralized mechanistic management system are efficient under low uncertainty; the matrix organization structure and the decentralized organic management system are efficient under high uncertainty; the pyramid organization structure is efficient if the mechanistic management system is efficient. These results are supported by the empirical research on Japanese firms in Chapter 4.

Chapter 5 examines the fundamental assumptions of this paper and derives another managerial implication: There is not the one best way of organizing, but there is a class of organizations which enable the top leader to choose the best way of organizing, that is, the "contingency organizations." I appreciate some contingency theorists by reason of their constructive suggestions about the convertible organizations.

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CONTENTS

CHAPTER 1	INTRODUCTION	1
CHAPTER 2	THE MODEL	
2.1	Organization Structures	10
2.2	Management Systems	17
2.3	The Decision Process Model	24
CHAPTER 3	EFFICIENT ORGANIZATION DESIGN	
3.1	Separation Theorem	30
3.2	Efficient Organization Structures	33
3.3	Efficient Management Systems	39
3.4	Categories of Uncertainty	50
3.5	Managerial Implications	54
CHAPTER 4	EMPIRICAL RESEARCH ON JAPANESE FIRMS	
4.1	Hypotheses	60
4.2	Methods	62
4.3	Organization Structures and Management Systems	68
4.4	Organization Structures under Uncertainty	77
4.5	Management Systems under Uncertainty	80
CHAPTER 5	SUMMARY: CONTINGENCY ORGANIZATIONS	86
APPENDIX A	MATHEMATICAL APPENDIX	92
APPENDIX B	TRIGRAPH: A COMPUTER PROGRAM	113
APPENDIX C	QUESTIONS IN JAPANESE	128
REFERENCES		133

CHAPTER 1 INTRODUCTION

This paper is focused on an organization design problem in management and organization theory from a decision theoretic viewpoint. The notion of organization design was first developed in the field of contingency theory. Contingency theory, which was named by Lawrence and Lorsch (1967), approached to organization design problems with intuitive appealing that the best organizational design was contingent on the situational conditions and that a more formal organization was appropriate to some situations while a more participative organization to other situations. The prototype of contingency theory is traced back to the research of Burns and Stalker (1961), which suggested that two ideal management systems, a mechanistic management system and an organic management system, were efficient under low uncertainty and high uncertainty respectively. They characterized the management systems as follows: In the mechanistic system, subordinates' activities are defined and adjusted by the superiors, and knowledge is exclusively located at the top of hierarchy and so on. In contrast, in the organic system, subordinates' activities are defined and adjusted through interaction with others, and knowledge may be located anywhere in the communication network.

On the other hand, Galbraith (1973) studied organization design from the viewpoint of information processing in the organizations. From this viewpoint, Davis and Lawrence (1977) intensively studied the matrix organization in contrast with the pyramid organization. The classical management theory (e.g., Koontz, O'Donnell and Weihrich 1980) stated the principle of unity of command, and business organizations have evolved as one boss unitary command structures. The pyramid organization is so constructed that the principle of unity of command is met, and it is the only concept that has existed in the classical management world. But the need to fully utilize human resources redeploys the unit organizations in a flexible manner so that it can work on more than one task at a time, or at least be readily available for assignment from one task to the next (Davis and Lawrence 1977; Janger 1979). In fact, the term "matrix organization" grew up in the United States aerospace industry, and has become the accepted term in both business and academic circles. Davis and Lawrence (1977) considered the matrix organization as any organization that abandons the precept of a single chain of command, and employs a multiple command system, and concluded that a necessary condition of the matrix organization to be preferred structural choice was "uncertainty."

But the discussion of contingency theory is mostly based on the empirical researches. Most of the "propositions" are drawn as only inferences from the results of them. In the conventional sense of theory, a well-developed set of interrelated propositions, contingency theory is not a theory at all (schoonhoven 1981). Therefore, Hax and Majluf (1981) pointed out that a useful normative approach to organization design had little literature ever published in management and organization theory.

On the other hand, mathematical models of "organizations" in stochastic environment have been studied by some economists (represented by Marschak and Radner 1972) independently of contingency theory. Padgett's (1980) mathematical model of a garbage can stochastic process within a bureaucratic organization structure was also independent of contingency theory, though it succeeded in deriving some managerial implications of garbage can theory of Cohen, March and Olsen (1972). Then their theories and results have little contribution to contingency theory.

If we attempt to devote our research to the advance of organization design theory, we must formulate the organization design problems in the conceptual framework of management and organization theory, and must pay attention to contingency theoretic implication of our results.

In modern organization theory, the organizational decision process is regarded as a chain of the decision processes of the members in the organization. An important decision by an organization which may be enunciated by one person in its final form may require the subsidiary decisions (or judgments) by several different persons (Barnard 1938, p.188). Simon (1947) called these subsidiary decisions <u>decision premises</u>, and defined a decision process in the organization as a process of drawing conclusions from decision premises made by several different persons. Instead of taking decisions as basic unanalyzable units, he regarded the decision premises as the smallest unit of analysis of organizations.

March and Simon (1958) constructed a model of rational choice that incorporates the actual properties of human beings and at the same time retains some of the formal clarity of the economic model. Their model incorporates two fundamental characteristics (March and Simon 1958, p.139):

> (1) Choice is always exercised with respect to a limited, approximate, simplified "model" of the real situation. The chooser's model is called his "definition of the situation." (2) The elements of the definition of the situation are not "given"... but are themselves the outcome of psychological and sociological processes, including the chooser's own activities and the activities of others in his environment.

Thus, in the organization, many decision premises are involved in any specific decision as the elements of the definition of the situation, which is simple enough for a chooser to make "rational" choice within his bounded rationality.

Furthermore, the elements of the definition of the situation is stated by March and Simon (1958, p.164):

> If its model of reality is not to be so complex as to paralyze it, the organization must develop radical simplifications of its response. One such simplification is

to have (a) a repertory of standard responses, (b) a classification of program-evoking situations, (c) a set of rules to determine what is the appropriate response for each class of situations.

These elements of the definition of the situation are identical in the form of those of statistical decision theory. Let a denote a standard response, and A denote the set of all such a's. We shall let u denote a class of program-evoking situations, and S_U denote the set of all such u's. Now we define L(u,a) as the loss incurred by the organization if u is the true class of program-evoking situations and a is a standard response inappropriate for u. Then the loss L assumes the same role of a set of rules to determine what is the inappropriate response for each class of situations. As stated by Ferguson (1967), statistical decision theory consists of these three basic elements: S_U, A and L.

It is remarkable to note that organization theory has studied the dynamics of the psychological and sociological processes in the organizations and that it feels not much interest in the outcomes derived from the definition of the situation. In contrast to organization theory, the purpose of statistical decision theory is to analize the decision models whose elements are given in advance, and the organizational processes behind the models have been neglected. This is the main reason that mathematical models of "organizations" in stochastic environment have been independently of organization theory and contingency theory. On the other hand, the preceding contingency theory literature only discussed the relationship between the organizational characteristics and its environment.

This gap between them can be bridged with the definition of the situation. The organizational characteristics can be connected with the definition of the situation in the conceptual framework of organization theory, and the definition of the situation can be connected with the stochastic environment by using the model of statistical decision theory. Therefore, as illustrated in Figure 1, the statistical decision model is the complement to organization theory in order to consider the adaptive problem of the organization to its environment, and the definition of the situation, i.e., the decision model in the organization, is the intersection of organization theory and statistical decision theory.

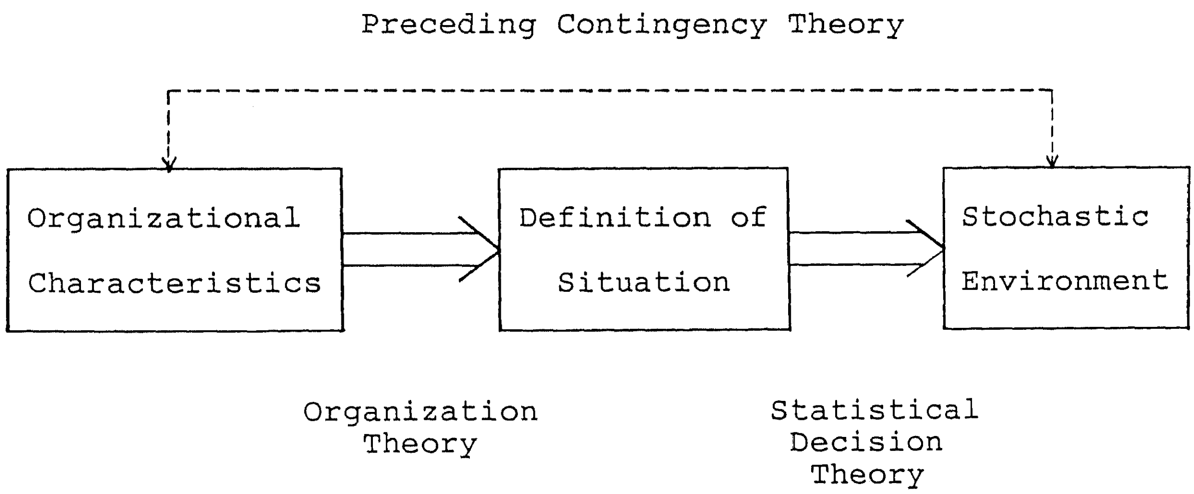

Figure 1. The Relationship between Organization Theory and Statistical Decision Theory.

In fact, lately, Takahashi and Takayanagi (1985) researched the large Japanese firms, and reported important relationships between the managers' decision procedures and management patterns of organizations. At the same time, they tested the hypothesis based on the decision procedure model under uncertainty. Their research offered us the following constructive suggestion: Using decision models associated with the specific management patterns, organization design problems can be incorporated in the managers' decision problems in the organization.

From this viewpoint, Takahashi (1983) had compared a sequential decision problem in the mechanistic management system with one in the organic management system, and obtained some normative propositions contributing to contingency theory. These propositions were supported by Takahashi's (1985) empirical research on Japanese firms. Takahashi (1986) formulated a task assignment problem in the matrix organization and proved the validity of the pyramid organization under low uncertainty, which was also supported by the empirical research.

In these researches and contingency theory, the design problem of the management system is discussed independently of the design problem of the organization structure, and conversely. But these two types of organization design problems share the same conceptual framework of management and organization theory, and the same decision theoretic viewpoint. Therefore, this paper discusses the integrated organization design problem which incorporates both organization structures and management systems in the framework of management and organization theory.

The purpose of this paper is to formulate the integrated organization design problems as a statistical decision problem in the framework of management and organization theory. Then we attempt to obtain some normative propositions on the efficient organizational design under uncertainty and to test these propositions through the empirical research on Japanese firms.

To attain these objectives, the remainder of this paper consists of four chapters. Chapter 2 formulates an organizational choice process of the task as the sequential decision process model in the conceptual framework of management and organization theory. This model incorporates the organization design represented by a combination of an organization structure and a management system, where the organization structure is defined as the system of task assignment, and the management system is defined as the communication system of the observation process on the stochastic environment.

Chapter 3 obtains the theoretical results that have the following managerial implications: The pyramid organization structure (strictly speaking, a line and staff organization) and the mechanistic management system are efficient under low uncertainty; the matrix organization structure and the organic management system are efficient under high uncertainty; the pyramid organization structure is efficient if the mechanistic management system is efficient. The first two implications respectively support the statements of Davis and Lawrence (1977) and Burns and Stalker (1961), but the last one has not been stated by contingency theorists.

These results are supported by the empirical research on Japanese firms in Chapter 4.

Chapter 5 examines the fundamental assumptions of our model and derives another managerial implication: There is not the one best way of organizing, but there is a class of organizations which enable the top leader to choose the best way of organizing, that is, the "contingency organizations." I appreciate some contingency theorists by reason of their constructive suggestions about the contingency organizations.

To facilitate the reading of the paper, mathematical derivations of somewhat intricate nature are put into the Appendix A, the reading of which may be omitted without impairing the understanding of the rest of the paper.

CHAPTER 2 THE MODEL

2.1 Organization Structures

In this chapter, the sequential decision problem of the task in the organization is formulated in the framework of management and organization theory. In this sequential decision problem, two types of organization structures, the pyramid organization and the matrix organization, are defined as the systems of task assignment, and two types of management systems, the mechanistic system and the organic system, are defined as the communication systems of the observation process on the environment. The organization design is represented by a combination of the organization structure and the management system, and constitutes a part of the sequential decision model of the task.

We consider the organization composed of three layers: (1) the top leader; (2) the managers, who may share unit organizations with other managers; (3) the unit organizations. We suppose that there exist m managers and n unit organizations.

A unit organization is defined as a small enough group of members to permit face-to-face communication to be mechanisms by which an integrated pattern of behavior can be obtained across all the interdependent members in it. In other words, the members of a unit organization jointly execute an activity through the face-to-face coordination mechanisms.

There exists the interdependence among unit organizations. The unit organizations are mutually dependent on a limited resources of the organization and interdependent of timing of their activities, then there exists the necessity of scheduling.

Let a^i denote the activity to be executed by a unit organization i, and A_i denote the set of all such a^i's. We write n-tuple of activities $a=(a^1,\ldots,a^n)\in A=A_1\times\ldots\times A_n$ for an organizational activity, which represents the activity of the whole organization, and A is called the repertory of the organization.

Each manager is in a specific position in the organization and counsels the top leader on overall organizational project, i.e., the manager chooses an organizational activity as a task which is preferred from his departmental or local perspective, and recommends it to the top leader. The organizational activity a_i recommended by a manager i is called a task, and $A'=\{a_1,\ldots,a_m\}$. The tasks in A' are specialized for the departmental objectives of managers, then A' is called the specialized repertory and $A'\subset A$.

The classical management theory (Koontz, O'Donnell and Weihrich 1980, p.427) stated as the principle of unity of command that the more completely an individual has a reporting relationship to a single superior, the less the problem of conflict in instructions and the greater the feeling of personal responsibility for results. In accordance with the principle, every subordinate should have a single superior in order to avoid the problem of conflict and to increase the feeling of personal responsibility. The organization structure is called the pyramid organization if it is so constructed that the principle of unity of command is met. Then in the pyramid organization, the unit organization is to implement a task defined by a single manager, and the top leader is confronted with the problem to choose a task from among the set $A'=\{a_1,\ldots,a_m\}$.

But the need to fully utilize expensive and highly specialized talents will develop to share existing human resources. These resources will need to be redeployed in a flexible manner so that people can work on more than one task at a time or at least be readily available assignment from one task to the next. A similar argument holds for sharing of expensive capital resources and physical facilities. High performance will result from high utilization of such human resources and facilities through effective sharing and redeployment of them (Davis and Lawrence 1977, pp.17-18). Then the term "matrix" grew up in the United States aerospace industry, and has become the accepted term in both business and academic circles. A matrix organization is any organization that employs a multiple command systems, and abandons the precept of a single chain of command in favor of a multiple command system (Davis and Lawrence 1977, p.3).

In accordance with the definition of the matrix organization of Davis and Lawrence (1977), the matrix organization is defined as an organization in which at least two managers stand in the line authority positions. In other words, in the matrix organization, the top leader can order the unit organization to distribute its effort among two or more tasks recommended by managers, that is, the top leader decides the "power" distribution over the managers. This characterizes the decision process in the matrix organization (Davis and Lawrence 1977, pp.77-81).

To represent such a distribution, a <u>mixed task</u> is defined as any probability distribution f on $A'=\{a_1,\ldots,a_m\}$, and the space of all mixed tasks is denoted by F. The mixed task, $f=(f_1,\ldots,f_m)$, which is a mixture of elements $a_1,\ldots,a_m$ in A', mixes $a_1,\ldots,a_m$ in the proportions $f_1,\ldots,f_m$ with $f_i \geq 0$ and $\sum_i f_i=1$. If the top leader chooses the mixed task $f=(f_1,\ldots,f_m)$, then the unit organizations distribute their efforts among the several managers' tasks and spend $100f_i$% of their working hours under the command of a manager i in the long enough term. The top leader gives the manager i an authority only if $f_i>0$, that is, the top leader decides the "power" distribution over the managers.

Any probability distribution f giving probability one to some single point a_i is called a <u>pure task</u>. We identify a point $a_i \in A'$ with the probability distribution $f \in F$ degenerate at the point a_i. The space A' of pure tasks may and shall be considered as a subset of the space F of mixed tasks, that is, $A' \subset F$.

The organization structure is defined as the system of task assignment which is represented in the probability distribution $f \in F$. In this paper, we classify organization structures into two categories, the pyramid organization and the matrix organization, which are formally defined as follows.

Definition 1. An organization structure is called the pyramid organization if the organization executes a pure task in A'. An organization structure is called the matrix organization if the organization executes a mixed task in F-A'.

Therefore, the top leader can choose a pure task from among A' if he takes the pyramid organization, and he can choose a mixed task from among F-A' if he takes the matrix organization. Figure 2 (1) illustrates the pyramid organization and Figure 2 (2) the matrix organization for the case of three managers and five unit organizations. This figure shows the line of authority by a "line." Some of lines of the matrix organization in Figure 2 (2) do not work in Figure 2 (1) of the pyramid organization.

The management theory distinguishes between the line and the staff (Koontz, O'Donnell and Weihrich 1980). A precise and logically valid concept of the line and staff is that they are simply a matter of relationships. The nature of the line is an authority relationship in which a superior exercises direct supervision over a subordinate. The nature of the staff is an advisory relationship. If $f_i>0$, then the manager i stands in a line authority position with respect to his subordinates in the unit organizations. But the manager i with $f_i=0$ is primarily advisory to the top leader and his relationship becomes only one of staff. Such a manager without the power is called a null manager. In the pyramid organization, the top leader commands each unit organization to contribute to a single manager, that is, to perform a task of the single manager. Then the top leader does not give the power to any other managers, and they become null managers. Therefore, the pyramid organization obtained by taking them from the lines of authority is called the line and staff organization. In Figure 2 (1), the managers 1 and 3 have no subordinates and no authority on the task, namely, they are only staffs to assist the top leader, and are null managers.

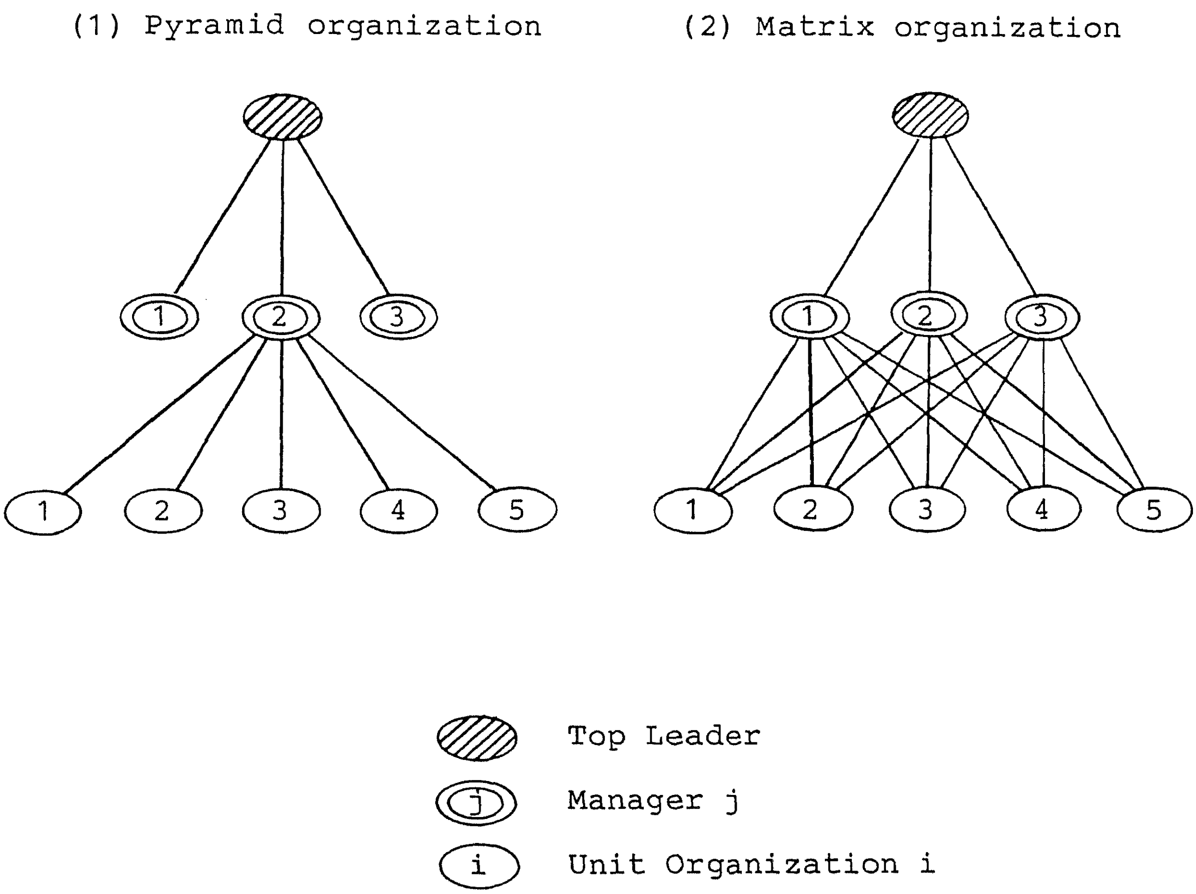

Figure 2. Examples of the pyramid organization and the matrix organization.

2.2 Management Systems

The same task can result in different outcomes, depending on factors not controlled by the members of the organization. These factors are called <u>environment</u> (e.g., Burns and Stalker 1961; Lawrence and Lorsch 1967). Let u denote a state of the environment, and let $S_U=\{u_1,\ldots,u_s\}$ denote the set of all possible states of the environment. Therefore, the top leader needs to coordinate and schedule the task recommended by managers in consideration of the state of the environment. The <u>loss function</u> associated with a pure task a is denoted by $L(u,a)$, a nonnegative function defined on $S_U \times A'$. The loss function associated with a mixed task $f=(f_1,\ldots,f_m)$ is then given by $L(u,f)=\sum_i f_i L(u,a_i)$. It is assumed that the top leader and the managers have the same loss function.

In general, the value of u is not known to the members in advance, but we suppose that the top leader and the managers have the same subjective probability distribution over the states of environment, $w=(w(u_1),\ldots,w(u_s))$, called the <u>prior distribution</u>, where $w(u_i)$ is the subjective probability of u_i for $i=1,\ldots,s$.

There exists uncertainty about the state of the environment, and the true state of the environment is generally not known to the organization in advance. To reduce the uncertainty about the environment, each manager can take the observation on the state of the environment through the unit organizations and communicates it if necessary. Each of the managers is called an <u>uncertainty absorption point</u> about the environment (March and

Simon 1958), who draws an inference (or an observation) from a body of evidence and then communicates it instead of the evidence itself. Since the observation is known through the manager's uncertainty absorption, the observation obtained by a manager i is the discrete random variable X_i whose distribution depends on the true state of the environment. The sample space of X_i is denoted by S_{Xi}. We write m-tuple of observations $Z=(X_1,\ldots,X_m)$ for the organizational observation, which represents the collection of managers' observations, and the sample space of Z is denoted by $S_Z=S_{X1}\times\ldots\times S_{Xm}$. It is assumed that for every $u\in S_U$ the probability mass function $p(z|u)$ is known.

To form the organizational observation, the organization has two alternative procedures to collect managers' observations: (1) The top leader directly collects managers' observations; (2) A manager is delegated the right to collect the observations of the other managers and of himself, and reports the collection of the organizational observations to the top leader. In other words, the organization has two alternative location of an observation center, where the observation center is defined as a member who has the rights to receive the managers' observations on the state of the environment and the obligations to transmit the organizational observation to the top leader. In the procedure (1), the top leader serves as an observation center.

Burns and Stalker (1961) defined a management system as the constitution of the way in which an organization conferred and defined, for each member, certain rights to control the actions of others and of himself and to receive information, and certain obligations to accept control and transmit information. Similarly, we define two ideal management systems, the mechanistic system and the organic system, in accordance with the two procedures to collect observations.

Definition 2. A management system is said to be the mechanistic system if the top leader serves as an observation center. A management system is said to be the organic system if a manager has an assignment to serve as an observation center.

As is seen in Section 3.4, Burns and Stalker's mechanistic and organic management systems are respectively subclasses of our mechanistic and organic system. From the definition, a management system defines the location of an observation center and then defines a pattern of communication.

The delegation of the sampling decision in the organic system may pose a serious problem in trying to find the optimal solution of the top leader's decision problem on the task assignment. Although the delegation poses a serious problem, the top leader might delegate the sampling decision to a manager in order to save a "cost." Simon (1947, p.236) stated a principal reason for decentralizing decisions:

> It is not enough to take into consideration the accuracy of decision; its cost must be weighted as well. The superior is presumably a higher paid individual than the subordinate.

His time must be conserved for the more important aspects of the work of the organization. If it is necessary, in order that he may make a particular decision, that he sacrifices time which should be devoted to more important decisions, the greater accuracy secured for the former may be bought at too high a price.

In order to formalize the above discussion, we consider the information costs in our decision process. For simplicity, the communication channels are assumed to be noiseless. But, one should note that the transmission of the observation costs much. Members of the organization have wages, then the transmitting time among members means a "cost." Furthermore, if the production line will be suspended till the top leader's terminal decision on the task, then the communication time is not productive time and means a "cost." In fact, machines in a certain Japanese factory are sign-boarded by quality control circle's members to show the cost of suspension time. With respect to the information cost, we make the following assumption.

Assumption 1. (a) Each manager obtains an observation on the state of the environment through the unit organizations at the cost of c_I. (b) The communication cost between the top leader and a manager is c_T, and that between two managers is c_M. (c) $c_T \geq c_M$.

The assumption that $c_T \geq c_M$ seems to be reasonable. In taking an observation, the top leader consumes almost same hours as the manager in face-to-face communication, telephonic communication, written communication and so on. The top leader has higher wages than the manager, then the wages per hour of the top leader is higher than that of the manager. Furthermore the opportunity cost of the top leader's business hours is greater than that of the manager's. Therefore the cost of communication time between the top leader and the manager is not less than that between two managers, that is, $c_T \geq c_M$.

Our definition of management systems implies the interesting relationships between the management patterns and the decision procedures. In the mechanistic system, the top leader serves as an observation center by definition, and he sequentially takes organizational observations. Then the following relationships are suggested: (1) The top leader is faced with a sequential decision problem in the organization where the information is exclusively located at the top leader and managers' activities are controlled by him (in the mechanistic system). (2) The top leader is faced with a fixed-size sample decision problem in the organization where the information is located at a manager and managers' observing activities are adjusted through interaction among them (in the organic system).

In fact, Takahashi and Takayanagi (1985) reported similar relationships obtained by the empirical research on Japanese firms. They considered a typology of decision procedures, the fixed-size procedure and the sequential procedure, associated with the way of discovering new alternatives. A decision procedure is called the fixed-size procedure if, first, plural

number of alternatives are made, and secondly, one of them is chosen after simultaneous consideration. A decision procedure is called the sequential procedure if alternatives are made and chosen in sequence, that is, first of all, an alternative is made and considered and then chosen if it is satisfactory, and if not, another alternative is made and ... . Their empirical research focused on the decision procedures of large Japanese firms when they decided the latest location plan at relocation or new establishment of a factory, a branch, and an office. Then they obtained the finding on the relationships between the decision procedures and the conflict resolution modes as follows:
The fixed-size procedure firm takes conflict resolution modes through the decision processes jointly made by many persons, that is, (a) resolution through debating on the issue in the conference and (b) resolution by formal terminal decision on mutual agreement obtained through informal negotiations; The sequential procedure firm takes conflict resolution modes through the decision processes by a single person, that is, (c) resolution by the common superior.

The item (b) is referred to as "nemawashi (root binding)" in Japanese, which is a generally known mode of conflict resolution in Japan. Much of the fixed-size procedure firms use so-called Japanese conflict resolution modes, "nemawashi" and conference, which are characterized as "Japanese management methods" by Pascale (1978) and Ouchi and Johnson (1978). Much of the sequential procedure firms take conflict resolution modes by a single powerful superior, which are characterized by them as

"American management methods."

2.3 The Decision Process Model

The decision process is now precisely formulated: the observation center sequentially chooses one action from among following two actions: (a) Action to obtain an organizational observation on the state of the environment; (b) Action to stop the observation process and transmit the organizational observations thus far collected to the top leader, and then the top leader chooses the appropriate task for the state of the environment.

It will be convenient to refer to action (a) as an <u>inspect action</u> and action (b) as a <u>stop action</u>.

The organizational decision problem is formulated as the sequential decision problem which was introduced by Wald (1947). Let $Z_1, Z_2, \ldots$ denote a sequence of independent and identically distributed random variables, where Z_j is the j-th organizational observation. We are assuming that the distribution of Z_j depends on the true state of the environment, and that the probability mass function $p(z_j|u)$ is known. The sample space of the random variable Z_j is denoted by S_{Zj}.

Let $w_j=(w_j(u_1),\ldots,w_j(u_s))$ denote a <u>posterior distribution</u> after the first j organizational observations $Z_1=z_1,\ldots,Z_j=z_j$ are observed. Using Bayes' formula, w_j is given by

$$
\begin{aligned}
w_j &= W_j(z_1,\ldots,z_j) \\
&= (W_j(u_1|z_1,\ldots,z_j),\ldots,W_j(u_s|z_1,\ldots,z_j)),
\end{aligned}
$$

where

$$W_j(u_i|z_1,\ldots,z_j)=\frac{w_0(u_i)p(z_1|u_i)\cdots p(z_j|u_i)}{\sum_{k=1}^{s} w_0(u_k)p(z_1|u_k)\cdots p(z_j|u_k)},\ i=1,\ldots s,$$

which represents a posterior probability of u_i given $Z_1=z_1,\ldots,Z_j=z_j$ and a prior distribution $w_0=(w_0(u_1),\ldots,w_0(u_s))$.

The following formula can be easily obtained and yields important properties of the posterior distribution.

$$W_j(u_i|z_1,\ldots,z_j)=W(u_i|z_j;w_{j-1})=\frac{w_{j-1}(u_i)p(z_j|u_i)}{\sum_{k=1}^{s} w_{j-1}(u_k)p(z_j|u_k)}.$$

Therefore, if $w_{j-1}=w$ is the current posterior distribution given that $Z_1=z_1,\ldots,Z_{j-1}=z_{j-1}$ and an organizational observation $Z_j=z$ is observed, then the new posterior distribution w_j is denoted by $W(z;w)$:

$$W(z;w)=(W(u_1|z;w),\ldots,W(u_s|z;w)).$$

The <u>decision rule</u> is denoted by a pair (q,d), in which q is a stopping rule and d is a terminal decision rule. A <u>stopping rule</u> is a sequence of functions $q=(q_0,q_1(z_1),q_2(z_1,z_2),\ldots)$, where $q_j(z_1,\ldots,z_j)$ represents the conditional probability that the observation center will stop sampling, given that $Z_1=z_1,\ldots,Z_j=z_j$. A <u>terminal (behavioral) decision rule</u> is a sequence of functions $d=(d_0,d_1(z_1),d_2(z_1,z_2),\ldots)$, where a <u>behavioral decision function</u> $d_j(z_1,\ldots z_j)$ is defined as a mapping from $S_{Z1}\times\ldots\times S_{Zj}$ into F, i.e., if it is decided to stop after observing $Z_1=z_1,\ldots,Z_j=z_j$, then a mixed task is chosen according to the distribution $d_j(z_1,\ldots,z_j)$. The space of all terminal behavioral decision rule is denoted by D. Any function $d_j'(z_1,\ldots,z_j)$ that maps the sample space $S_{Z1}\times\ldots\times S_{Zj}$ into A' is called a pure decision function. A sequence of pure decision functions $d'=(d_0',d_1'(z_1),d_2'(z_1,z_2),\ldots)$ is called a terminal pure decision rule. The space of all terminal pure decision rule is denoted by D'. The terminal pure decision rules are the special cases of terminal behavioral decision rules, that is, $D'\subset D$.

As stated in the previous section, the management system defines a pattern of communication and determines the information costs (including the communication costs). The patterns of information flow are obtained corresponding to two action phases in the mechanistic system and the organic system, and they are illustrated in Figure 3. From Assumption 1, an inspect action to take an organizational observation is taken at the cost of $C_1(I)=mc_I+mc_T$ in the mechanistic system and $C_2(I)=mc_I+(m-1)c_M$ in the organic system, where m is the number of managers defined in Section 2.1. A stop action is taken at the cost of $C_1(S)=0$ in the mechanistic system and $C_2(S)=c_T$ in the organic system.

For a stopping rule $q=(q_0,q_1(z_1),q_2(z_1,z_2),\ldots)$, we now define a sequence of functions $Q=(Q_0,Q_1(z_1),Q_2(z_1,z_2),\ldots)$, where

$$Q_0=q_0,$$
$$Q_j(z_1,\ldots,z_j)=(1-q_0)\ldots(1-q_{j-1}(z_1,\ldots,z_{j-1}))q_j(z_1,\ldots,z_j)$$
$$j=1,2,\ldots$$

$Q_j(z_1,\ldots,z_j)$ represents the conditional probability of not stopping after the first j-1 organizational observations and then stopping after the j-th organizational observation, given that $Z_1=z_1,\ldots,Z_j=z_j$. Let N denote the random stopping time, then the conditional distribution of N, given that $Z_1=z_1,Z_2=z_2,\ldots$, is defined by the formula

$$P\{N=j \mid Z_1=z_1, Z_2=z_2, \ldots; w_0\}=Q_j(z_1,\ldots,z_j), \quad j=0,1,\ldots$$

and we obtain

$$\begin{aligned} &P\{N=j \mid w_0\} \\ &=\textstyle\sum_{(z_1,z_2,\ldots)} P\{N=j \mid Z_1=z_1,Z_2=z_2,\ldots;w_0\}P\{Z_1=z_1,Z_2=z_2,\ldots\} \\ &=E\{Q_j(Z_1,\ldots,Z_j) \mid w_0\}. \end{aligned}$$

For any prior distribution w_0 and any stopping rule q, the expectation of N is given by

$$EN=\textstyle\sum_{j=0}^{\infty} jP\{N=j\}=\sum_{j=0}^{\infty} jE\{Q_j(Z_1,\ldots,Z_j) \mid w_0\}.$$

To obtain a finite expected information cost, it must be assumed that EN is finite (see Appendix A.1).

Then, for any prior distribution w_0 and any decision rule (q,d), the <u>risk</u> is defined as

$$\begin{aligned} r_k(w_0,(q,d))=\textstyle\sum_{i=1}^{S} w_0(u_i)\sum_{j=0}^{\infty} &E\{Q_j(Z_1,\ldots,Z_j) \\ &\times[L(u_i,d_j(Z_1,\ldots,Z_j))+jC_k(I)+C_k(S)] \mid U=u_i\} \end{aligned}$$

where

$$\begin{cases} k=1 & \text{if the top leader takes the mechanistic system,} \\ k=2 & \text{if he takes the organic system.} \end{cases}$$

In terms of the random stopping time N, the risk may be written

$$r_k(w_0,(q,d)) = \sum_{i=1}^{s} w_0(u_i) E\{L(u_i, d_N(Z_1,\ldots,Z_N)) + NC_k(I) + C_k(S) \mid U=u_i\}.$$

In this notation, $E\{\cdot \mid U=u_i\}$ represents the expectation given u_i as the true state of the environmemt and given the stopping rule q. From the above discussion, the stopping rule q determines the distribution of N.

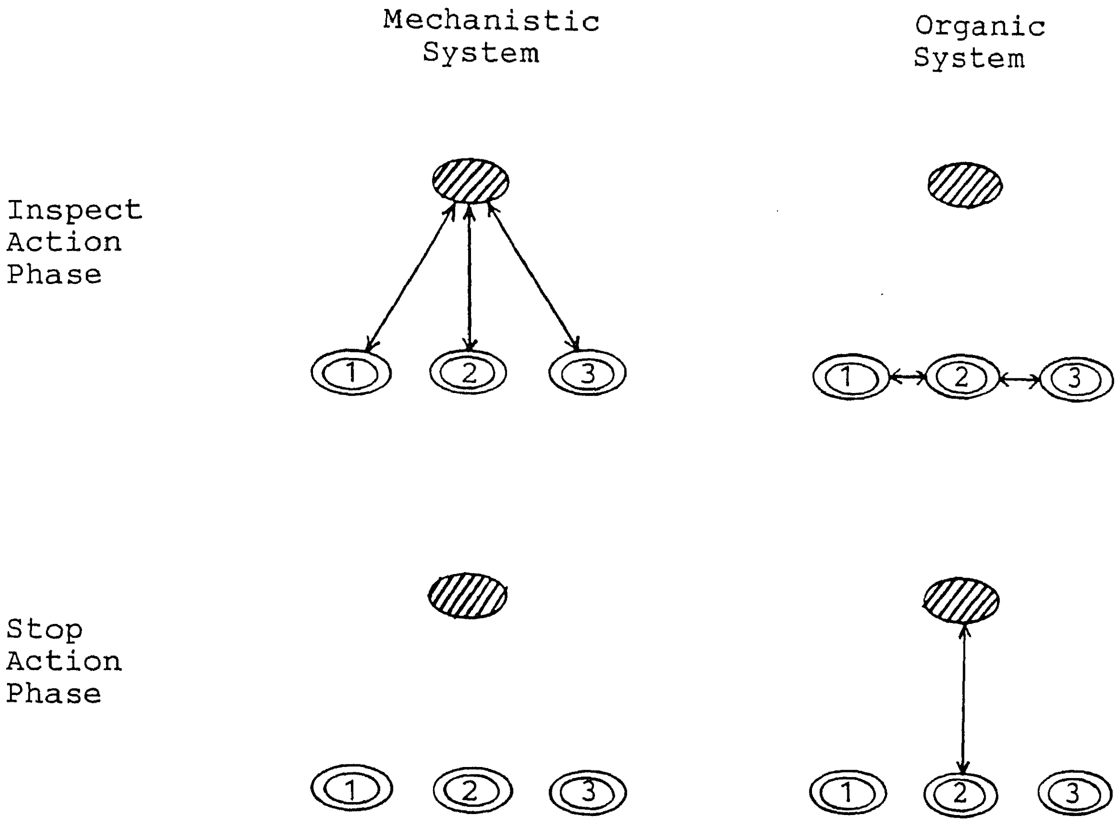

Figure 3. Communication patterns between the top leader and managers for different management systems. In the organic system, the manager 2 serves as an observation center.

CHAPTER 3 EFFICIENT ORGANIZATIONAL DESIGN

3.1 Separation Theorem

We apply the methodology of statistical decision theory to the organizational design problem. The problem is to find a decision rule (q,d) and a management system k which minimize the risk. In this section, we state the "separation theorem" of the organization structure design problem and the management system design problem, which makes the organizational design problem easier.

We consider a Bayes terminal decision function which minimizes the conditional Bayes expected loss given that $Z_1=z_1,\ldots,Z_j=z_j$

$$E\{L(U,d_j(z_1,\ldots,z_j))\,|\,Z_1=z_1,\ldots,Z_j=z_j\}$$
$$=\sum_i W_j(u_i\,|\,z_1,\ldots,z_j)L(u_i,d_j(z_1,\ldots,z_j))$$

except for $(z_1,\ldots,z_j)$ in a set of probability zero. Bayes terminal decision function $d_j{*}$ is the optimal decision function for the statistical decision problem based on a fixed-size sample $Z_1,\ldots,Z_j$ with respect to a prior distribution w_0. The following theorem can be proved.

Theorem 1. Let $d_j^*(Z_1,\ldots,Z_j)$ be a Bayes terminal decision function for the statistical decision problem based on $Z_1,\ldots,Z_j$, with respect to a prior distribution w_0. Then, for any fixed q and k, $r_k(w_0,(q,d))$ is minimized by $d^*=(d_0^*,d_1^*,d_2^*,\ldots)$.

Proof. See the proof of Ferguson's (1967) Theorem 7.2.1, which is restated in Appendix A.2 with some remarks.

This theorem states that the optimal terminal decision rule d* of the organizational design problem is independent of a management system k and a stopping rule q. Then with respect to a prior distribution w_0, the organizational design problem occurs in two separate and distinct steps: (1) First fix both a management system k and q, and try to find d (or try to find an organization structure) which minimizes $r_k(w_0,(q,d))$, then (2) try to find a management system k and q which minimize $\inf_d r_k(w_0,(q,d))$. The separation of the organization structure design problem and the management system design problem is restated as the separation theorem.

Separation Theorem. The efficient organization structure is independent of the management system.

An important implication for management and organization theory is that the sampling decision can be delegated to managers. The delegation of the sampling decision in the organic system does not pose a serious problem in trying to find the optimal solution of the top leader's decision problem on the task assignment.

Suppose that, in the organic system, a manager as an observation center comes to the top leader with his data, using some given loss function. Lack of knowledge concerning the stopping rule used by the observation center does not hinder the top leader in arriving at a terminal decision rule. He acts as if he were faced with a fixed-size sample decision problem and chooses a Bayes terminal decision rule with respect to the prior distribution. Therefore this theorem ensures the validity of delegation in the organic system.

3.2 Efficient Organization Structures

The minimal conditional Bayes expected loss in the pyramid organization is compared with that in the matrix organization. The organization structure is called efficient if it ensures the organization to attain the less minimal conditional Bayes expected loss. From Definition 1 and the definition of terminal decision rule, if the Bayes terminal decision rule $d^* \in D'$, then the efficient organization structure is in the pyramid organizations. Using the results of statistical decision theory, we can prove the following theorem.

Theorem 2. There exists an efficient pyramid organization.

The proof directly follows the lemma:

Lemma 1. There exists a pure Bayes terminal decision function for the statistical decision problem based on $Z_1, \ldots, Z_j$, with respect to w_0.

Proof. See Appendix A.3. Another proof is made by using the results of statistical decision theory. See Takahashi (1986) for details.

Proof of Theorem 2. From Lemma 1, there exists a Bayes terminal decision rule $d^* = (d_0^*, d_1^*, d_2^*, \ldots)$ in D'. By definition, this Bayes terminal decision rule implies a pyramid organization.

The theorem is proved.

This theorem does not deny the possibility of the efficient matrix organization, but it is not essential and seldom happens that the matrix organization is efficient as illustrated in the following simple example.

Example 1. Now consider the following simple example as the illustration of Theorem 2. The organization has two managers. The organization produces two types of products, a product 1 and a product 2, and the managers 1 and 2 are in positions for producing a product 1 and a product 2 respectively. The organization is confronted with either the state u_1 or u_2 of the environment, that is, $S_U=\{u_1,u_2\}$, where the state u_1 is the state of the environment in which there exists the demand for a product 1 but not the demand for a product 2, and the state 2 is that in which there exists the demand for a product 2 but not the demand for a product 1. The unit organizations have production facilities working either in the production line of a product 1 or in that of a product 2. The specialized repertory of the tasks of the organization is $A'=\{a_1,a_2\}$, where the task a_i is the one recommended by the manager i. The loss function is given by

$$L(u_1,a_1)=0, \quad L(u_1,a_2)=100,$$
$$L(u_2,a_1)=100, \quad L(u_2,a_2)=0.$$

The observation center takes the organizational observation $Z_j=(X_{j1},X_{j2})$ through the managers, where the sample spaces of X_{j1}

and X_{j2} are $S_{Xj1}=\{1,2\}$ and $S_{Xj2}=\{1,2\}$. Then $S_{Zj}=\{(1,1),(1,2),(2,1),(2,2)\}$. Taken the bias of the managers' favor into account, Z_j has the same conditional probability function $p(\cdot|u_i)$ as defined by

$$p((1,1)|u_1)=0.4,\ p((2,2)|u_1)=0.6,$$
$$p((1,1)|u_2)=0.6,\ p((2,2)|u_2)=0.4,$$
$$p((1,2)|u_1)=p((1,2)|u_2)=p((2,1)|u_1)=p((2,1)|u_2)=0.$$

Now, consider the following two cases:

<u>Case I</u>: The observation center comes to the top leader with his data z_1, that is, the top leader is confronted with the statistical decision problem based on z_1. For any given prior distribution $w_0=(w_0(u_1),w_0(u_2))$ with $w_0(u_1)+w_0(u_2)=1$, it is seen from the loss function that to take a_2 is Bayes if $0\leqq W_1(u_2|z_1)\leqq 1/2$ and that to take a_1 is Bayes if $1/2\leqq W_1(u_1|z_1)\leqq 1$. Then we obtain the following results:

(1) If $0\leqq w_0(u_1)\leqq 0.4$, then to take a_2 is a Bayes terminal decision rule regardless of the observed value of Z_1.

(2) If $0.4\leqq w_0(u_1)\leqq 0.6$, then $d_1*(1,1)=(0,1)$ and $d_1*(2,2)=(1,0)$, i.e., the top leader should take a_2 if (1,1) is observed, and a_1 if (2,2) is observed.

(3) If $0.6\leqq w_0(u_1)\leqq 1$, then to take a_1 is a Bayes terminal decision rule regardless of the observed value of Z_1.

Therefore, for any prior distribution, the pyramid organization is efficient. In the case (1) and the case (2) with $Z_1=(1,1)$, the manager 2 stands in a line authority position and the manager 1 is only advisory to the top leader. In the case (3) and the case (2) with $Z_1=(2,2)$, the manager 1 stands in a line authority position and the manager 2 is only advisory to the top leader.

If the prior distribution $w_0=(0.4,0.6)$ and the observed value $Z_1=(2,2)$, then both tasks a_1 and a_2 are Bayes terminal decision rules. Similarly, if $w_0=(0.6,0.4)$ and $Z_1=(1,1)$, then both tasks a_1 and a_2 are Bayes. Hence only in these two cases, any mixture of a_1 and a_2 is Bayes. But, these mixing of tasks are not essential for the organization.

Case II: The observation center comes to the top leader with his data z_1 and z_2. By using the similar method of Case I, we obtain the following results:

(1) If $0 \leqq w_0(u_1) \leqq 4/13$, then to take a_2 is a Bayes terminal decision rule regardless of the observed value of (Z_1,Z_2).

(2) If $4/13 \leqq w_0(u_1) \leqq 1/2$, then

$$d_2^*((1,1),(1,1))=d_2^*((1,1),(2,2))=d_2^*((2,2),(1,1))=(0,1),$$
$$d_2^*((2,2),(2,2))=(1,0),$$

i.e., the top leader should take a_1 if $(Z_1,Z_2)=((2,2),(2,2))$ is observed, and a_2 otherwise.

(3) If $1/2 \leqq w_0(u_1) \leqq 9/13$, then

$$d_2^*((1,1),(1,1))=(0,1),$$
$$d_2^*((1,1),(2,2))=d_2^*((2,2),(1,1))=d_2^*((2,2),(2,2))=(1,0),$$

i.e., the top leader should take a_2 if $(Z_1,Z_2)=((1,1),(1,1))$ is observed, and a_1 otherwise.

(4) If $9/13 \leqq w_0(u_1) \leqq 1$, then to take a_1 is a Bayes terminal decision rule regardless of the observed value of (Z_1, Z_2).

Therefore, for any prior distribution, the pyramid organization is efficient. In the following three cases any mixture of a_1 and a_2 is Bayes: (a) $w_0=(4/13, 9/13)$ and $(Z_1, Z_2)=((2,2),(2,2))$; (b) $w_0(u_1)=(1/2, 1/2)$ and $(Z_1, Z_2)=((1,1),(2,2))$ or $((2,2),(1,1))$; (c) $w_0=(9/13, 4/13)$ and $(Z_1, Z_2)=((1,1),(1,1))$.

From the results of Case I and Case II, the matrix organization is not efficient in Case I for the prior distribution for which a matrix organization is efficient in Case II. Therefore, we conclude that the matrix organization is not efficient in this sequential decision problem for any prior distribution.

In this paper, we consider the pyramid organization and the matrix organization as alternatives in an organizational choice process, and then, in comparison between them, we neglect "decision costs" caused by decision-making itself, e.g., the costs of evaluating actions and the costs of choosing among actions. But if we compare the choice process among tasks in the pyramid organization with the one in the matrix organization (cf. Takahashi 1986), the choice process in the matrix organization has the greater number of alternative tasks and then needs greater decision costs than that in the pyramid organization. Furthermore, as proved by our Theorem 2, there exists an efficient pyramid organization in the set of organization structures including the pyramid organizations and the matrix organizations. Therefore, in this case, we conclude that the choice process in the pyramid organization is better than that in the matrix organization. But, in the decision process of this paper, the choice problem between the pyramid organization and the matrix organization has no relationship to such decision costs, therefore we only conclude that there exists an efficient pyramid organization.

3.3 Efficient Management Systems

Now, turn the attention to the efficient management system. The minimal risk in the mechanistic system is compared with that in the organic system. The management system is called efficient if it ensures the organization to attain the less minimal risk.

Let us seek the optimal decision rule minimizing risk. Now let

$$V_k(w_0)=\inf_{(q,d)} r_k(w_0,(q,d))$$

for a given w_0 and a management system k. A decision rule (q^*,d^*) is said to be k-optimal if

$$r_k(w_0,(q^*,d^*))=V_k(w_0) \quad \text{for each } w_0$$

and V_k is called a k-optimal risk function.

The following theorem yields a functional equation satisfied by the k-optimal risk function V_k.

Theorem 3. For a given management system k,

$$V_k(w)=\min[B_k(w);\ E\{V_k(W(Z;w))|w\}+C_k(I)] \qquad (1)$$

where

$$B_k(w)=\inf_{a\in A'}\sum_i w(u_i)L(u_i,a)+C_k(S).$$

Proof. The proof is analogous to the proof of Ross's (1970) Theorem 6.10. See Appendix A.4 for details.

The following theorem proves that there exists a k-optimal decision rule.

Theorem 4. For a given management system k, let d* be as in Theorem 1 and let q' be defined as follows:

$$q_j'(z_1,\ldots,z_j)=\begin{cases}1 & \text{if } B_k(w_j)<E\{V_k(W(Z_{j+1};w_j))|w_j\}+C_k(I)\\ \text{any} & \text{if } B_k(w_j)=E\{V_k(W(Z_{j+1};w_j))|w_j\}+C_k(I)\\ 0 & \text{if } B_k(w_j)>E\{V_k(W(Z_{j+1};w_j))|w_j\}+C_k(I)\end{cases}$$

for $j=0,1,2,\ldots$, and let $V_k'(w)=r_k(w,(q',d^*))$. Then

$$V_k'(w)=V_k(w) \text{ for all } w$$

and hence (q',d^*) is k-optimal.

Proof. The proof is analogous to the proof of Ross's (1970) Theorem 6.12. See Appendix A.5 for complete details.

The optimal stopping rule described in Theorem 4 can be summarized as follows: Suppose that $Z_1=z_1,\ldots,Z_j=z_j$ has been observed, $B_k(w_j)$ is the conditional expected loss plus information cost if the observation center stops without observing Z_{j+1}, and $E\{V_k(W(Z_{j+1};w_j))|w_j\}+C_k(I)$ is that if he does look at Z_{j+1}. Then he should stop the observation process if the former is smaller than the latter and should take at least one more observation if the latter is smaller than the former.

Now, the minimal risk in the mechanistic system will be compared with that in the organic system. The minimal risk of adaptive process models in the mechanistic system and the organic system respectively mean the best attainable outcomes of the decisions permitted in the mechanistic system and the organic system. The mechanistic system is said to be efficient if the minimal risk in the mechanistic system is less than or equal to that in the organic system. If the minimal risk in the organic system is less than or equal to that in the mechanistic system, the organic system is said to be efficient. Let

$$S=\{w=(w(u_1),\ldots,w(u_s)):\ \sum_i w(u_i)=1,\ w(u_i)\geqq 0,\ i=1,\ldots,s\}.$$

Hence, S is the (s-1)-dimensional simplex spanned by the unit vectors in Euclidean s-space. S is the set of all prior distributions. The region of the prior distributions over which the mechanistic system is efficient is defined by

$$S^*=\{w\in S:\ V_1(w)\leqq V_2(w)\}.$$

The organic system is efficient for $w\in C(S-S^*)$, where $C(S-S^*)$ represents the closure of $S-S^*$. The following theorem shows the important characteristics of S^*.

Theorem 5. Define $R_j(w)=\sum_{i=1}^{s} w(u_i)L(u_i,a_j)$, and $S_j^*=\{w\in S:\ R_j(w)\leqq V_2(w)\}$. Then $S^*=\bigcup_{j=1}^{m} S_j^*$.

Proof. See Appendix A.6.

From this theorem, if $w\in S^*$, i.e., $w\in S_j^*$ for some j, then the mechanistic system is efficient, and that if $w\in C(S-S^*)$, the organic system is efficient.

Let us discuss the structure of the solutions S* and C(S-S*) for comparison between the mechanistic system and the organic system. The following theorems show the important characteristics of S*. Their prototype is shown by Arrow, Blackwell and Girshick (1949) for a simpler sequential decision problem. They assume that m=s and that $L(u_i,a_i)=0$ for all i. Then

$$R_j(e_j)=L(u_j,a_j)=0\leqq V_2(e_j).$$

Thus the unit vector e_j with unity in the j-th component belongs to S_j* and all the subsets S_j* are nonempty. Therefore following Theorem 6 and Theorem 7 (a) are obvious on their assumption. This paper takes up the extended case of s states of environment (i.e., s states of nature), m tasks (i.e., m alternatives or actions) and more general loss structure. Some subsets S_j* may be empty (see Appendix A.7).

<u>Theorem</u> <u>6</u>. Let $e_i=(0,\ldots,0,1,0,\ldots,0)$ with unity in the i-th place. Then $e_i\in S^*$, $i=1,\ldots,s$.

<u>Proof</u>. See Appendix A.8.

Note that e_i means the certainty case in which the top leader and the managers have complete and accurate knowledge that the true state of the environment is u_i. Therefore this theorem states that the mechanistic system is efficient if the organization is confronted with the case of certainty.

Theorem 7. Let e_i be as defined in Theorem 6. If S_r* is not empty, then (a) there exists e_i such that $e_i \in S_r*$, and (b) S_r* is a convex set.

Proof. See Appendix A.9.

From this theorem, the region S_j*, $j=1,\ldots,m$, is a convex set containing at least one vertex. Since the prior distribution is a direct expression of uncertainty with respect to the state of the environment, S_j* is the set of the prior distributions which represent low uncertainty about the environment, and $C(S-S*)$ is the set of the prior distributions which represent high uncertainty. As a result, it is shown that the mechanistic system is the efficient management system under low uncertainty and the organic system under high uncertainty.

To illustrate the characteristics of $S*$ of Theorems 6 and 7, we consider the following examples.

Example 2. Now suppose that in the decision problem of Example 1, the information costs are $c_I=3$, $c_T=2$, $c_M=1$. Then the information cost function is

$$C_1(I)=10,\quad C_1(S)=0,$$
$$C_2(I)=7,\quad C_2(S)=2.$$

The region $S*$ can be computed by the procedure developed in the original paper of Arrow, Blackwell and Girshick (1949), or the subsequent book by Blackwell and Girshick (1954). We first obtain the following result:

$$\inf_{(q,d)} r_2(w,(q,d))=\begin{cases} 100w(u_1)+9 & \text{if } \quad 0\leq w(u_1)<0.4 \\ 49 & \text{if } \ 0.4\leq w(u_1)<0.6 \\ 109-100w(u_1) & \text{if } \ 0.6\leq w(u_1)\leq 1 \end{cases}$$

and then it follows that

$$S_1{}^*=\{w=(w(u_1),w(u_2)):\ 0.51\leq w(u_1)=1-w(u_2)\leq 1\},$$
$$S_2{}^*=\{w=(w(u_1),w(u_2)):\ 0\leq w(u_1)=1-w(u_2)\leq 0.49\}.$$

Thus $S_1{}^*$ and $S_2{}^*$ are convex regions, and respectively contain $w=(1,0)$ and $(0,1)$, which are vertices of a 1-dimensional simplex. The efficient management system is found from the above $S_1{}^*$ and $S_2{}^*$ to be as follows:

(1) If $0\leq w(u_1)\leq 0.49$ or $0.51\leq w(u_1)\leq 1$, then the mechanistic system is efficient.

(2) If $0.49\leq w(u_1)\leq 0.51$, then the organic system is efficient.

Therefore the mechanistic system is efficient under low uncertainty and the organic system is efficient under high uncertainty.

Example 3. To illustrate the characteristics of $S_j{}^*$, we consider a following example. The organization is confronted with the problem to reduce the defective rate. The factor of increasing the defective article rate is one of three classes of situations, $S_U=\{u_1,u_2,u_3\}$. The organization has three managers and the specialized repertory is given by $A'=\{a_1,a_2,a_3\}$, to cope with these factors. However, this organization incurs losses if it takes wrong tasks. The losses are given as the following loss function.

$L(u_1,a_1)=0,\quad L(u_1,a_2)=60,\ L(u_1,a_3)=40,$

$L(u_2,a_1)=70,\ L(u_2,a_2)=0,\quad L(u_2,a_3)=80,$

$L(u_3,a_1)=50,\ L(u_3,a_2)=60,\ L(u_3,a_3)=0,$

If unit organizations check and test their operating machines at the field, they takes some data about the situation and the observation center obtains the organizational observation. The organizational observation obtained through this observation process is of such a property that it eliminates completely the likelihood of one u_i, i.e., if $Z_j=(i,i,i)$ is observed, then u_i is counted out as the possible "cause". Then

$p((1,1,1)|u_1)=0,\quad p((2,2,2)|u_1)=1/2,\ p((3,3,3)|u_1)=1/2,$

$p((1,1,1)|u_2)=1/2,\ p((2,2,2)|u_2)=0,\quad p((3,3,3)|u_2)=1/2,$

$p((1,1,1)|u_3)=1/2,\ p((2,2,2)|u_3)=1/2,\ p((3,3,3)|u_3)=0,$

and $p(z_j|u_i)=0$ for the other z_j's and $i=1,2,3$. It is known that $c_I=2$, $c_T=4$ and $c_M=2$, then

$C_1(I)=18,\ C_1(S)=0,$

$C_2(I)=10,\ C_2(S)=4.$

The region S* can be computed by the procedure developed by Arrow, Blackwell and Girshick (1949), Blackwell and Girshick (1954). A prior distribution $w=(w(u_1),w(u_2),w(u_3))$ with $w(u_1)+w(u_2)+w(u_3)=1$ may be represented by a point in an equilateral triangle with unit altitude. The distances from the

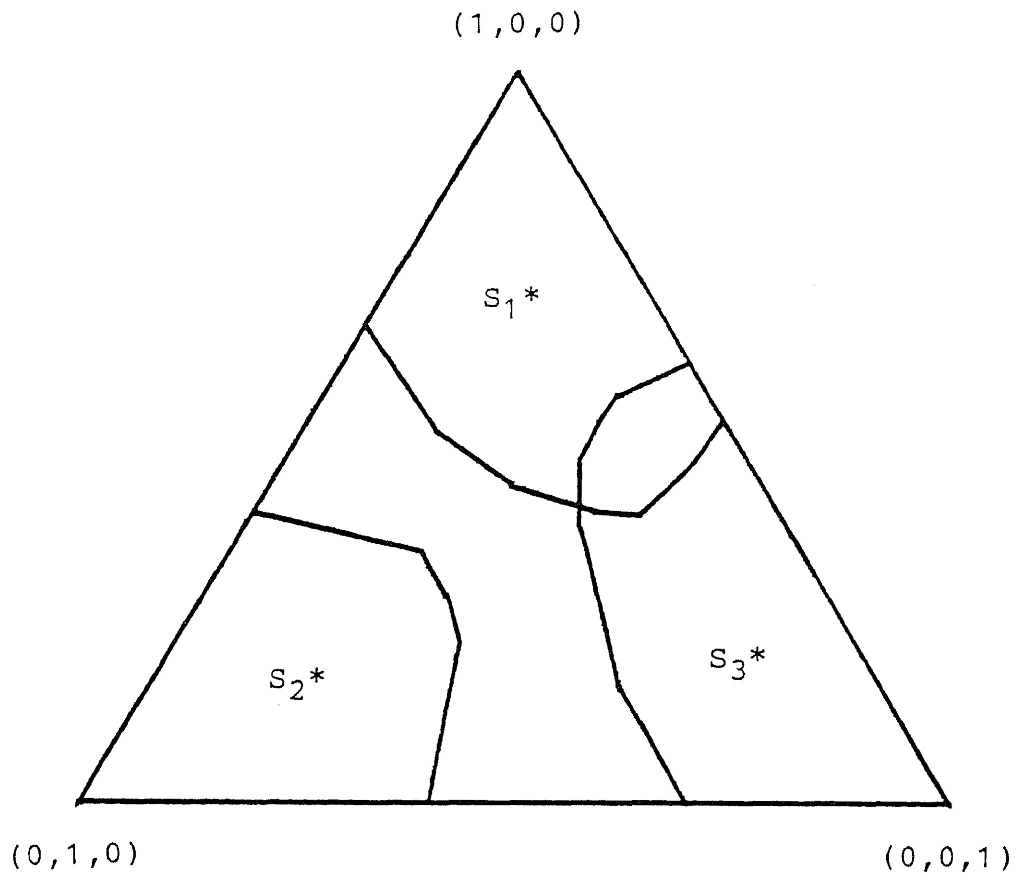

Figure 4. Example 3. $S^*=S_1^*\cup S_2^*\cup S_3^*$.

point to the three sides are $w(u_1)$, $w(u_2)$ and $w(u_3)$ since

$$bw(u_1)/2+bw(u_2)/2+bw(u_3)/2=b/2$$

where b is the length of side of the equilateral triangle.

We develop a computer program TRIGRAPH given in Appendix B to calculate and draw the region S*, and Figure 4 is obtained. This Figure illustrates the characteristics proved by Theorems 6 and 7. S_1*, S_2* and S_3* respectively contain w=(1,0,0), (0,1,0) and (0,0,1), which are vertices of a triangle, 2-dimensional simplex. They are convex regions.

The following theorem provides interesting properties of S*.

Theorem 8. S_j* is nondecreasing in c_I, c_T and c_M, j=1,...,m.

Proof. By definition, information costs $C_2(I)$ and $C_2(S)$ are nondecreasing in c_I, c_T and c_M. Then from the definition of S_j* in Theorem 5, the proof is straightforward.

Thus the greater information costs including the communication costs, the greater possibility that the mechanistic system is efficient. Under high uncertainty, the need to observe the state of the environment and to reduce the expected loss makes the organic system efficient. But the high information cost impair the merits of the organic system and then makes the mechanistic system efficient.

Example 4. To illustrate Theorem 8, we continue Example 3. Information cost, c_I and c_M, are same ones as before. For c_T, we now consider following five cases.

(1) Case I: $c_T=2$, $C_1(I)=12$, $C_1(S)=0$;
$C_2(I)=10$, $C_2(S)=2$.

(2) Case II: $c_T=4$, $C_1(I)=18$, $C_1(S)=0$;
$C_2(I)=10$, $C_2(S)=4$.

(3) Case III: $c_T=6$, $C_1(I)=24$, $C_1(S)=0$;
$C_2(I)=10$, $C_2(S)=6$.

(4) Case IV: $c_T=8$, $C_1(I)=30$, $C_1(S)=0$;
$C_2(I)=10$, $C_2(S)=8$.

(5) Case V: $c_T=10$, $C_1(I)=36$, $C_1(S)=0$;
$C_2(I)=10$, $C_2(S)=10$.

Case II has been already considered in Example 3. For other four cases, we compute the regions S* and illustrate them in Figure 5 by using our computer program TRIGRAPH given in Appendix B. The extreme points of the region S_j* are also given in Appendix B. This figure shows that S_1*, S_2* and S_3* are increasing in c_T. Thus Theorem 8 is demonstrated.

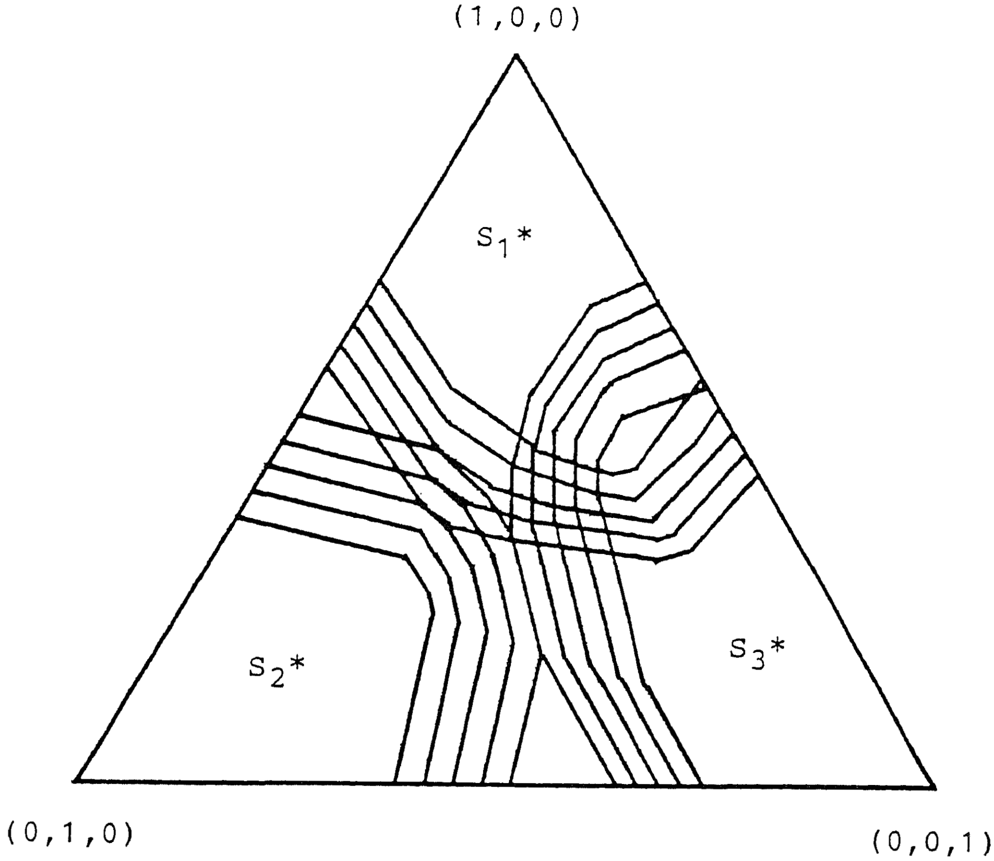

Figure 5. Example 4. Numerical examples for five cases: S_1*, S_2* and S_3* are increasing in c_T.

3.4 Categories of Uncertainty

Thus far we suppose that the top leader and the managers know their prior distribution, but this case is not general and is only one of the various cases in the real world. In accordance with March and Simon (1958, p.137), we classify "uncertainty" into three categories: (a) Certainty: the top leader and the managers have complete and accurate knowledge of the true state of environment. (b) Risk: they have accurate knowledge of a probability distribution over the states of environment. (c) Uncertainty: they know only the set of the states of environment. Thus, in the previous sections, we study the case of certainty and the case of risk. The case of certainty is a special case of risk, where the subjective probability distribution is $w=(0,\ldots,0,1,0,\ldots,0)$ with probability 1 assigned to one particular state of environment.

In the case of uncertainty, the top leader and the managers do not have the subjective probability and only knows that $S_U=\{u_1,\ldots,u_s\}$, then they are confronted with fairly greater uncertainty than in the case of certainty or risk, and the definition of optimality becomes problematic.

The best known method which does not require the specification of a prior distribution w is the minimax principle of choice (e.g., March and Simon 1958; Ferguson 1967; DeGroot 1970): Consider the worst consequence that could happen to the organization for each state of the environment and then select the decision rule whose worst consequence is preferred to the worst consequence attached to other decision rules. There are other proposals, and it is difficult to judge which proposal is the best one. But the minimax principle widely spreads in the decision theory context. Then, in this section, we consider the minimax decision rule as the optimal one of the sequential decision problem for the case of uncertainty.

A pair of a decision rule (q^0,d^0) and a management system k^0 is said to be minimax if

$$\sup_w r_{k0}(w,(q^0,d^0))=\inf_{(q,d),k}\sup_w r_k(w,(q,d)).$$

The value on the right side of this equation is called the minimax risk. For the case of uncertainty, the organization structure is called efficient if it ensures the organization to attain the minimax risk. Similarly, the management system is called efficient if it ensures the organization to attain the minimax risk.

In the terminology of decision theory, a prior distribution w^0 is said to be least favorable if

$$\inf_{(q,d),k} r_k(w^0,(q,d))=\sup_w \inf_{(q,d),k} r_k(w,(q,d)).$$

The famous minimax theorem is stated.

Theorem 9. $\inf_{(q,d),k}\sup_w r_k(w,(q,d))=\sup_w \inf_{(q,d),k} r_k(w,(q,d))$, and there exists a least favorable distribution w^0.

Proof. See the proof of Ferguson's (1967) Theorem 2.9.1.

Using the least favorable distribution, the following theorem provides important relationships between the efficient management system and the efficient organization structure for the case of uncertainty.

Theorem 10. Define $R_{j^*}(w^*)=\sup_w \min_j R_j(w)$. Then (a) if $w^* \in S^*$, w^* is the least favorable distribution, and (b) otherwise, the least favorable distribution $w^0 \in C(S-S^*)$.

Proof. See Appendix A.10.

Note that w^* is the least favorable distribution for the no data decision problem. In the case of part (a) of this theorem, the least favorable distribution $w^* \in S^*$, then the mechanistic system is the efficient management system. Furthermore, from the definition of w^* that $R_{j^*}(w^*)=\sup_w \min_j R_j(w)$, the task $a_{j^*} \in A'$ is obviously the minimax terminal decision rule, then the manager j^* stands in a line authority position and other managers are only advisory to the top leader. Thus, the pyramid organization is the efficient organization structure.

In the case of part (b), the least favorable distribution belongs to the set $C(S-S^*)$, then the organic system is the efficient management system. But, neither organization structures are universally efficient in this case.

Therefore, for the case of uncertainty, this theorem implies the following relationship between the efficient management system and the efficient organization structure: If the mechanistic system is efficient, then the pyramid organization is efficient.

We now consider the example that the pyramid organization and the organic system are efficient.

Example 5. Suppose that in the decision problem of Example 2, the top leader shall choose the minimax decision rule for the case of uncertainty.

By definition, $w^*=(0.5,0.5)$, and it follows from the region S^* in Example 2 that $w^*\in S-S^*$. Then from Theorem 10 (b), the least favorable distribution w^0 shall belong to $C(S-S^*)$. In fact, from the results of Example 2, it follows that

$$\inf_{(q,d),k} r_k(w,(q,d))=\begin{cases} 100w(u_1) & \text{if } 0\leqq w(u_1)<0.49 \\ 49 & \text{if } 0.49\leqq w(u_1)<0.51 \\ 100-100w(u_1) & \text{if } 0.51\leqq w(u_1)\leqq 1 \end{cases}$$

and then all points in the set

$$C(S-S^*)=\{w=(w(u_1),w(u_2)):\ 0.49\leqq w(u_1)=1-w(u_2)\leqq 0.51\}$$

are the least favorable distributions from the definition and the minimax theorem.

The result we have just obtained has the following interpretation. For the case of uncertainty, the top leader should take one organizational observation in the organic system and then choose a_2 if $Z_1=(0,0)$ or choose a_1 if $Z_1=(1,1)$, that is, the pyramid organization is efficient.

3.5 Managerial Implications

This paper has discussed the organization design problem from a decision theoretic viewpoint, and has derived a number of managerial implications for the top leader interested in designing his organization. Now, we summarize them as the propositions on the efficient organizational design.

For the cases of certainty and risk, Theorem 2 is restated as follows.

Proposition 1. If the organization is confronted with the case of certainty or risk, then the pyramid organization obtained by taking off the null managers from the lines of authority is efficient.

Theorems 6 and 7 are restated as follows.

Proposition 2. If the organization is confronted with the case of certainty, then the mechanistic system is efficient. If it is confronted with the case of risk, then the mechanistic system is efficient under low uncertainty and the organic system is efficient under high uncertainty.

These propositions seem to support the statements of Davis and Lawrence (1977) and Burns and Stalker (1961). In fact, Proposition 1 supports Davis and Lawrence's statement that a necessary condition of the matrix organization to be preferred structural choice is "uncertainty."

Davis and Lawrence (1977) concluded that the matrix organization was preferred structual choice when three basic conditions existed simultaneously; (a) "outside pressures for dual focus," (b) "pressures for high information-processing capacity," and (c) "pressures for shared resources." (b) of their three conditions is caused by "uncertainty" in the environment. From Proposition 1, the matrix organization may be at least as good as the pyramid organization only if the top leader is confronted with the case of uncertainty. Thus our Proposition 1 partially supports their discussion. In accordance with Davis and Lawrence (1977), we formalize Proposition 1 as follows: A necessary condition that the matrix organization is preferred is that the top leader is confronted with the case of uncertainty.

Now, let us see the relationship between Burns and Stalker's (1961) management systems and our management systems. Burns and Stalker listed up eleven items of characteristics of their mechanistic system and organic system. The characteristics of their management systems are summarized in Table 1. The items in Table 1 are condensed and paraphrased from the original items in Burns and Stalker (1961, pp.119-122) in order to facilitate the use of this table in the question in the next chapter, and for each item, (a) designates a characteristic of the mechanistic system and (b) designates a characteristic of the organic system.

From Definition 2, in our mechanistic system, the top leader defines and adjusts the managers' observing activities and then the knowledge of the environment is exclusively located at him.

Thus, our mechanistic system has characteristics (1a) and (4a) of Burns and Stalker's mechanistic system. In our organic system, an observation center in the network of the managers defines and adjusts other managers' observing activities through horizontal interaction and then the knowledge of the environment is located at him. Hence, our organic system has (1b) and (4b) of Burns and Stalker's organic system. On the other hand, in our mechanistic system, there only exist vertical communication paths (see Figure 3), while in our organic system most of the directions of the communication is horizontal in the network of managers. Therefore, our mechanistic system has characteristics (2a) and (3a) of Burns and Stalker's mechanistic system, and our organic system has (2b) and (3b) of their organic system. Other items (items 5 through 9 in Table 1) have no direct relationship to our mechanistic system and organic system.

Therefore Burns and Stalker's mechanistic system is a subclass of our mechanistic system and their organic system is a subclass of our organic system. Then Proposition 2 partially supports Burns and Stalker's statement that the mechanistic system and the organic system are efficient under low uncertainty and high uncertainty respectively.

Our results, Propositions 1 and 2, agree on these statements obtained from the empirical studies by Burns and Stalker, and Davis and Lawrence.

As discussed in the previous section, in the case of uncertainty, the definition of optimality becomes problematic, then we remark that neither organization structures and neither management systems are universally efficient if the organization is confronted with the case of uncertainty. We only state the relationship that the pyramid organization is efficient if the mechanistic system is efficient as stated in Theorem 10 for the minimax principle case of uncertainty. Theorems 2, 6 and 7 also imply this relationship for the cases of certainty and risk as summarized in Propositions 1 and 2. Thus, by assuming that the minimax principle is used for the case of uncertainty, we obtain the following theoretical tendency.

Proposition 3. The pyramid organization is efficient if the mechanistic system is efficient.

This proposition has not been stated by contingency theorists. It can be stated only if the integrated organization design problem is considered which incorporates both organization structures and management systems. This relationship suggests to the top leader a method to check the validity of his decision on the organizational design.

Table 1. Characteristics of the Mechanistic System and the Organic System.

Item number[a]	
1.	(a) For each level in the hierarchy, individual tasks are defined and adjusted by the immediate superiors.
	(b) Individual tasks are defined and adjusted through interaction with others.
2.	(a) A tendency for interaction between members is vertical, i.e., communication between the superior and the subordinate.
	(b) A direction of communication through the organization is lateral rather than vertical.
3.	(a) The structure of control, authority and communication is hierarchical.
	(b) The structure of control, authority and communication is network.
4.	(a) When the activities are coordinated, knowledge is exclusively located at the top of hierarchy.
	(b) Knowledge may be located at the ad hoc center in the network.
5.	(a) The tasks facing the firm as a whole are broken down into functionally specialized tasks.
	(b) Members' special knowledge and experience have the contributive nature to the common task of the firm.

6. (a) Each individual task has the abstract nature and each member tends to pursue the technical improvement of means, rather than the accomplishment of the ends of the firm.
   (b) Each individual task is seen as set by total situation of the firm.
7. (a) Rights, obligations and methods for each job are precisely defined.
   (b) Problems may not be posted as being someone else's responsibility, then commitment to the firm and task goes beyond any technical definition.
8. (a) A content of communication consists of instructions and decisions.
   (b) A content of communication consists of information and advice rather than instructions and decisions.
9. (a) Greater importance is attached to local rather than cosmopolitan knowledge, experience and skill.
   (b) Greater importance is attached to expertise valid in the environment external to the firm.

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[a] For each item, (a) indicates the characteristic of Burns and Stalker's mechanistic system, and (b) indicate the ones of their organic system. The items are condensed and paraphrased from the original items in Burns and Stalker (1961, pp.119-122) in order to facilitate the use of this table in the question in the next chapter. Especially, items 1 through 4 indicate the characteristics of our management systems, the mechanistic system and the organic system.

CHAPTER 4 EMPIRICAL RESEARCH ON JAPANESE FIRMS

4.1 Hypotheses

In this chapter, we test the propositions on the efficient organization structures and the efficient management systems. These propositions have been obtained in the previous chapter through the statistical decision theoretic approach and summarized in Section 3.5. Since we have no absolute measures to identify the actual condition with the case of "certainty," "risk" or "uncertainty," precisely, in order to test our Propositions 1 and 2 we derive the following three hypotheses.

Hypothesis 1. The high performing pyramid organizations and the low performing matrix organizations are confronted with the lower uncertainty than the low performing pyramid organizations and the high performing matrix organizations.

Hypothesis 2. The high performing mechanistic systems and the low performing organic systems are confronted with the lower uncertainty than the low performing mechanistic systems and the high performing organic systems.

Hypotheses 1 and 2 are the direct restatements of Propositions 1 and 2, respectively.

Hypothesis 3. The high performing mechanistic systems use the pyramid organizations.

Hypothesis 3 is also the direct restatement of Proposition 3. Hypotheses 1 and 2 suggest a similarity of the fitness for environment between the pyramid organization and the mechanistic system and a similarity between the matrix organization and the organic system. Hypothesis 3 agrees with such relationships between the organization structures and the management systems. Therefore, if the data support Hypothesis 3, they partially and indirectly testify to the truth of Hypotheses 1 and 2.

4.2 Methods

To test these hypotheses, the study focused on the organization structures and the management systems of Japanese firms listed on the Securities Exchanges and mutual life insurance companies. The research was carried out in January 1983. This chapter reports on data obtained from the mailed questionnaires.

Each questionnaire was addressed to a planning manager of the head office at a firm. Actual respondents include three managing directors, 28 general managers, 24 assistant general managers, 80 managers, nine assistant managers, 25 subsection heads, and the others (N=299). The industries of 299 firms include construction (27), food and kindred products (16), textile mill products (12), paper, chemical and petroleum products (30), iron, steel and nonferrous metal (23), nonelectrical machinery (36), electrical machinery (25), transportation equipment (12), precision machinery (11), wholesale and retail trade (28), banking (22), insurance (16), public utility (41). Insurance includes five mutual life insurance companies.

To test Hypotheses, the respondents were asked to answer the questions. The original questions are written in Japanese and they are given in Appendix C.

Using the similar figure of Figure 2 (eliminating two null managers from (1)), we developed the following question:

Question 1. The figure shows the line of authority between the superiors and the unit organizations when the unit organizations execute activity programs. Which type of command system is used by your organization? Please circle the number of the appropriate figure.

On the other hand, we use the list of characteristics of management systems stated by Burns and Stalker (1961) to investigate management systems. The respondents were also asked to answer the characteristics of their management systems. Using Table 1, the following question was developed:

Question 2. How would you characterize the actual management pattern of your organization? Please circle one of two statements for each item.

As discussed in Section 3.5, our management systems have only communication and coordination aspects of Burns and Stalker's (1961) management systems, which are characterized by items 1 through 4 in Table 1. To examine the validity of our modeling of management systems on items 1 through 4 basis, we investigate the other characteristics (items 5 through 9) of Burns and Stalker's management systems.

Although we asked Questions 1 and 2 of the respondents in all industries, we could not develop the instruments for measuring uncertainty for the non-manufacturing industry. For the manufacturing industry, the questions developed by Kagono (1980) can be reformed for our use. Then we restricted the respondents of the questions to the ones in the manufacturing industry, and used the following questions (cf. Kagono 1980):

<u>Question</u> <u>3</u>. How many years long is the revamping cycle of production lines for economy reasons in the latest case? Please indicate the number of years.

_____ year(s).

<u>Question</u> <u>4</u>. How many years long is the life cycle of the leading product in the latest case? Please indicate the number of years.

_____ year(s).

Question 3 investigates the revamping cycle of production lines, and Question 4 the life cycle of the leading product. If the organization revamps its production lines, it must take long time to get the control state. Then the organization is confronted with high uncertainty until it gets the control state. The change of the leading product means to gain access to a new product market, then the organization is confronted with high uncertainty in this new market. The shorter revamping cycle or the shorter life cycle must cause the decision maker to be confronted with the higher uncertainty about the environment. For simplicity of the description in this chapter, the variable measured by Question 3 is denoted by REVAMP and Question 4 by LIFE.

To test Hypotheses 1 and 2, we calculate the mean numbers of REVAMP and LIFE. If Hypothesis 1 is true, then REVAMP and LIFE of the high performing pyramid organizations and the low performing matrix organizations are greater than those of the low performing pyramid organizations and the high performing matrix organizations. If Hypothesis 2 is true, then REVAMP and LIFE of the high performing mechanistic systems and the low performing organic systems are greater than those of the low performing mechanistic systems and the high performing organic systems.

For these analyses, we use categories of "high-performers" and "low-performers." These categories base on the subjective self-estimations by respondents, obtained by the following question (cf. Lawrence and Lorsch 1967):

Question 5. We need to obtain your subjective estimation of the overall performance of your entire organization as it relates to competitors in this industry. Please indicate the performance of your organization in this industry.

"I feel that our organization should be

1. above average
2. average
3. below average

} in success in this industry."

We objectively check the validities of the self-estimations by the analysis of financial indicators as follows: For "high-performers" ("above average" firms in Question 5) and "low-performers" ("average" and "below average" firms in the same question), we calculate mean numbers of following seven indicators (1) growth rate of sales (2) ratio of net profit to total liabilities and net worth (3) ratio of net profit to net worth (4) ratio of net profit to sales (5) turnover ratio of total liabilities and net worth (6) ratio of net worth to total liabilities and net worth (7) sales per employee, and we compare the mean numbers of these indicators for "high-performers" and "low-performers" by t-tests. The results are shown in Table 2.

There exist statistically significant differences for only three indicators; (1) growth rate of sales, (4) ratio of net profit to sales, and (6) ratio of net worth to total liabilities and net worth. For these three indicators, "high-performers" are significantly higher performing than "low-performers" at level 0.001. We have no significant differences for other four indicators at significant level 0.1.

Table 2. Mean Numbers of Financial Indicators for Different Performance Levels.

Indicator	Performance level: High-performer	Performance level: Low-performer	t[a]
(1) Growth rate of sales (%)	13.15 (152)	9.64 (134)	3.59 ***
(2) Ratio of net profit to total liabilities and net worth (%)	3.16 (136)	1.97 (120)	1.54
(3) Ratio of net profit to net worth (%)	10.66 (149)	12.58 (134)	-0.48
(4) Ratio of net profit to sales (%)	2.78 (154)	1.42 (137)	3.97 ***
(5) Turnover ratio of total liabilities and net worth	1.40 (136)	4.40 (120)	-0.99
(6) Ratio of net worth to total liabilities and net worth (%)	33.48 (137)	22.28 (122)	4.84 ***
(7) Sales per employee (a million yen)	70.43 (154)	64.15 (137)	0.32

[a] t-tests (the numbers of effective samples are within parentheses).

*** Significant at level 0.001.

4.3 Organization Structures and Management Systems

Let us begin on the analysis of Hypothesis 3 that the high performing mechanistic systems use the pyramid organizations.

Table 3 describes actual conditions of the organization structures of Japanese firms. The proportions of the pyramid organizations and the matrix organizations are summarized; 63.6% of total firms take the pyramid organizations, and it is amazing fact that 36.4% of total firms take the matrix organizations contradicting the principle of unity of command in the classical management theory. Especially, 78.3% of "iron, steel, and nonferrous metal industry" answered to take the matrix organization, whereas more than 90% of "textile mill products" and "precision machinery" the pyramid organizations.

Table 4 describes actual characteristics of the management systems of Japanese firms. For all items but items 4 and 6, more than 70% of the total firms answered to take the characteristics of Burns and Stalker's (1961) mechanistic systems. Only for item 6, the proportion of the organizations characterized by the organic system is greater than 50%.

Items 1 through 4 indicate the characteristics of our management systems. 60.6% of "nonelectrical machinery" answered to take the fourth characteristic of the organic system, but for the other combinations of items and industries, more than 50% of the firms answered to take the characteristics of the mechanistic system.

Table 3. Organizations Structures of Japanese Firms by Industry.

Industry	Organization structure[a]		
	Pyramid	Matrix	
Construction	53.8	46.2	(26)
Food and kindred products	62.5	37.5	(16)
Textile mill products	90.9	9.1	(11)
Paper, chemical and petroleum products	63.3	36.7	(30)
Iron, steel and nonferrous metal industry	21.7	78.3	(23)
Nonelectrical machinery	57.1	42.9	(35)
Electrical machinery	80.0	20.0	(25)
Transportation equipment	75.0	25.0	(12)
Precision machinery	90.0	10.0	(10)
Wholesale and retail trade	78.6	21.4	(28)
Banking	45.5	54.5	(22)
Insurance	68.8	31.2	(16)
Public utility	70.0	30.0	(40)
Total	63.6	36.4	(294)

[a] Expressed in percentage terms (the numbers of effective samples are within parentheses).

Table 4. Characteristics of Management Systems of Japanese Firms by Industry.

Industry	Item number[a] =	1	2	3	4
Construction	(a)	96.3	70.4	81.5	55.6
	(b)	3.7	29.6	18.5	44.4
		(27)	(27)	(27)	(27)
Food and kindred products	(a)	81.3	75.0	75.0	62.5
	(b)	18.7	25.0	25.0	37.5
		(16)	(16)	(16)	(16)
Textile mill products	(a)	100.0	83.3	83.3	66.7
	(b)	0.0	16.7	16.7	33.3
		(12)	(12)	(12)	(12)
Paper, chemical and petroleum products	(a)	66.7	73.3	76.7	56.7
	(b)	33.3	26.4	23.3	43.3
		(30)	(30)	(30)	(30)
Iron, steel and non-ferrous metal industry	(a)	87.0	52.2	60.9	50.0
	(b)	13.0	47.8	39.1	50.0
		(23)	(23)	(23)	(22)
Nonelectrical machinery	(a)	73.5	61.8	65.7	39.4
	(b)	26.5	38.2	34.3	60.6
		(34)	(34)	(35)	(33)
Electrical machinery	(a)	88.0	87.5	88.0	60.0
	(b)	12.0	12.5	12.0	40.0
		(25)	(24)	(25)	(25)
Transportation equipment	(a)	91.7	83.3	91.7	66.7
	(b)	8.3	16.7	8.3	33.3
		(12)	(12)	(12)	(12)
Precision machinery	(a)	81.8	81.8	72.7	63.6
	(b)	18.2	18.2	27.3	36.4
		(11)	(11)	(11)	(11)
Wholesale and retail trade	(a)	89.3	71.4	82.1	57.1
	(b)	10.7	28.6	17.9	42.9
		(28)	(28)	(28)	(28)
Banking	(a)	77.3	86.4	86.4	52.4
	(b)	22.7	13.6	13.6	47.6
		(22)	(22)	(22)	(21)
Insurance	(a)	81.3	68.8	87.5	56.3
	(b)	18.7	31.2	12.5	43.7
		(16)	(16)	(16)	(16)
Public utility	(a)	94.9	82.1	82.5	65.0
	(b)	5.1	17.9	17.5	35.0
		(39)	(39)	(40)	(40)
Total	(a)	83.6	74.1	78.8	56.7
	(b)	16.4	25.9	21.2	43.3
		(295)	(294)	(297)	(293)

Industry	Item number[a] =	5	6	7	8	9
Construction	(a)	81.5	40.7	66.7	74.1	85.2
	(b)	18.5	59.3	33.3	25.9	14.8
		(27)	(27)	(27)	(27)	(27)
Food and kindred products	(a)	68.8	18.8	75.0	75.0	81.3
	(b)	31.2	81.2	25.0	25.0	18.7
		(16)	(16)	(16)	(16)	(16)
Textile mill products	(a)	83.3	58.3	81.8	75.0	83.3
	(b)	16.7	41.7	18.2	25.0	16.7
		(12)	(12)	(11)	(12)	(12)
Paper, chemical and petroleum products	(a)	73.3	36.7	76.7	66.7	83.3
	(b)	26.7	63.3	23.3	33.3	16.7
		(30)	(30)	(30)	(30)	(30)
Iron, steel and non-ferrous metal industry	(a)	78.3	52.2	59.1	54.5	85.0
	(b)	21.7	47.8	40.9	45.5	15.0
		(23)	(23)	(22)	(22)	(20)
Nonelectrical machinery	(a)	71.4	25.7	51.4	58.8	67.6
	(b)	28.6	74.3	48.6	41.2	32.4
		(35)	(35)	(35)	(34)	(34)
Electrical machinery	(a)	76.0	32.0	60.0	88.0	88.0
	(b)	24.0	68.0	40.0	12.0	12.0
		(25)	(25)	(25)	(25)	(25)
Transportation equipment	(a)	75.0	8.3	83.3	63.6	75.0
	(b)	25.0	91.7	16.7	36.4	25.0
		(12)	(12)	(12)	(11)	(12)
Precision machinery	(a)	100.0	45.5	45.5	81.8	81.8
	(b)	0.0	54.5	54.5	18.2	18.2
		(10)	(11)	(11)	(11)	(11)
Wholesale and retail trade	(a)	82.1	32.1	85.7	75.0	64.3
	(b)	17.9	67.9	14.3	25.0	35.7
		(28)	(28)	(28)	(28)	(28)
Banking	(a)	52.4	9.1	85.7	84.2	70.0
	(b)	47.6	90.9	14.3	15.8	30.0
		(21)	(22)	(21)	(19)	(20)
Insurance	(a)	81.3	33.3	75.0	62.5	62.5
	(b)	18.7	66.7	25.0	37.5	37.5
		(16)	(15)	(16)	(16)	(16)
Public utility	(a)	84.6	43.6	71.8	86.8	80.0
	(b)	15.4	56.4	28.2	13.2	20.0
		(39)	(39)	(39)	(38)	(40)
Total	(a)	76.9	33.9	70.0	73.0	77.3
	(b)	23.1	66.1	30.0	27.0	22.7
		(294)	(295)	(293)	(289)	(291)

[a] Expressed in percentage terms (the numbers of effective samples are within parentheses). Item numbers correspond to those given in Table 1.

For the high-performers, we make four-fold tables of organization structures with characteristics of Burns and Satlker's (1961) management systems for each item of Table 1. The results are given in Table 5 with respect to items 1 through 4 which characterize our management systems, the mechanistic system and the organic system. From Table 5 (A), the pyramid organizations are used by 69.4% of the firms having the mechanistic system characteristic that individual tasks are defined and adjusted by the immediate superiors at significant level 0.01. Table 5 (B) suggests that 75.0% of the firms characterized by the vertical directions of communication take the pyramid organizations, and 77.2% of the firms having hierarchical communication structure take the pyramid organizations from Table 5 (C). These relationships are statistically significant at level 0.001. Furthermore, 77.2% of the firms whose top leaders exclusively possess the knowledge in the organizations take the pyramid organizations at significant level 0.01 from Table 5 (D). Thus, around 70% of the firms characterized by the mechanistic system use the pyramid organizations. These tendencies become glaringly noticeable in comparison with the firms characterized by the organic system.

The other results are summarized in Table 6. For items 5 through 9, we only show the phi coefficients and significances obtained through chi-square tests in this table.

All the statistically significant relationships between the organization structures and the characteristics of Burns and Stalker's (1961) management systems indicate a tendency that the organizations characterized by the mechanistic systems take the pyramid organizations. Especially, for items 1 through 4, i.e., the characteristics of our mechanistic system and organic system, we have the statistically significant relationships between organization structures and management systems at significant level 0.01. Compared with other items, these aspects of Burns and Stalker's (1961) management systems are especially important in designing organizations. Thus these tables support our Hypothesis 3, and shows the validity of our modeling of management systems on items 1 through 4 basis and our discussion.

As discussed in Section 4.1, these results partially and indirectly testify to the truth of Hypotheses 1 and 2.

Table 5. Cross-Tabulations by Organization Structures and Characteristics of Management Systems for High-Performers.

(A)

Characteristic of management systems (Item number = 1)	Organization structure		
	Pyramid	Matrix	Total
(Mechanistic) Individual tasks are defined and adjusted by the immediate superiors.	89 (69.4)	35 (30.6)	124 (100.0)
(Organic) Individual tasks are defined and adjusted through interaction with others.	9 (36.0)	16 (64.0)	25 (100.0)
Total	98	51	149

Phi coefficient = 0.263, chi-square = 10.29, $P < 0.01$.

(B)

Characteristic of management systems (Item number = 2)	Organization structure		
	Pyramid	Matrix	Total
(Mechanistic) A tendency for interaction between members is vertical.	78 (75.0)	26 (25.0)	104 (100.0)
(Organic) A direction of communication through the organization is lateral rather than vertical.	19 (42.2)	26 (57.8)	45 (100.0)
Total	97	52	149

Phi coefficient = 0.300, chi-square = 13.45, $P < 0.001$.

(C)

Characteristic of management systems (Item number = 3)	Organization structure		
	Pyramid	Matrix	Total
(Mechanistic) The structure of control, authority and communication is hierarchical.	88 (77.2)	26 (22.8)	114 (100.0)
(Organic) The structure of control, authority and communication is network.	10 (27.8)	26 (72.2)	36 (100.0)
Total	98	52	150

Phi coefficient = 0.427, chi-square = 27.36, $P < 0.001$.

(D)

Characteristic of management systems (Item number = 4)	Organization structure		
	Pyramid	Matrix	Total
(Mechanistic) Knowledge is exclusively located at the top of hierarchy.	61 (77.2)	18 (22.8)	79 (100.0)
(Organic) Knowledge may be located at the ad hoc center in the network.	36 (51.4)	34 (48.6)	70 (100.0)
Total	97	52	149

Phi coefficient = 0.256, chi-square = 9.76, $P < 0.01$.

Table 6. Summary of Cross-Tabulations by Organization Structures and Characteristics of Management Systems for High-Performers.

Item number[a]	Phi coefficient	Chi-square[b]		
1	0.263	10.29	**	(149)
2	0.300	13.45	***	(149)
3	0.427	27.36	***	(150)
4	0.256	9.76	**	(149)
5	0.298	13.12	***	(148)
6	0.110	1.82		(149)
7	0.133	2.61		(147)
8	0.207	6.28	*	(147)
9	0.078	0.90		(147)

[a] Item numbers correspond to those given in Table 1. Items 1 through 4 indicate the characteristics of our management systems.

[b] Chi-square tests (the numbers of effective samples are within parentheses).

+ Significant at level 0.1.

* Significant at level 0.05.

** Significant at level 0.01.

*** Significant at level 0.001.

4.4 Organization Structures under Uncertainty

In the previous section, we analyze the organization structures and management systems in all industries, but unfortunately we could not develop the instruments for measuring uncertainty for the non-manufacturing industry. Then in this section and the next section, we restrict the analysis of the relationship between organizational design and uncertainty within the manufacturing industry.

To test Hypothesis 1, we use the categories of "high-performers" and "low-performers." The validities of these categories have been checked by the analysis of financial indicators in Section 4.2. Using the categories of high-performers and low-performers, Tables 7 and 8 compare the mean numbers of REVAMP and LIFE for different organization structures. The data are analyzed by a two-way analysis of variance of "organization structure" (pyramid organization, matrix organization) and "performance level" (high-performer, low-performer), and the results are indicated in Table 8. For LIFE, no significant effects are found. But for REVAMP, the matrix organizations are confronted with significantly greater revamping cycles than the pyramid organizations at level 0.05, and the high-performers are confronted with significantly less revamping cycles than the low-performers at level 0.05. Furthermore, we find the significant interactions of "organization structure" and "performance level" at level 0.1.

The estimates of these interactions for REVAMP are indicated in Table 9. The signs of these interactions support our Hypothesis 1, that is, the high performing pyramid organizations and the low performing matrix organizations are confronted with significantly greater revamping cycles than the others.

Thus, Tables 8 and 9 support our Hypothesis 1, and the validity of Proposition 1 is checked through this empirical research on a case of Japanese firms.

Table 7. Mean Numbers of REVAMP and LIFE for Different Organization Structures.

Organization structure	Performance level					
	High-performer			Low-performer		
	Mean	S.D.		Mean	S.D.	
REVAMP:						
Pyramid organization	8.56	4.45	(52)	8.80	3.94	(46)
Matrix organization	8.90	3.67	(29)	11.92	4.64	(26)
LIFE:						
Pyramid organization	16.46	28.40	(50)	14.20	23.36	(46)
Matrix organization	11.36	18.28	(28)	13.83	19.07	(24)

(The numbers of effective samples are within parentheses.)

Table 8. A Two-Way Analysis of Variance of "Organization Structure" and "Performance Level."

	Organization structure[a]	Performance level[a]	Interaction[a]
REVAMP	5.98 *	5.34 *	3.83 +
LIFE	0.44	0.00	0.33

[a] F-tests.

+ Significant at level 0.1.

* Significant at level 0.05.

Table 9. Two-Way Analysis of Variance Significant Interactions of "Organization Structure" and "Performance Level" for REVAMP.

Organization structure	Performance level	
	High-performer	Low-performer
Pyramid organization	0.473	-0.532
Matrix organization	-0.842	0.933

$F(1,149)=3.83$; $P<0.1$.

4.5 Management Systems under Uncertainty

Using the categories of high-performers and low-performers, Tables 10 and 11 compare the mean numbers of REVAMP and LIFE for different characteristics of Burns and Stalker's (1961) management systems. Items 1 through 4 indicate the characteristics of our management systems. The data are analyzed by the two-way analysis of variance of "characteristic of management systems" and "performance level," and the results are indicated in Table 11. For REVAMP, the low-performers are confronted with significantly greater revamping cycles than the high-performers except for the characteristic of item number 9. But for LIFE, these significant effects cannot be found.

We find the significant interactions of "characteristic of management systems" and "performance level" in items 2 and 3 for REVAMP and items 4 and 6 for LIFE. The estimates of these interactions in Table 12 (A), (B), (C) and (D). The signs of the interactions in (A), (B) and (C) support our Hypothesis 2, that is, the high performing mechanistic systems and the low performing organic systems are confronted with significantly greater revamping cycles or life cycles than the others for items 2, 3 and 4. But the signs of the interactions in (D) (item 6) are exactly converse. This sixth item has no direct relationship to our management systems as discussed in Section 3.4.

Thus these results support our Hypothesis 2. Conversely, these significant interactions can be found only for items 2, 3 and 4, which have direct relationship to our management systems.

The other characteristics of Burns and Stalker's (1961) management systems are not supported by our empirical research. Therefore the validity of our modeling of management systems on items 1 through 4 basis is shown as also shown in Section 4.3.

Table 10. Mean Numbers of REVAMP and LIFE for Different Characteristics of Management Systems.

(A) REVAMP

Characteristic of management systems (Item number[a])		Performance level					
		High-performer			Low-performer		
		Mean	S.D.		Mean	S.D.	
1	(a)	8.30	4.10	(64)	9.47	4.26	(60)
	(b)	10.12	4.24	(17)	12.50	4.56	(12)
2	(a)	9.04	4.48	(55)	9.47	4.13	(57)
	(b)	8.04	3.40	(25)	11.56	5.10	(16)
3	(a)	8.81	4.25	(58)	9.36	4.30	(58)
	(b)	8.35	4.02	(23)	12.13	4.26	(15)
4	(a)	8.71	4.11	(41)	9.13	4.00	(45)
	(b)	8.65	4.28	(40)	11.31	4.96	(26)
5	(a)	8.86	4.43	(56)	9.68	4.24	(60)
	(b)	8.28	3.55	(25)	10.75	5.23	(12)
6	(a)	7.95	3.22	(20)	10.19	4.23	(32)
	(b)	8.92	4.43	(61)	9.73	4.58	(41)
7	(a)	9.56	4.70	(48)	9.83	4.69	(52)
	(b)	7.38	2.88	(32)	9.95	3.62	(20)
8	(a)	8.47	4.17	(55)	9.80	4.61	(50)
	(b)	9.12	4.21	(26)	10.57	3.87	(21)
9	(a)	8.73	4.07	(60)	9.95	4.43	(62)
	(b)	8.63	4.69	(19)	9.80	4.73	(10)

(B) LIFE

Characteristic of management systems (Item number[a])		Performance level					
		High-performer			Low-performer		
		Mean	S.D.		Mean	S.D.	
1	(a)	14.63	25.92	(62)	11.61	17.31	(59)
	(b)	14.63	23.14	(16)	18.73	27.97	(11)
2	(a)	18.00	30.10	(52)	14.20	24.42	(55)
	(b)	7.92	6.52	(25)	13.27	7.48	(15)
3	(a)	16.77	28.94	(57)	15.28	23.97	(57)
	(b)	8.81	7.50	(21)	8.50	4.99	(14)
4	(a)	17.44	27.87	(41)	10.47	14.75	(43)
	(b)	11.51	21.90	(37)	19.62	29.97	(26)
5	(a)	16.57	27.40	(54)	14.88	24.04	(57)
	(b)	10.25	19.30	(24)	9.38	4.87	(13)
6	(a)	10.16	8.76	(19)	20.12	30.32	(33)
	(b)	16.07	28.50	(59)	8.58	5.76	(38)
7	(a)	19.09	31.76	(46)	16.36	25.35	(50)
	(b)	8.42	6.72	(31)	8.10	5.27	(20)
8	(a)	15.98	27.66	(53)	11.82	19.03	(49)
	(b)	11.76	19.28	(25)	19.53	28.62	(19)
9	(a)	17.52	28.70	(58)	15.10	23.60	(59)
	(b)	6.11	2.97	(18)	6.90	2.85	(10)

[a] Item numbers correspond to those given in Table 1. Items 1 through 4 indicate the characteristics of our management systems.

(The numbers of effective samples are within parentheses.)

Table 11. A Two-Way Analysis of Variance of "Characteristic of Management Systems" and "Performance Level."

Item number[a]		Characteristic of management system[b]	Performance level[b]	Interaction[b]
REVAMP:	1	7.61 **	4.08 *	0.48
	2	0.48	6.25 *	3.80 +
	3	2.05	7.24 **	4.03 *
	4	2.22	4.72 *	2.47
	5	0.08	3.74 +	0.93
	6	0.12	4.13 *	0.90
	7	1.95	3.68 +	2.44
	8	0.88	3.39 +	0.01
	9	0.02	1.63	0.00
LIFE:	1	0.53	0.01	0.53
	2	1.50	0.03	1.04
	3	2.54	0.04	0.02
	4	0.16	0.02	3.59 +
	5	1.61	0.08	0.01
	6	0.46	0.09	4.42 *
	7	5.25 **	0.14	0.09
	8	0.16	0.17	1.90
	9	3.60 +	0.03	0.10

[a] Item numbers correspond to those given in Table 1. Items 1 through 4 indicate the characteristics of our management systems.

[b] F-tests (+ $P<0.1$; * $P<0.05$; ** $P<0.01$; *** $P<0.001$).

Table 12. Two-Way Analysis of Variance Significant Interactions of "Characteristic of Management System" and "Performance Level."

(A) REVAMP

Characteristics of management systems (Item number = 2)	Performance level	
	High-performer	Low-performer
(Mechanistic) A direction of communication through the organization is vertical rather than lateral.	0.353	-0.416
(Organic) A direction of communication through the organization is lateral rather than vertical.	-0.799	1.517

$F(1,149)=3.80$; $P<0.1$.

(B) REVAMP

Characteristics of management systems (Item number = 3)	Performance level	
	High-performer	Low-performer
(Mechanistic) Communication structure is hierarchical.	0.318	-0.383
(Organic) Communication structure is network.	-0.901	1.632

$F(1,150)=4.03$; $P<0.05$.

(C) LIFE

Characteristics of management systems (Item number = 6)	Performance level	
	High-performer	Low-performer
(Mechanistic) Knowledge is exclusively located at the top of hierarchy.	3.23	-3.02
(Organic) Knowledge may be located anywhere in the network.	-3.68	5.14

F(1,143)=3.59; P<0.1.

(D) LIFE

Characteristics of management systems (Item number = 4)	Performance level	
	High-performer	Low-performer
(Mechanistic) The specialized tasks are performed by functionaries, as ends in themselves.	-6.65	4.00
(Organic) The individual task is seen as set by total situation of the firm.	2.61	-4.20

F(1,145)=4.42; P<0.05.

CHAPTER 5 SUMMARY: CONTINGENCY ORGANIZATIONS

In this paper, we consider the design problem of an organization whose choice process of the task is formulated as the sequential decision process in the conceptual framework of management and organization theory. The organization design is represented by a combination of the organization structure and the management system, and constitutes a part of the sequential decision model of the task. Two types of management systems, the mechanistic system and the organic system, are defined as the communication systems of the observation process on the environment, and two types of organization structures, the pyramid organization and the matrix organization, are defined as the systems of task assignment.

We consider the organization composed of three layers: the top leader; the managers; the unit organizations. Each manager is in a specific position and counsels the top leader on overall organizational project. The matrix organization is defined as an organization in which at least two managers stand in the line authority positions, whereas, in the pyramid organization, each unit organization is to implement a task of a single manager.

There exists uncertainty about the state of the environment, and the same task can result in different outcomes depending on it. The situation of the top leader might be greatly improved by introducing the observation process on the environment in advance of the decision on the task assignment. In our model, each manager can take the observation on the state of the environment through the unit organizations and communicate it if necessary. The top leader has two alternative procedures to collect managers' observations: (1) The top leader directly collects managers' observations; (2) A manager is delegated the right to collect the observations of the other managers and of himself and reports to the top leader. Two management systems, the mechanistic system and the organic system, are defined as communication systems corresponding to these two procedures to collect observations, respectively. The decision process is formulated as the sequgential decision process.

We apply the methodology of the statistical decision theory to the organizational design problems. We classify "uncertainty" into three categories: certainty, risk and uncertainty. Using these three categories, we obtain the results that have the following managerial implications: (a) If the organization is confronted with the case of certainty or risk, then the pyramid organization is efficient; (b) If the organization is confronted with the case of certainty, then the mechanistic system is efficient. If it is confronted with the case of risk, then the mechanistic system is efficient under low uncertainty and the organic system is efficient under high uncertainty; (c) The pyramid organization is efficient if the mechanistic system is efficient.

These managerial implications may be orthodox in organization and contingency theory. In fact, these results partially support some preceding contingency theoretic statements on organizational design: the result (a) partially supports Davis and Lawrence's (1977) statement and (b) supports Burns and Stalker's (1961) statement. But the implications of decision theory are expected to be orthodox since the basic mechanisms of organizations are familiar to the structure of the model in decision theory as discussed in Chapters 1 and 2. By showing a decision theoretic perspective of organization design under uncertainty, this paper advances understanding of the organization design problems and organization theory.

To test these results, the study focused on the organization structures and the management systems of Japanese firms. Our empirical research supports our theoretic results.

We obtain the above results on the following fundamental assumptions: (1) The top leader can choose a mixed task, i.e., the managers agree on sharing the unit organizations with other managers and each unit organization has the ability to implement any manager's task; (2) The top leader and the managers share the same subjective probability distribution over the states of environment if it exists, and share the same loss function associated with a pure task.

We refer to fundamental assumption (1) as the <u>acceptability of mixed tasks</u> and fundamental assumption (2) as the <u>existence of the management team</u>, where the group of the top leader and the managers who share the same prior distribution and the same loss function is called the <u>management team</u>. The management "team" is named in accordance with Marschak and Radner's (1972) definition of the team: an organization whose members have the same interests and beliefs.

As stated in our propositions, the efficient organizational design depends on the environment. But our design problem is only meaningful on the above fundamental assumptions. The organization satisfying these fundamental assumptions is called the contingency organization.

If the organization does not satisfy the fundamental assumption (1), then it has no opportunity to be the matrix organization and must be the pyramid organization. If it does not satisfy (2), Theorem 1 (the separation theorem) does not hold and it is impossible to delegate the authority of the observation center to a manager, and the organization has no opportunity to be the organic system, that is, it must be the mechanistic system. If neither of the fundamental assumptions (1) and (2) are satisfied, the organization must use the pyramid organization structure and the mechanistic system, and it is called a bureaucratic organization which is an only organization model in the classical organization theory.

Use of the contingency organization expands the opportunity of choice for the top leader in comparison with the bureaucratic organization. The matrix organization and the organic system are alternative design permitted only in the contingency organization. Thus the contingency organization has greater opportunity for taking an appropriate organization design than the others. Therefore the contingency organization is "efficient" although the efficient organization structure and management system depends on the environment.

In Table 1, items 5 through 9 of the characteristics of Burns and Stalker's (1961) management systems do not have direct relationship to our management systems and for these items our empirical research could not find any tendencies under uncertainty expected by Burns and Stalker (Section 4.5). But some of these items have relationship to the contingency organization, especially the existence of the management team. Items 5 through 7 in Table 1 represent the necessary condition that the management team exists, that is, if there exists the management team, then members contribute their special knowledge and experience to the common task of the firm (item 5); the individual task is seen as set by total situation of the firm (item 6); problems may not be posted as being someone else's responsibility, then commitment to the firm and task goes beyond any technical definition (item 7). Therefore, their concept of management systems consists of two types of characteristics. Items 1 through 4 have direct relationship to our management systems, whereas items 5 through 7 have relationship to the contingency organization.

There is not the one best way of organizing, but there is a class of organizations which enable the top leader to choose the best way of organizing, that is, a class of the contingency organizations. Burns and Stalker (1961) and Davis and Lawrence (1977) respectively considered the organic system and the matrix organization in order to enlarge the opportunities for taking an appropriate organization design. They substantially meant the "contingency" design of the organization. I appreciate Burns and Stalker (1961) and Davis and Lawrence (1977) by reason of their constructive suggestions about the contingency organizations.

APPENDIX A MATHEMATICAL APPENDIX

A.1 Counterexample

Ferguson (1967) and DeGroot (1970) assumed that

$$P\{N<\infty\}=\lim_{n\to\infty} P\{N\leq n\}$$
$$=\sum_{j=0}^{\infty} E\{Q_j(Z_1,\dots,Z_j)\mid w_0\}=1 \qquad (1)$$

to obtain a finite expected information cost. But this assumption is not sufficient as illustrated by the following counterexample: We consider the stopping rule $q=(q_0,q_1(z_1),\dots)$ defined as

$$q_j(z_1,\dots,z_j)=\begin{cases}1/2 & \text{for } j=2^n,\ n=0,1,2,\dots\\ 0 & \text{otherwise.}\end{cases}$$

Therefore we obtain

$$Q_j(z_1,\dots,z_j)=\begin{cases}1/2^{n+1} & \text{for } j=2^n,\ n=0,1,2,\dots\\ 0 & \text{otherwise,}\end{cases}$$

and

$$\sum_{j=0}^{\infty} E\{Q_j(Z_1,\dots,Z_j)\mid w_0\}=\sum_{n=0}^{\infty} 1/2^{n+1}=1.$$

Now we calculate the expectation of the random stopping time N,

$$EN=\sum_{j=0}^{\infty} j\,E\{Q_j(Z_1,\dots,Z_j)\mid w_0\}=\sum_{n=0}^{\infty} 2^n/2^{n+1}=\sum_{n=0}^{\infty} 1/2.$$

Then EN is infinite, that is, the expected information cost $E\{NC_k(I)+C_k(S)|w_0\}$ is infinite.

Remark. This counter example shows that equation (1) is not a sufficient condition that the expected information cost be finite. We shall prove the necessity of condition (1). We first note that

$$\sum_{j=0}^{\infty} E\{Q_j(Z_1,\ldots,Z_j)|w_0\}=\lim_{n\to\infty} P\{N\leqq n\}=1-\lim_{n\to\infty} P\{N\geqq n+1\}$$

and

$$P\{N\geqq n+1\}\leqq\sum_{j=n+1}^{\infty} jP\{N=j\}=\sum_{j=0}^{\infty} jP\{N=j\}-\sum_{j=0}^{n} jP\{N=j\}$$

Since the expected information cost is finite, EN is finite and

$$0\leqq\lim_{n\to\infty} P\{N\geqq n+1\}\leqq EN-EN=0$$

Then

$$\sum_{j=0}^{\infty} E\{Q_j(Z_1,\ldots,Z_j)|w_0\}=1$$

which completes the proof. Therefore, equation (1) is a necessary condition that the expected information cost be finite. On the assumption that EN is finite, we can prove the existence of an optimal stopping rule. A proof of this result crucially depends on this assumption, and it can be found in the proof of Lemma 3 of theorem 4.

A.2 Proof of Theorem 1

By definition, risk may be written as

$$r_k(w_0,(q,d))=\sum_{j=0}^{\infty}E\{Q_j(Z_1,\ldots,Z_j)L(U,d_j(Z_1,\ldots,Z_j))\}$$
$$+\sum_{j=0}^{\infty}E\{Q_j(Z_1,\ldots,Z_j)[jC_k(I)+C_k(S)]\}. \qquad (1)$$

Because both w_0 and q are given, we may minimize (1) by choosing d_j for each j to minimize

$$E\{Q_j(Z_1,\ldots,Z_j)L(U,d_j(Z_1,\ldots,d_j))\}$$
$$=E\{Q_j(Z_1,\ldots,Z_j)E\{L(U,d_j(Z_1,\ldots,d_j))|Z_1,\ldots,Z_j\}\}$$

which may be minimized by choosing d_j to minimize

$$E\{L(U,d_j(Z_1,\ldots,d_j))|Z_1,\ldots,Z_j\},$$

that is, the Bayes terminal decision function with respect to w_0. If these Bayes terminal decision functions are denoted by d_j^*, j=0,1,2,..., then $d^*=(d_0^*,d_1^*,d_2^*,\ldots)$ clearly minimizes $r_k(w_0,(q,d))$, which proves the theorem.

Remark. This theorem agrees with Bellman's principle of optimality (Bellman 1957): In a multistage decision process, an optimal policy has the property that whatever the initial state and decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision. This principle underlies the concept of dynamic programming.

A.3 Proof of Lemma 1

Since d_j* is Bayes terminal decision function with respect to w_0,

$$E\{L(U,d_j(z_1,\ldots,z_j))|Z_1=z_1,\ldots,Z_j=z_j\}$$
$$=\sum_i w_j(u_i)L(u_i,d_j*(z_1,\ldots,z_j))$$
$$=\sum_k f_k*\sum_i w_j(u_i)L(u_i,a_k)$$
$$\leqq\sum_i w_j(u_i)L(u_i,a) \quad \text{for all } a\in A'$$

where $d_j*(z_1,\ldots,z_j)=(f_1*,\ldots,f_m*)$. Suppose that

$$E\{L(U,d_j(z_1,\ldots,z_j))|Z_1=z_1,\ldots,Z_j=z_j\}<\sum_i w_j(u_i)L(u_i,a)$$

for all $a\in A'$, then by definition

$$E\{L(U,d_j(z_1,\ldots,z_j))|Z_1=z_1,\ldots,Z_j=z_j\}$$
$$<\sum_k f_k*\sum_i w_j(u_i)L(u_i,a_k)$$
$$=E\{L(U,d_j(z_1,\ldots,z_j))|Z_1=z_1,\ldots,Z_j=z_j\}$$

which is impossible. Thus, there exists a $a_k\in A'$ such that

$$\sum_i w_j(u_i)L(u_i,d_j*(z_1,\ldots,z_j))=\sum_i w_j(u_i)L(u_i,a_k).$$

This implies that there exists a pure Bayes terminal decision function d_j, which chooses a_k if $Z_1=z_1,\ldots,Z_j=z_j$, thus completing the proof.

A.4 Proof of Theorem 3

We first define $r_k^1(W(z;w_0),(q,d))$ as in Theorem 5, which represents the risk of the decision process to start when the first organizational observation has been observed and the state of decision process is $w_1=W(z_1;w_0)$, given that (q,d) is being used.

Let d^* be as in Theorem 1 and let q be any arbitrary stopping rule. From Theorem 2,

$$r_k(w_0,(q,d^*))=q_0B_k(w_0) \\ +(1-q_0)E\{r_k^1(W(Z_1;w_0),(q,d^*))|w_0\}.$$

From the definition of V_k, it follows that

$$r_k^1(W(z_1;w_0),(q,d^*))\geq V_k(W(z_1;w_0))+C_k(I) \quad \text{for all } z_1$$

and hence that

$$\begin{aligned} r_k(w_0,(q,d^*)) &\geq q_0B_k(w_0)+(1-q_0)[E\{V_k(W(Z_1;w_0))|w_0\}+C_k(I)] \\ &\geq q_0\min[B_k(w_0);\ E\{V_k(W(Z_1;w_0))|w_0\}+C_k(I)] \\ &\quad +(1-q_0)\min[B_k(w_0);\ E\{V_k(W(Z_1;w_0))|w_0\}+C_k(I)] \\ &\geq \min[B_k(w_0);\ E\{V_k(W(Z_1;w_0))|w_0\}+C_k(I)], \end{aligned}$$

which implies that

$$\begin{aligned} V_k(w_0) &= \inf_{(q,d)} r_k(w_0,(q,d)) \\ &\geq \min[B_k(w_0);\ E\{V_k(W(Z_1;w_0))|w_0\}+C_k(I)]. \end{aligned} \tag{1}$$

Now we consider following two cases:

(a) If $B_k(w_0)=\min[B_k(w_0);\ E\{V_k(W(Z_1;w_0))|w_0\}+C_k(I)]$ and let q be the stopping rule that takes no more observations: $q_0=1$, then

$$V_k(w_0)=B_k(w_0)$$
$$=\min[B_k(w_0);\ E\{V_k(W(Z_1;w_0))|w_0\}+C_k(I)]. \qquad (2)$$

(b) If $E\{V_k(W(Z_1;w_0))|w_0\}+C_k(I)$

$=\min[B_k(w_0);\ E\{V_k(W(Z_1;w_0))|w_0\}+C_k(I)]$,

we consider the process following a stopping rule q such that

$$r_k^{\,1}(W(z_1;w_0),(q,d^*))\leqq V_k(W(z_1;w_0))+\varepsilon \quad \varepsilon>0 \text{ for all } z_1,$$

and $q_0=0$. Hence

$$r_k(w_0,(q,d^*))=E\{r_k^{\,1}(W(Z_1;w_0),(q,d^*))\,|w_0\}+C_k(I)$$
$$\leqq E\{V_k(W(Z_1;w_0))|w_0\}+C_k(I)+\varepsilon.$$

Since $V_k(w_0)\leqq r_k(w_0,(q,d^*))$,

$$V_k(w_0)\leqq E\{V_k(W(Z_1;w_0))|w_0\}+C_k(I)+\varepsilon$$
$$=\min[B_k(w_0);\ E\{V_k(W(Z_1;w_0))|w_0\}+C_k(I)]+\varepsilon.$$

Since ε is arbitrary,

$$V_k(w_0)\leqq\min[B_k(w_0);\ E\{V_k(W(Z_1;w_0))|w_0\}+C_k(I)]. \qquad (3)$$

From (1), (2) and (3), the result then follows.

A.5 Proof of Theorem 4

We consider an alternative stopping rule: $b=(b_0(w_0),b_1(w_1),\ldots)$, where $b_j(w_j)$ represents the conditional probability of stopping after the j-th observation and then the posterior distribution $w_j=W_j(z_1,\ldots,z_j)$, given that $Z_1=z_1,\ldots,Z_j=z_j$. The functions q and b are related by the formula:

$$b_j(W_j(z_1,\ldots,z_j))=q_j(z_1,\ldots,z_j),$$

that is, q_j is the composition of b_j and W_j. Therefore, in order to obtain the optimal q, it is sufficient to get the optimal b.

A stopping rule b is said to be <u>stationary</u> if the action it chooses at j only depends on the posterior distribution at j, that is, $b_0(w)=b_1(w)=b_2(w)=\ldots$ for all w.

The <u>state space of the decision process</u> is denoted by S and

$$S=\{w=(w(u_1),\ldots,w(u_s)): \sum_i w(u_i)=1,\ w(u_i)\geq 0,\ i=1,\ldots,s\}$$

Hence, S is the (s-1)-dimensional simplex spanned by the unit vectors in Euclidean s-space. Let N(S) denote the set of all nonnegative functions on the state space S. To prove this theorem, we use the following mapping. For any stationary stopping rule $b=(b(w_0),b(w_1),\ldots)$ and d*, T_b that maps N(S) into N(S) is defined in the following manner:

$$(T_b v_k)(w)=b(w)B_k(w)+(1-b(w))[E\{v_k(W(Z;w))|w\}+C_k(I)]. \quad (1)$$

For a function $v_k\in N(S)$, $T_b v_k$ is the function whose value at state w is given by (1). We use the following notation: Let $T_b^1 = T_b$ and let $T_b^j = T_b(T_b^{j-1})$.

Before we prove this theorem, we require the following lemmas, which provide important properties of T_b.

<u>Lemma 2</u>. If $v_k(w) \leqq v_k'(w)$ for all w, then

$(T_b v_k)(w) \leqq (T_b v_k')(w)$ for all w.

<u>Proof</u>. By definition,

$$\begin{aligned}(T_b v_k)(w) &= b(w)B_k(w)+(1-b(w))[E\{v_k(W(Z;w))|w\}+C_k(I)] \\ &\leqq b(w)B_k(w)+(1-b(w))[E\{v_k'(W(Z;w))|w\}+C_k(I)] \\ &= (T_b v_k')(w) \qquad \text{for all } w\end{aligned}$$

completing the proof.

<u>Lemma 3</u>. Let 0 represent the function which is identically zero, and let $b=(b(w_0),b(w_1),\ldots)$ be a stationary stopping rule defined as follows:

$$b(w_j)=\begin{cases}1 & \text{if } B_k(w_j)<E\{V_k(W(Z_{j+1};w_j))|w_j\}+C_k(I) \\ \text{any} & \text{if } B_k(w_j)=E\{V_k(W(Z_{j+1};w_j))|w_j\}+C_k(I) \\ 0 & \text{if } B_k(w_j)>E\{V_k(W(Z_{j+1};w_j))|w_j\}+C_k(I)\end{cases}$$

Then

$$\lim_{n\to\infty}(T_b^n 0)(w)=V_k'(w) \qquad \text{for all } w.$$

Proof. We first note that

$$(T_b{}^2 0)(w)$$
$$=b(w)B_k(w)+(1-b(w))[E\{(T_b0)(W(Z;w))|w\}+C_k(I)]$$
$$=b(w)B_k(w)$$
$$+(1-b(w))[E\{b(W(Z;w))B_k(W(Z;w))+(1-b(W(Z;w)))C_k(I)|w\}+C_k(I)]$$
$$=b(w)B_k(w)$$
$$+(1-b(w))E\{b(W(Z;w))[B_k(W(Z;w))+C_k(I)]|w\}$$
$$+(1-b(w))E\{(1-b(W(Z;w))2C_k(I)|w\}$$
$$=Q_0'B_k(w)+E\{Q_1'(Z)[B_k(W(Z;w))+C_k(I)]|w\}$$
$$+[1-Q_0'-E\{Q_1'(Z)|w\}]2C_k(I),$$

where $(Q_0',Q_1',\ldots)$ corresponds to the stopping rule q'. A simple induction argument then shows that

$$(T_b{}^n 0)(w)=\sum_i w(u_i)\sum_{j=0}^{n-1}E\{Q_j'(Z_1,\ldots,Z_j)$$
$$\times[L(u_i,d_j{}^*(Z_1,\ldots,Z_j))+jC_k(I)+C_k(S)|U=u_i\}$$
$$+[1-\sum_{j=0}^{n-1}E\{Q_j'(Z_1,\ldots,Z_j)|w\}]nC_k(I),$$

where $1-\sum_{j=0}^{n-1}E\{Q_j'(Z_1,\ldots,Z_j)|w\}=P\{N\geq n\}$, and

$$\sum_{j=n}^{\infty}jP\{N=j\}=\sum_{j=0}^{\infty}jP\{N=j\}-\sum_{j=0}^{n-1}jP\{N=j\}.$$

From the assumption that EN is finite,

$$\lim_{n\to\infty}\sum_{j=n}^{\infty}jP\{N=j\}=\sum_{j=0}^{\infty}jP\{N=j\}-\sum_{j=0}^{\infty}jP\{N=j\}=EN-EN=0.$$

Then we have

$$0\leq\lim_{n\to\infty}nP\{N\geq n\}=\lim_{n\to\infty}\sum_{j=n}^{\infty}nP\{N=j\}$$
$$\leq\lim_{n\to\infty}\sum_{j=n}^{\infty}jP\{N=j\}=0.$$

Therefore

$$\lim_{n\to\infty}(T_b{}^n 0)(w)=r_k(w,(q',d^*))=V_k'(w)$$

which completes the proof of the lemma.

We now return to the proof of the theorem. Let b as in Lemma 3. By applying T_b to V_k, we obtain

$$\begin{aligned}(T_bV_k)(w) &= b(w)B_k(w)+(1-b(w))[E\{V_k(W(Z;w))|w\}+C_k(I)] \\ &= \min[B_k(w);E\{V_k(W(Z;w))|w\}+C_k(I)] \\ &= V_k(w) \quad \text{for all } w.\end{aligned}$$

Now, by definition, $L(u_i,a)\geqq 0$ and $C_k(I)$, $C_k(S)\geqq 0$, which implies that $V_k(w)\geqq 0$, and hence we obtain using Lemma 2

$$(T_b0)(w)\leqq(T_bV_k)(w)=V_k(w) \quad \text{for all } w,$$

and by successively applying T_b,

$$(T_b{}^n 0)(w)\leqq V_k(w) \quad \text{for all } w.$$

Therefore, from Lemma 3

$$\lim_{n\to\infty}(T_b{}^n 0)(w)=V_k'(w)\leqq V_k(w) \quad \text{for all } w.$$

By definition, $V_k(w)\leqq V_k'(w)$, then

$$V_k'(w)=V_k(w) \quad \text{for all } w,$$

thus completing the proof.

A.6 Proof of Theorem 5

The proof uses the following lemma.

Lemma 2. For any prior distribution w,

$$E\{V_1(W(Z_1;w))|w\}+C_1(I)\geq E\{V_2(W(Z_1;w))|w\}+C_2(I).$$

Proof. We define

$$r_k^{\,1}(W(z_1;w_0),(q,d))=\sum_{i=1}^{s}W_1(u_i|z_1)\sum_{j=1}^{\infty}E\{Q_j^{\,1}(z_1,Z_2,\ldots,Z_j)$$
$$\times[L(u_i,d_j(z_1,Z_2,\ldots,Z_j))+jC_k(I)+C_k(S)]|Z_1=z_1,U=u_1\}$$

where

$$Q_j^{\,1}(z_1,\ldots,z_j)$$
$$=(1-q_1(z_1))\ldots(1-q_{j-1}(z_1,\ldots,z_{j-1}))q_j(z_1,\ldots,z_j).$$

Let (q^*,d^*) be the 1-optimal decision rule with respect to a prior distribution w, then

$$E\{r_1^{\,1}(W(Z_1;w),(q^*,d^*))|w\}=E\{V_1(W(Z_1;w))+C_1(I)|w\}.$$

From Assumption 1,

$$C_1(S)<C_2(S),$$
$$jC_1(I)+C_1(S)\geq jC_2(I)+C_2(S),\ j=1,2,\ldots$$

Then we obtain

$$r_2^{\,1}(W(z_1;w),(q^*,d^*))\leq r_1^{\,1}(W(z_1;w),(q^*,d^*))\quad \text{for all } z_1.$$

Hence

$$E\{V_2(W(Z_1;w))+C_2(I)|w\} \leq E\{r_2{}^1(W(Z_1;w),(q^*,d^*))|w\}$$
$$\leq E\{r_1{}^1(W(Z_1;w),(q^*,d^*))|w\}$$
$$=E\{V_1(W(Z_1;w))+C_1(I)|w\}$$

completing the proof of the lemma.

Proof of Theorem 5. From the definition of risk, we have

$$S^*=\{w\in S:\ \min[B_1(w);\ E\{V_1(W(Z_1;w))|w\}+C_1(I)] \leq \min[B_2(w);\ E\{V_2(W(Z_1;w))|w\}+C_2(I)]\}$$

and from Lemma 2, it is shown that

$$S^*=\{w\in S:\ B_1(w)\leq \min[B_2(w);\ E\{V_2(W(Z_1;w))|w\}+C_2(I)]\}.$$

On the other hand, by definition

$$B_1(w)=\min_j R_j(w).$$

Hence,

$$S^*=\{w\in S:\ \min_j R_j(w)\leq V_2(w)\}$$
$$=\cup_{j=1}^{m}\{w\in S:\ R_j(w)\leq V_2(w)\}$$
$$=\cup_{j=1}^{m} S_j{}^*$$

and the theorem is proved.

A.7 Example of Empty S_j*

We first show the simple example of empty S_j*.

Example. To illustrate the case that $S_j*=\phi$ for some j, we add the manager 3 to Example 2, who recommends a_3 with the loss function

$$L(u_1,a_3)=50,\ L(u_2,a_3)=50.$$

The new organizational observation $Z_j=(X_{j1},X_{j2},X_{j3})$ is assumed to have the conditional probability function $p(\cdot|u_i)$ as defined by

$$p((i,j,k)|u_1)=\begin{cases}1 & \text{if } i=j=k=1\\ 0 & \text{otherwise}\end{cases}$$

where the sample space of X_{j3} is $S_{Xj3}=\{1,2\}$.

Information cost c_I, c_T and c_M are same ones as before. Then

$$C_1(I)=15,\ C_1(S)=0,$$
$$C_2(I)=11,\ C_2(S)=2.$$

By definition

$$R_3(w)=50 \quad \text{for all } w,$$
$$V_2(w)=\min[100(1-w)+2;\ 100w+2;\ 0+2+11].$$

Then for all w

$$R_3(w)>V_2(w).$$

From the definition of S_j*, we obtain $S_3*=\phi$.

Remark. If $S_j^*=\phi$, then the task a_j will not be chosen by the top leader and the manager j is always a null manager. Therefore such a manager j with $S_j^*=\phi$ is called an absolutely null manager. Generally speaking, if the organization has an absolutely null manager, he is the best candidate for the observation center since he can act the "neutral" in the process of task assignment and power distribution.

A necessary and sufficient condition that a manager j be an absolutely null manager is given by the following theorem.

Theorem A.1. S_j^* is empty if and only if for all u,

$$L(u,a_j) > \min_a L(u,a)+C_2(S) \tag{1}$$

Proof. To prove this theorem we need the following lemma.

Lemma 1. S_j^* is empty if and only if $e_i \notin S_j^*$ for all e_i.

Proof. Necessity is contraposition of Theorem 7 (a), and sufficiency is obvious.

We now return to the proof of Theorem A.1.

(a) Necessity: We first note that

$$\begin{aligned} V_2(e_i) &= \min[B_2(e_i);\ V_2(e_i)+C_2(I)] \\ &= B_2(e_i) \\ &= \min_a L(u_i,a)+C_2(S) \end{aligned} \tag{2}$$

$$R_j(e_i)=L(u_i,a_j). \tag{3}$$

Assume that (1) holds. From (2) and (3), we obtain

$$R_j(e_i) > V_2(e_i)$$

for all e_i. From Lemma 1 and the definition of S_j^* (in Theorem 5), S_j^* is empty.

(b) Sufficiency: Assume that S_j^* is empty. Then from Lemma 1, $e_i \notin S_j^*$ for all e_i. Thus from the definition of S_j^*, we have

$$R_j(e_i) > V_2(e_i)$$

for all e_i. From (2) and (3), we obtain for all u_i

$$L(u_i, a_j) > \min_a L(u_i, a) + C_2(S)$$

which completes the proof of the theorem.

Remark. A task a_j is called neutral for the states of the environment if it satisfies (1). The manager chooses an organizational activity as a task which is preferred from his departmental perspective. A neutral task for the states of the environment will most probably be chosen by a manager of a service department since it is a facilitating, auxiliary and support department whose objective is most likely to be expense savings almost independent of the state of the environment (typical service departments are personnel, accounting, statistical reports, electronic data processing, and typing pools). The managers of the service departments likely become absolutely null managers or "absolutely staffs" (cf. the remark of Definition 1), then the service departments are often thought of as "staff" departments although service departments are essentially a grouping of activities which might be carried on in other departments but are brought together in a specialized department for purposes of efficiency (cf. Koontz, O'Donnell and Weihrich 1980, pp.374-375).

A.8 Proof of Theorem 6

For any e_r, there exists j such that $R_j(e_r)=\min_i R_i(e_r)$. Then, by definition,

$$B_k(e_r)=R_j(e_r)+C_k(S).$$

Since $W(z;e_i)=e_i$ for any e_i and z, we have from Theorem 3,

$$\begin{aligned} V_k(e_r) &= \min[B_k(e_r); E\{V_k(W(Z;e_r))|e_r\}+C_k(I)] \\ &= \min[B_k(e_r); V_k(e_r)+C_k(I)] \\ &= B_k(e_r) \\ &= R_j(e_r)+C_2(S) \\ &> R_j(e_r) \end{aligned}$$

Thus $e_r \in S_j^*$. Hence, for any e_r, there exists S_j^* such that $e_r \in S_j^*$. This completes the proof of the theorem.

A.9 Proof of Theorem 7

To prove part (a), let

$$G_i=\{g=(g_1,\ldots,g_s):\ g\cdot e_i\geq 0\}$$
$$=\{g=(g_1,\ldots,g_s):\ g_i\geq 0\},\quad i=1,\ldots,s,$$
$$H_r=\{h=(h_1,\ldots,h_s):\ h_i=\textstyle\sum_{j=0}^{\infty}E\{Q_j(Z_1,\ldots,Z_j)$$
$$\times[L(u_i,d_j(Z_1,\ldots,Z_j))+jC_2(I)+C_2(S)]\,|\,U=u_i\}$$
$$-L(u_i,a_r)\quad \text{for all } (q,d)\}$$

where $g\cdot e_i$ denotes inner product of g and e_i. Note that $w\cdot h\geq 0$ for any $h\in H_r$ if and only if $w\in S_r^*$.

Assume the contrary, then there exists (q,d) such that $r_2(e_i,(q,d))<R_r(e_i)$ for all e_i, i.e., there exists $h\in H_r$ such that $e_i\cdot h<0$ for all e_i. This is equivalent to $G^c\cap H_r\neq\phi$, where $G=\cup_{i=1}^{s}G_i$. Then for any $h\in G^c\cap H_r$ and $w\in S$,

$$w\cdot h<0$$

since

$$G^c=\{g=(g_1,\ldots,g_s):\ g_i<0,\ i=1,\ldots,s\}$$
$$S=\{w=(w(u_1),\ldots,w(u_s)):\ w(u_i)\geq 0,\ i=1,\ldots,s \text{ and } \textstyle\sum_i w(u_i)=1\}.$$

But this contradicts the fact that S_r^* is not an empty set, and the proof of part (a) is completed.

To prove part (b), it will be shown that if $w^1\in S_r^*$ and $w^2\in S_r^*$, then $w^3=tw^1+(1-t)w^2\in S_r^*$ for $t\in[0,1]$. By the definition of h in the proof of part (a), we have

$$r_2(w^3,(q,d))-R_r(w^3)=w^3\cdot h$$
$$=\{tw^1+(1-t)w^2\}\cdot h$$
$$=tw^1\cdot h+(1-t)w^2\cdot h\geq 0 \text{ for all } h\in H_r$$

since $w^1\in S_r*$ and $w^2\in S_r*$. Therefore $r_2(w^3,(q,d))\geq R_r(w^3)$ for all (q,d). The result then follows.

A.10 Proof of Theorem 10

We first prove part (a). From the proof of Theorem 5,

$$\inf_{(q,d),k} r_k(w,(q,d)) = \min[\min_j R_j(w); \inf_{(q,d)} r_2(w,(q,d))].$$

For $w^* \in S^*$, we have

$$\inf_{(q,d),k} r_k(w^*,(q,d)) = \min_j R_j(w^*) = R_{j^*}(w^*).$$

On the other hand,

$$\begin{aligned} &\sup_w \inf_{(q,d),k} r_k(w,(q,d)) \\ &= \sup_w \min[\min_j R_j(w); \inf_{(q,d)} r_2(w,(q,d))] \\ &\leqq \sup_w \min_j R_j(w) \\ &= R_{j^*}(w^*). \end{aligned}$$

Therefore we obtain

$$\sup_w \inf_{(q,d),k} r_k(w,(q,d)) \leqq \inf_{(q,d),k} r_k(w^*,(q,d))$$

and then

$$\sup_w \inf_{(q,d),k} r_k(w,(q,d)) = \inf_{(q,d),k} r_k(w^*,(q,d)),$$

that is, w^* is the least favorable distribution. The proof of part (a) is completed.

To prove part (b), assume the contrary that the least favorable distribution $w^0 \notin C(S-S^*)$. Then there exists $t \in (0,1)$ such that

$$w' = tw^0 + (1-t)w^*$$
$$R_{j'}(w') = V_2(w')$$

where

$$R_{j'}(w') = \min_j R_j(w').$$

By definition, we have

$$R_{j'}(w') \leqq R_{j*}(w') \leqq R_{j*}(w^*) \leqq R_{j'}(w^*).$$

From $w' \in S^*$, $w' \neq w^*$. If $R_{j'}(w') = R_{j*}(w^*)$, $w' \in S^*$ is another least favorable distribution for the no data problem and this is the case of (a). Then $R_{j'}(w') \neq R_{j*}(w^*)$. Therefore from the definition of w',

$$R_{j'}(w^0) < R_{j'}(w') < R_{j'}(w^*).$$

Hence

$$\begin{aligned} & \min[R_1(w^0);\ldots;R_m(w^0);V_2(w^0)] \\ \leqq\ & R_{j'}(w^0) < R_{j'}(w') \\ =\ & \min[R_1(w');\ldots;R_m(w');V_2(w')] \end{aligned}$$

then w' is the least favorable distribution and w^0 is not. The result then follows.

APPENDIX B TRIGRAPH: A COMPUTER PROGRAM

This appendix contains a listing of the BASIC source code for a computational procedure to calculate and draw the region S*. A program listing is placed at the end of this appendix. The numerical examples shown in Figures 4 and 5 have been calculated and drawn by this computer program called TRIGRAPH.

Language

N_{88}-BASIC(86) for NEC PC9801 personal computers.

Purpose

The original paper of Arrow, Blackwell and Girshick (1949), or the subsequent book by Blackwell and Girshick (1954) developed the computational procedure to calculate the region S* for the case that $S_U=\{u_1,u_2,u_3\}$ and $A'=\{a_1,a_2,a_3\}$ and $L(u_i,a_i)=0$ for all i. They assumed that

$$p((1,1,1)|u_1)=0,\quad p((2,2,2)|u_1)=1/2,\quad p((3,3,3)|u_1)=1/2,$$
$$p((1,1,1)|u_2)=1/2,\quad p((2,2,2)|u_2)=0,\quad p((3,3,3)|u_2)=1/2,$$
$$p((1,1,1)|u_3)=1/2,\quad p((2,2,2)|u_3)=1/2,\quad p((3,3,3)|u_3)=0.$$

But their computational procedure is too complicate to compute S* for many cases. In fact, their loss function matrix is invariant under a cyclic permutation of the states and organizational activities. They only calculate S_1* and the vertices of the polygons bounding S_2* and S_3* are obtained by cyclic permutation of the coordinates.

We develop the computer program called TRIGRAPH to calculate and draw S* for a more general case. The loss function is only assumed that $L(u_i,a_i)=0$ for all i. The information cost may have the constant term. Furthermore, it is the most important characteristic of TRIGRAPH that the calculation of S* uses fractions. Therefore, TRIGRAPH can attain the satisfactory precision on the personal computer.

Description

From the assumption that $L(u_i,a_i)=0$ for all i,

$R_j(e_j)=L(u_j,a_j)=0\leq V_2(e_j)$,

then the unit vector $e_j=(0,\ldots,0,1,0,\ldots,0)$ with unity in the j-th component belongs to S_j* and the subsets S_j* are nonempty. Therefore TRIGRAPH calculates the set of all the extreme points of the region S_j* containing e_j, j=1,2,3.

A prior distribution $w=(w(u_1),w(u_2),w(u_3))$, with $w(u_1)+w(u_2)+w(u_3)=1$, may be presented by a point in an equilateral triangle with unit altitude. The distances from the point to the three sides are $w(u_1)$, $w(u_2)$, and $w(u_3)$, since $bw(u_1)/2+bw(u_2)/2+bw(u_3)/2=b/2$ where b is the length of side of the equilateral triangle. TRIGRAPH draws S_1*, S_2* and S_3* on the equilateral triangle.

Restrictions

The data input are assumed to be integers. If the original data contain decimals or fractions, all the data input must be multiplied by the same number to become integers in advance.

Additional Remarks

The numerical results are printed out on the printer. The graphical results are drawn on the CRT display. These graphical results will be printed out on the printer by inputting a command "COPY 2" using the keyboard if necessary.

Sample TRIGRAPH Dialogue

We illustrate the operation of TRIGRAPH with Example 3.

On the CRT display.

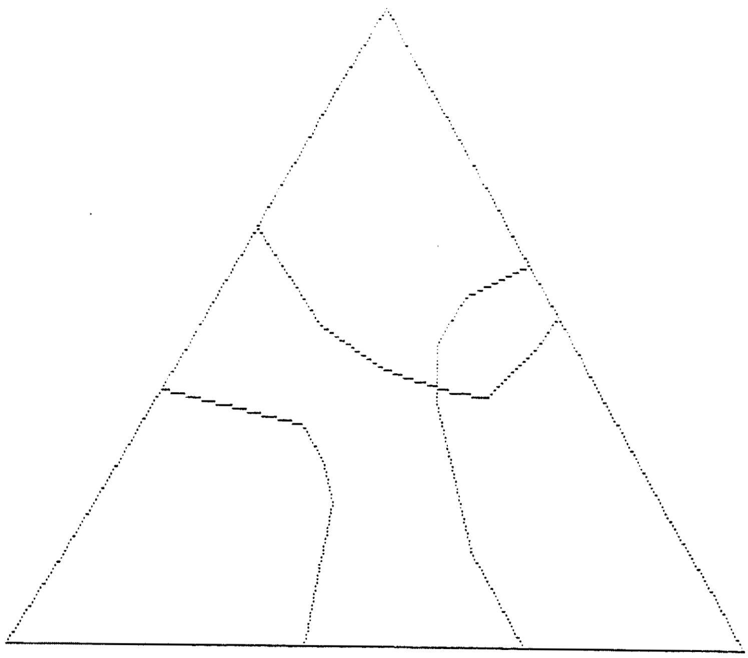
```
Ok
RUN "TRIGRAPH"
Wellcome to TRIGRAPH.
I can calculate and draw S*.
All input data must be integers!!
Input the loss function.
L(1,1)=0
L(1,2)=? 60
L(1,3)=? 40
L(2,1)=? 70
L(2,2)=0
L(2,3)=? 80
L(3,1)=? 50
L(3,2)=? 60
L(3,3)=0
Input the number of the managers, m=? 3
Input the observation cost, cI=? 2
Input the communication cost, cT=? 4
Input the communication cost, cM=? 2
```

On the printer.

```
State                Task
                     1              2              3
 1                    0              60             40
 2                    70             0              80
 3                    50             60             0
c1(S)= 0           c1(I)= 18
c2(S)= 4           c2(I)= 10
Stopping region to take a task 1 has the following extreme points:
(1,0,0)
( 23 / 35 , 12 / 35 , 0 / 140 )
( 73 / 145 , 48 / 145 , 24 / 145 )
( 54 / 125 , 7 / 25 , 36 / 125 )
( 2 / 5 , 1 / 5 , 2 / 5 )
( 13 / 33 , 26 / 165 , 74 / 165 )
( 89 / 225 , 34 / 225 , 34 / 75 )
( 19 / 40 , 1 / 20 , 19 / 40 )
( 13 / 25 , 0 / 100 , 12 / 25 )
Stopping region to take a task 2 has the following extreme points:
(0,1,0)
( 0 / 120 , 3 / 5 , 2 / 5 )
( 9 / 40 , 9 / 20 , 13 / 40 )
( 17 / 60 , 13 / 30 , 17 / 60 )
( 17 / 50 , 13 / 30 , 17 / 75 )
( 19 / 55 , 24 / 55 , 12 / 55 )
( 2 / 5 , 3 / 5 , 0 / 120 )
Stopping region to take a task 3 has the following extreme points:
(0,0,1)
( 3 / 5 , 0 / 80 , 2 / 5 )
( 63 / 115 , 13 / 115 , 39 / 115 )
( 63 / 125 , 4 / 25 , 42 / 125 )
( 17 / 36 , 17 / 90 , 61 / 180 )
( 23 / 60 , 7 / 30 , 23 / 60 )
( 3 / 20 , 3 / 10 , 11 / 20 )
( 0 / 160 , 3 / 10 , 7 / 10 )
```

On the CRT display.

Ok



Numerical Examples Shown in Figures 4 and 5

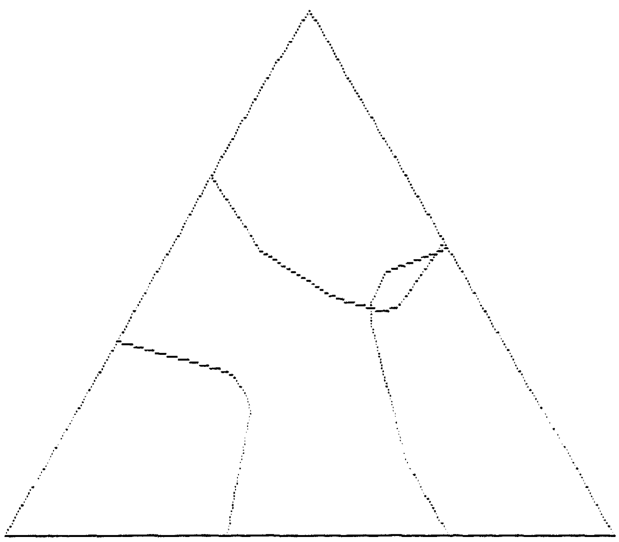
State	Task 1	Task 2	Task 3
1	0	60	40
2	70	0	80
3	50	60	0

c1(S)= 0 c1(I)= 12
c2(S)= 2 c2(I)= 10

Stopping region to take a task 1 has the following extreme points:
(1,0,0)
(24 / 35 , 11 / 35 , 0 / 140)
(79 / 145 , 44 / 145 , 22 / 145)
(57 / 125 , 6 / 25 , 38 / 125)
(3 / 7 , 6 / 35 , 2 / 5)
(67 / 155 , 22 / 155 , 66 / 155)
(14 / 25 , 0 / 100 , 11 / 25)

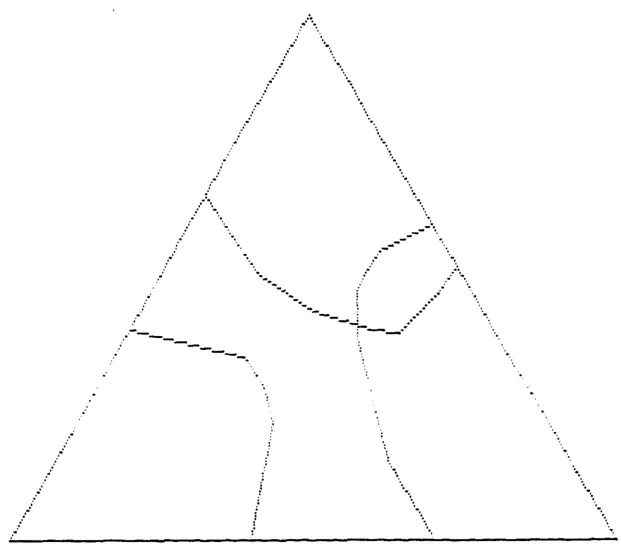
Stopping region to take a task 2 has the following extreme points:
(0,1,0)
(0 / 120 , 19 / 30 , 11 / 30)
(19 / 80 , 19 / 40 , 23 / 80)
(4 / 15 , 7 / 15 , 4 / 15)
(3 / 10 , 7 / 15 , 7 / 30)
(11 / 35 , 10 / 21 , 22 / 105)
(11 / 30 , 19 / 30 , 0 / 120)

Stopping region to take a task 3 has the following extreme points:
(0,0,1)
(11 / 20 , 0 / 80 , 9 / 20)
(73 / 145 , 18 / 145 , 54 / 145)
(4 / 9 , 8 / 45 , 17 / 45)
(2 / 5 , 1 / 5 , 2 / 5)
(11 / 80 , 11 / 40 , 47 / 80)
(0 / 160 , 11 / 40 , 29 / 40)



State	Task 1	2	3
1	0	60	40
2	70	0	80
3	50	60	0

c1(S)= 0 c1(I)= 18
c2(S)= 4 c2(I)= 10
Stopping region to take a task 1 has the following extreme points:
(1,0,0)
(23 / 35 , 12 / 35 , 0 / 140)
(73 / 145 , 48 / 145 , 24 / 145)
(54 / 125 , 7 / 25 , 36 / 125)
(2 / 5 , 1 / 5 , 2 / 5)
(13 / 33 , 26 / 165 , 74 / 165)
(89 / 225 , 34 / 225 , 34 / 75)
(19 / 40 , 1 / 20 , 19 / 40)
(13 / 25 , 0 / 100 , 12 / 25)
Stopping region to take a task 2 has the following extreme points:
(0,1,0)
(0 / 120 , 3 / 5 , 2 / 5)
(9 / 40 , 9 / 20 , 13 / 40)
(17 / 60 , 13 / 30 , 17 / 60)
(17 / 50 , 13 / 30 , 17 / 75)
(19 / 55 , 24 / 55 , 12 / 55)
(2 / 5 , 3 / 5 , 0 / 120)
Stopping region to take a task 3 has the following extreme points:
(0,0,1)
(3 / 5 , 0 / 80 , 2 / 5)
(63 / 115 , 13 / 115 , 39 / 115)
(63 / 125 , 4 / 25 , 42 / 125)
(17 / 36 , 17 / 90 , 61 / 180)
(23 / 60 , 7 / 30 , 23 / 60)
(3 / 20 , 3 / 10 , 11 / 20)
(0 / 160 , 3 / 10 , 7 / 10)



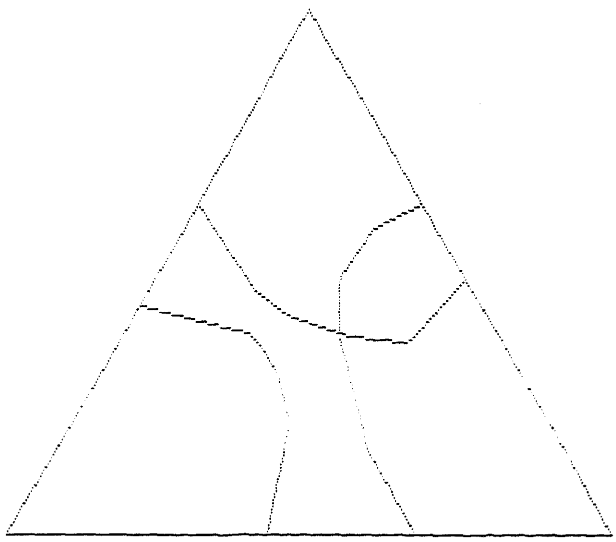
State	Task 1	2	3
1	0	60	40
2	70	0	80
3	50	60	0

c1(S)= 0   c1(I)= 24
c2(S)= 6   c2(I)= 10

Stopping region to take a task 1 has the following extreme points:
(1, 0, 0)
(22 / 35 , 13 / 35 , 0 / 140)
(67 / 145 , 52 / 145 , 26 / 145)
(51 / 125 , 8 / 25 , 34 / 125)
(17 / 45 , 11 / 45 , 17 / 45)
(53 / 145 , 23 / 145 , 69 / 145)
(17 / 46 , 17 / 115 , 111 / 230)
(17 / 35 , 0 / 140 , 18 / 35)

Stopping region to take a task 2 has the following extreme points:
(0, 1, 0)
(0 / 120 , 17 / 30 , 13 / 30)
(17 / 80 , 17 / 40 , 29 / 80)
(3 / 10 , 2 / 5 , 3 / 10)
(9 / 25 , 2 / 5 , 6 / 25)
(21 / 55 , 68 / 165 , 34 / 165)
(13 / 30 , 17 / 30 , 0 / 120)

Stopping region to take a task 3 has the following extreme points:
(0, 0, 1)
(41 / 65 , 0 / 130 , 24 / 65)
(67 / 115 , 12 / 115 , 36 / 115)
(51 / 103 , 102 / 515 , 158 / 515)
(33 / 70 , 3 / 14 , 11 / 35)
(11 / 30 , 4 / 15 , 11 / 30)
(13 / 80 , 13 / 40 , 41 / 80)
(0 / 160 , 13 / 40 , 27 / 40)



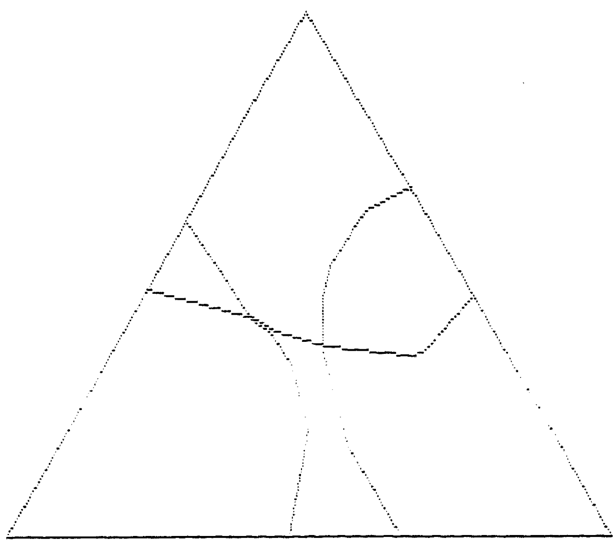
State	Task 1	2	3
1	0	60	40
2	70	0	80
3	50	60	0

c1(S)= 0 c1(I)= 30
c2(S)= 8 c2(I)= 10

Stopping region to take a task 1 has the following extreme points:
(1, 0, 0)
(3 / 5 , 2 / 5 , 0 / 140)
(61 / 145 , 56 / 145 , 28 / 145)
(48 / 125 , 9 / 25 , 32 / 125)
(16 / 45 , 13 / 45 , 16 / 45)
(49 / 145 , 24 / 145 , 72 / 145)
(8 / 23 , 16 / 115 , 59 / 115)
(16 / 35 , 0 / 140 , 19 / 35)

Stopping region to take a task 2 has the following extreme points:
(0, 1, 0)
(0 / 120 , 8 / 15 , 7 / 15)
(1 / 5 , 2 / 5 , 2 / 5)
(19 / 60 , 11 / 30 , 19 / 60)
(19 / 50 , 11 / 30 , 19 / 75)
(23 / 55 , 64 / 165 , 32 / 165)
(7 / 15 , 8 / 15 , 0 / 120)

Stopping region to take a task 3 has the following extreme points:
(0, 0, 1)
(43 / 65 , 0 / 130 , 22 / 65)
(71 / 115 , 11 / 115 , 33 / 115)
(53 / 103 , 106 / 515 , 144 / 515)
(9 / 20 , 1 / 4 , 3 / 10)
(7 / 20 , 3 / 10 , 7 / 20)
(7 / 40 , 7 / 20 , 19 / 40)
(0 / 160 , 7 / 20 , 13 / 20)



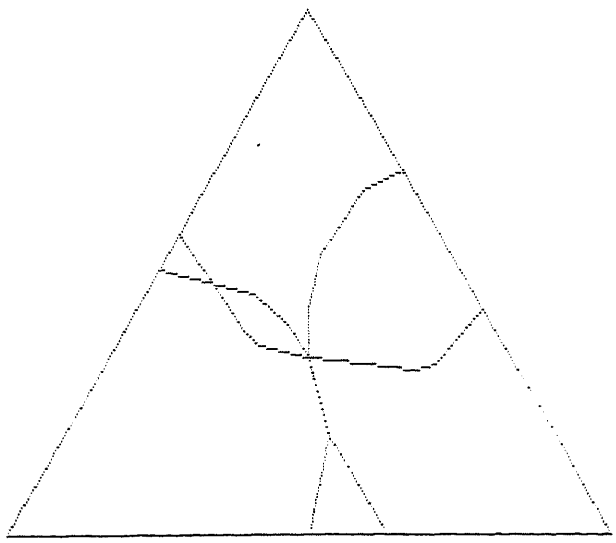
State	Task 1	2	3
1	0	60	40
2	70	0	80
3	50	60	0

c1(S)= 0 c1(I)= 36
c2(S)= 10 c2(I)= 10

Stopping region to take a task 1 has the following extreme points:
(1, 0, 0)
(4 / 7 , 3 / 7 , 0 / 140)
(11 / 29 , 12 / 29 , 6 / 29)
(9 / 25 , 2 / 5 , 6 / 25)
(1 / 3 , 1 / 3 , 1 / 3)
(9 / 29 , 5 / 29 , 15 / 29)
(15 / 46 , 3 / 23 , 25 / 46)
(3 / 7 , 0 / 140 , 4 / 7)

Stopping region to take a task 2 has the following extreme points:
(0, 1, 0)
(0 / 120 , 1 / 2 , 1 / 2)
(3 / 16 , 3 / 8 , 7 / 16)
(1 / 3 , 1 / 3 , 1 / 3)
(2 / 5 , 1 / 3 , 4 / 15)
(5 / 11 , 4 / 11 , 2 / 11)
(1 / 2 , 1 / 2 , 0 / 120)

Stopping region to take a task 3 has the following extreme points:
(0, 0, 1)
(9 / 13 , 0 / 130 , 4 / 13)
(15 / 23 , 2 / 23 , 6 / 23)
(55 / 103 , 22 / 103 , 26 / 103)
(3 / 7 , 2 / 7 , 2 / 7)
(1 / 3 , 1 / 3 , 1 / 3)
(3 / 16 , 3 / 8 , 7 / 16)
(0 / 160 , 3 / 8 , 5 / 8)



Program Listing for TRIGRAPH

```
1000 REM *****************************************************************
1010 REM * TRIGRAPH:                                                     *
1020 REM *   A computer program written by Nobuo Takahashi               *
1030 REM *   in the N88-BASIC(86) for NEC PC9801.                        *
1040 REM *   It will calculate and draw the stopping region S*           *
1050 REM *   for the case of trichotomy.                                 *
1060 REM *   See the text of Appendix B for details.                     *
1070 REM *****************************************************************
1080 DIM P(8,7):DIM D(12,3):DIM E(12,3)
1090 DIM A(3,3):DIM W(7):DIM B(3)
1100 REM *****************************************************************
1110 REM *   Data input                                                  *
1120 REM *****************************************************************
1130 PRINT "Wellcome to TRIGRAPH."
1140 PRINT "I can calculate and draw S*."
1150 PRINT "All input data must be integers!!"
1160 PRINT "Input the loss function."
1170 PRINT "L(1,1)=0":A(1,1)=0
1180 INPUT "L(1,2)=";A(1,2)
1190 INPUT "L(1,3)=";A(1,3)
1200 INPUT "L(2,1)=";A(2,1)
1210 PRINT "L(2,2)=0":A(2,2)=0
1220 INPUT "L(2,3)=";A(2,3)
1230 INPUT "L(3,1)=";A(3,1)
1240 INPUT "L(3,2)=";A(3,2)
1250 PRINT "L(3,3)=0":A(3,3)=0
1260 INPUT "Input the number of the managers, m=";M
1270 INPUT "Input the observation cost, cI=";CI
1280 INPUT "Input the communication cost, cT=";CT
1290 INPUT "Input the communication cost, cM=";CM
1300 K=CT:C=M*CI+(M-1)*CM
1310 LPRINT "State              Task"
1320 LPRINT " ","1","2","3"
1330 FOR I=1 TO 3
1340 LPRINT I,A(I,1),A(I,2),A(I,3)
1350 NEXT I
1360 LPRINT "c1(S)= 0 ","c1(I)=";M*CI+M*CT
1370 LPRINT "c2(S)=";K,"c2(I)=";C
1380 REM *****************************************************************
1390 REM *   Coefficients                                                *
1400 REM *****************************************************************
1410 D(1,1)=0:D(1,2)=1:D(1,3)=0
1420 D(2,1)=0:D(2,2)=2*C-A(2,3):D(2,3)=2*C
1430 D(3,1)=0:D(3,2)=2*C:D(3,3)=2*C-A(3,2)
1440 D(4,1)=0:D(4,2)=0:D(4,3)=1
1450 D(5,1)=0:D(5,2)=0:D(5,3)=1
1460 D(6,1)=2*C:D(6,2)=0:D(6,3)=2*C-A(3,1)
1470 D(7,1)=2*C-A(1,3):D(7,2)=0:D(7,3)=2*C
1480 D(8,1)=1:D(8,2)=0:D(8,3)=0
1490 D(9,1)=1:D(9,2)=0:D(9,3)=0
1500 D(10,1)=2*C-A(1,2):D(10,2)=2*C:D(10,3)=0
1510 D(11,1)=2*C:D(11,2)=2*C-A(2,1):D(11,3)=0
1520 D(12,1)=0:D(12,2)=1:D(12,3)=0
1530 E(1,1)=0:E(1,2)=K+C+A(2,3):E(1,3)=K+C
1540 E(2,1)=0:E(2,2)=K+3*C:E(2,3)=K+3*C
1550 E(3,1)=0:E(3,2)=K+C:E(3,3)=K+C+A(3,2)
1560 E(5,1)=K+C:E(5,2)=0:E(5,3)=K+C+A(3,1)
1570 E(6,1)=K+3*C:E(6,2)=0:E(6,3)=K+3*C
1580 E(7,1)=K+C+A(1,3):E(7,2)=0:E(7,3)=K+C
1590 E(9,1)=K+C+A(1,2):E(9,2)=K+C:E(9,3)=0
1600 E(10,1)=K+3*C:E(10,2)=K+3*C:E(10,3)=0
1610 E(11,1)=K+C:E(11,2)=K+C+A(2,1):E(11,3)=0
```

```
1620 REM ****************************************************************
1630 REM *   Graphic procedure 1 of 2                                   *
1640 REM *   Delete the following 6 lines except for NEC PC9801.        *
1650 REM ****************************************************************
1660 CLS 3
1670 DEF FNX(X)=100+400*X
1680 DEF FNY(Y)=180-200*Y
1690 LINE (FNX(0),FNY(0))-(FNX(1),FNY(0))
1700 LINE (FNX(0),FNY(0))-(FNX(1/2),FNY(1.732/2))
1710 LINE (FNX(1),FNY(0))-(FNX(1/2),FNY(1.732/2))
1720 REM ****************************************************************
1730 REM *   Main program                                               *
1740 REM ****************************************************************
1750 FOR N=1 TO 3
1760 IF N=1 THEN J1=2:J2=3
1770 IF N=2 THEN J1=3:J2=1
1780 IF N=3 THEN J1=1:J2=2
1790 FOR J=2 TO 8
1800 P(J,1)=0:P(J,2)=0:P(J,3)=0
1810 P(J,J1+4)=1:P(J,J2)=1:P(J,J2+4)=1
1820 NEXT J
1830 LPRINT "Stopping region to take a task";N;"has the following extreme points
1840 IF N=1 THEN LPRINT "(1,0,0)"
1850 IF N=2 THEN LPRINT "(0,1,0)"
1860 IF N=3 THEN LPRINT "(0,0,1)"
1870 FOR I1=1 TO 3
1880 FOR I2=5 TO 7
1890 FOR I3=9 TO 11
1900 FOR I=1 TO 3
1910 B(I)=E(I1,I)+E(I2,I)+E(I3,I)-2*A(I,N)
1920 NEXT I
1930 I=I1
1940 GOSUB 2660
1950 GOSUB 2390
1960 I=I1+1
1970 GOSUB 2660
1980 GOSUB 2390
1990 I=I2
2000 GOSUB 2740
2010 GOSUB 2390
2020 I=I2+1
2030 GOSUB 2740
2040 GOSUB 2390
2050 I=I3
2060 GOSUB 2820
2070 GOSUB 2390
2080 I=I3+1
2090 GOSUB 2820
2100 GOSUB 2390
2110 NEXT I3
2120 NEXT I2
2130 NEXT I1
2140 FOR M=1 TO 8
2150 S=0
2160 IF P(M,1)=0 THEN S=S+1
2170 IF P(M,2)=0 THEN S=S+1
2180 IF P(M,3)=0 THEN S=S+1
2190 IF S>1 GOTO 2330
2200 FOR J=1 TO 7
2210 W(J)=P(M,J)
2220 NEXT J
2230 LPRINT "(";W(1);"/";W(5);",";W(2);"/";W(6);",";W(3);"/";W(7);")"
```

```
2240 REM ************************************************************
2250 REM *   Graphic procedure 2 of 2                               *
2260 REM *   Delete the following 4 lines except for NEC PC9801.    *
2270 REM ************************************************************
2280 C=1-W(2)/W(6)-W(1)/W(5)/2:D=(W(1)/W(5))*1.732/2
2290 IF M=1 GOTO 2310
2300 LINE (FNX(A),FNY(B))-(FNX(C),FNY(D))
2310 A=C:B=D
2320 NEXT M
2330 NEXT N
2340 END
2350 REM ************************************************************
2360 REM *   Constraint check subroutine                            *
2370 REM ************************************************************
2380 S=0
2390 IF W(4)=0 THEN RETURN
2400 I4=I1:A=2
2410 GOSUB 2550
2420 I4=I2:A=6
2430 GOSUB 2550
2440 I4=I3:A=10
2450 GOSUB 2550
2460 IF S=1 THEN RETURN
2470 FOR J=1 TO 4
2480 W(J)=ABS(W(J))
2490 NEXT J
2500 FOR J=1 TO 3
2510 GOSUB 2890
2520 NEXT J
2530 GOSUB 3040
2540 RETURN
2550 IF I4=A GOTO 2590
2560 IF (D(I4,1)*W(1)+D(I4,2)*W(2)+D(I4,3)*W(3))/W(4)<0 THEN S=1
2570 IF (D(I4+1,1)*W(1)+D(I4+1,2)*W(2)+D(I4+1,3)*W(3))/W(4)<0 THEN S=1
2580 RETURN
2590 IF (D(I4,1)*W(1)+D(I4,2)*W(2)+D(I4,3)*W(3))/W(4)>0 THEN S=1
2600 IF (D(I4+1,1)*W(1)+D(I4+1,2)*W(2)+D(I4+1,3)*W(3))/W(4)>0 THEN S=1
2610 RETURN
2620 REM ************************************************************
2630 REM *   Type 1 intersection subroutine                         *
2640 REM ************************************************************
2650 W(1)=B(3)*D(I,2)-B(2)*D(I,3)
2660 W(2)=B(1)*D(I,3)
2670 W(3)=-B(1)*D(I,2)
2680 W(4)=D(I,3)*(B(1)-B(2))+D(I,2)*(B(3)-B(1))
2690 RETURN
2700 REM ************************************************************
2710 REM *   Type 2 intersection subroutine                         *
2720 REM ************************************************************
2730 W(1)=-B(2)*D(I,3)
2740 W(2)=B(1)*D(I,3)-B(3)*D(I,1)
2750 W(3)=B(2)*D(I,1)
2760 W(4)=D(I,3)*(B(1)-B(2))+D(I,1)*(B(2)-B(3))
2770 RETURN
2780 REM ************************************************************
2790 REM *   Type 3 intersection subroutine                         *
2800 REM ************************************************************
2810 W(1)=B(3)*D(I,2)
2820 W(2)=-B(3)*D(I,1)
2830 W(3)=B(2)*D(I,1)-B(1)*D(I,2)
2840 W(4)=D(I,2)*(B(3)-B(1))+D(I,1)*(B(2)-B(3))
2850 RETURN
```

```
2860 REM ****************************************************************
2870 REM *   Reduction subroutine                                       *
2880 REM ****************************************************************
2890 X=W(J):Y=W(4)
2900 S=X
2910 IF S<2 GOTO 2990
2920 IF Y-S*(INT(Y/S))=0 GOTO 2950
2930 S=S-1
2940 GOTO 2910
2950 IF X-S*(INT(X/S))=0 GOTO 2970
2960 GOTO 2930
2970 X=INT(X/S):Y=INT(Y/S)
2980 GOTO 2900
2990 W(J)=X:W(J+4)=Y
3000 RETURN
3010 REM ****************************************************************
3020 REM *   Sort and arrange subroutine                                *
3030 REM ****************************************************************
3040 L=2
3050 IF W(J1)=0 GOTO 3270
3060 IF W(J2)=0 GOTO 3230
3070 X=(W(J1)/W(J1+4))/(W(J2)/W(J2+4))
3080 FOR J3=2 TO 8
3090 Y=(P(J3,J1)/P(J3,J1+4))/(P(J3,J2)/P(J3,J2+4))
3100 IF X=Y GOTO 3220
3110 IF X>Y GOTO 3140
3120 L=L+1
3130 NEXT J3
3140 FOR M=2 TO 8-L
3150 FOR J=1 TO 7
3160 P(8-M+1,J)=P(8-M,J)
3170 NEXT J
3180 NEXT M
3190 FOR J=1 TO 7
3200 P(L,J)=W(J)
3210 NEXT J
3220 RETURN
3230 FOR J=1 TO 7
3240 P(1,J)=W(J)
3250 NEXT J
3260 RETURN
3270 FOR J=1 TO 7
3280 P(8,J)=W(J)
3290 NEXT J
3300 RETURN
```

APPENDIX C QUESTIONS IN JAPANESE

This appendix is intended to give the interested reader a Japanese description of the questions referred to in the text. Since these questions have not been planned to be used in English at the research, the questions might be loosely translated and not word for word in the text to facilitate the understanding of their real meaning. The reader who is interested in other questions on this research is referred to Takahashi and Takayanagi (1985).

The questions referred to in the text correspond to the questions in this appendix as follows:

Text	Appendix
Question 1.	II.4.(b)
Question 2.	II.3.
Question 3.	III.1.
Question 4.	III.2.
Question 5.	II.2.

The financial indicators in Section 4.2 are calculated using the data obtained by Question I in this appendix.

The items in Table 1 correspond to the items of the question II.3 in this appendix as follows:

Item number in Table 1	Question II.3
1	(c)
2	(g)
3	(e)
4	(f)
5	(a)
6	(b)
7	(d)
8	(h)
9	(i)

記入にあたってのお願い

1. 設問に対して予め用意されている解答が貴社の実情を正確に表現していない場合があると思いますが，この場合にもおおよその見当で結構ですから，貴社の実情に最も近いと思われるものを選んで下さい。
2. [1．2] の形式の質問には，1つだけ番号に○をつけて下さい。
3. 数字は1枠に1字ずつご記入下さい。
4. 調査票は，昭和58年1月20日までに必ずご投函下さるようにお願いいたします。

企業におけるコミュニケーションの将来形態についての質問調査表

（提出期限　昭和58年1月20日）

貴社名	
ご記入者の職名および氏名	（職名） （氏名）　　　　（電話）

＊この調査結果のまとめの資料をご希望の場合は，資料がまとまり次第，記入者様あてに資料をお送りいたしますので，どちらかに○印をおつけ下さい。

a．必　要 ──→ 資料の送付先（住所）

b．必要ない

I．

貴社の経営指標をお教え下さい。（年2回決算の場合には年間合計数字でご記入下さい。）

		昭和53年度	昭和54年度	昭和55年度	昭和56年度
売上高		百万円	百万円	百万円	百万円
税引後純利益					百万円
使用総資本	他人資本			百万円	百万円
	自己資本			百万円	百万円
通信費		百万円	百万円	百万円	百万円

注）マイナスの数字は頭部に▲印をおつけ下さい。

II

1. これ以後の設問は，貴社にとって最も売上高が大きいというように，主力となっている業種に属する部門の組織について，お答えしていただきたいと思いますが，その業種名を具体的にお答え下さい。

〔　　　　　　　　　　　　　　　　　　　　　　　　　　　　〕

2. その業種の競争他社と比べて，あなた自身は，貴社のその業種に属する部門の組織の全体業績を個人的にはどう評価していますか。次の中から1つ選んで○印をおつけ下さい。

1. この業種での平均的業績より上である。
2. この業種では平均的な業績である。
3. この業種での平均的業績より下である。

3. 次の(a)〜(i)の各項目について，貴社が該当すると思われる方を実態に即して考えて，1か2のどちらか1つを○印でかこんで下さい。

(a)
1. 企業全体のタスク（課題・業務）は，あらかじめ職能別に分化されていて，その職能別の専門化が行なわれている。
2. 知識と経験は，企業の共通のタスク（課題・業務）に貢献するように専門化されている。

(b)
1. 個々の課業は抽象的で，従業員は企業全体の目標の達成よりも，むしろ，目の前の手段の技術的改善を追及しがちである。
2. 個々の課業は具体的に，企業の全体的状況の中で把握されている。

(c)
1. 組織の各階層では，個々の課業は，その直接の上司によって調整されている。
2. 個々の課業の調整は，他の人との相互作用を通して行なう。

(d)
1. 各職務には明確に限定された権限と義務と手続とが与えられている。
2. 問題が発生したような場合でも，誰か他の人の責任として片付けられることはなく，そこには職務としての技術的な規定を越えての企業とのかかわりがある。

(e)
1. 統制，権限，伝達はピラミッド構造をしている。
2. 統制，権限，伝達はネットワーク構造をしている。

(f)
1. 調整を行なう際には，情報は上位層へ独占的に集中する。
2. 情報は，特定問題ごとに定められた統制，権限，伝達のセンターに集められる。

(g)
1. 組織のメンバー間の相互作用は，上司と部下との間の指示伝達のように，垂直的に行なわれる。
2. 組織を通しての伝達は，垂直的というよりは，むしろ水平的に行なわれる。

(h)
1. 伝達の内容は，指示，決定である。
2. 伝達の内容は，指示，決定よりも，むしろ情報，助言である。

(i)
1. 組織内部で役立つ特定の知識，経験，技能が重要視される。
2. 企業の外部でも通用する専門知識が重要視される。

4. 貴社での活動計画の決定，実行についてお答え下さい。

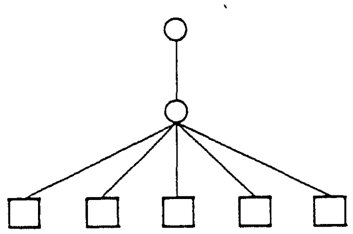
(a) 貴社で，会社の活動計画を決定する際にとる方法は，次のうちのどれに該当するとお考えですか。１つだけ○印でかこんで下さい。

1. 将来起こりうる事態について，積極的に評価・予測を行ない，その結果，将来起こるだろう事態についての確信に基づいて，活動計画を決定する。
2. むしろ，将来どんな事態になっても，損失を最小に抑え，最低限の成果を確保できるように，活動計画を決める。
3. その他（具体的にご記入下さい）

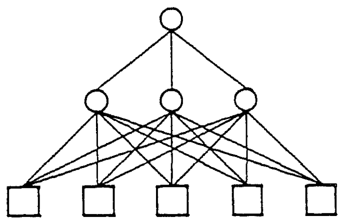
[　　　　　　　　　　　　　　　　　　　　]

(b) 貴社では，そのようにして決定した活動計画を実行する際に，実行する部門（□で示す）とその上司（○で示す）との間の権限関係はどのようになっているでしょうか。次のうちのどちらか１つをお選び下さい。

1.



2.



＊以下の設問は，貴社が製造業の場合だけお答え下さい。

Ⅲ

1. 貴社の生産設備や装置の経済的な陳腐化の年数（スクラップ・アンド・ビルドの周期）は，最近ではどの程度でしょうか。

約□□年

2. 貴社の主要製品の最近でのライフ・サイクルの長さはどの程度でしょうか。

約□□年

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