Simulation Modeling of Information Flows in Decision Making Processes for Design-to-Manufacturing Strategies

by

Yee-tien Fu

Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

Master of Science

in

Industrial Engineering and Operations Research

APPROVED:

H. JoAnne Freeman, Ph.D., P.E., Chair

Marvin H. Agee, Ph.D.

James V. Jucker, Ph.D.

Jeffrey D. Tew, Ph.D.

May, 1989

Blacksburg, Virginia

Simulation Modeling of Information Flows in Decision Making Processes for Design-to-Manufacturing Strategies

by

Yee-tien Fu

H. JoAnne Freeman, Ph.D., P.E., Chair

Industrial Engineering and Operations Research

(ABSTRACT)

Most successful manufacturing companies were initially formed around a unique or superior product design. As a result of this trend, many companies, especially in high-technology industries, considered design and marketing the company's primary functions. When the United States had superior manufacturing technological capabilities in the 1950's and 1960's, corporate management could systematically neglect manufacturing and still be successful. Manufacturing was treated as a service organization and evaluated in the negative terms of poor quality, low productivity, high wage rates, and so on. Manufacturing was not expected to make a positive contribution to a company's success. Recent successes of the Japanese in building higher quality, lower cost products show the critical error in this philosophy. Manufacturing is now a major factor in a company's competitive position (Priest, 1988).

Manufacturing strategies are the framework for accomplishing the long-term corporate goals for the manufacturing function. This framework helps to focus manufacturing goals and provides plans for integrating the necessary functions and resources into a coordinated effort to improve production. Communication of this strategy sets the right climate for the teamwork and long-term planning that are necessary in developing improved manufacturing capabilities. The strategy should be well publicized throughout the company, with regularly scheduled reviews to monitor progress toward the goals.

Recently, emphasis on manufacturing strategy, as advocated by leading scholars in the 1970's and 1980's, has been recognized as one way to regain the competitive advantage for American

manufacturers. Work carried out recently at Harvard and Stanford by Porter (1985), Skinner (1985), Wheelwright and Hayes (1984) has given more attention to the central role and potential importance of manufacturing; this work helps to explain the relative success of Japanese and German companies. Their work also sets a sound background for further research in this area. However, current studies in manufacturing strategy have delved into technology and financial considerations. But technology, capital, and work force are all planned by the people (managers) who are always located in some kind of organizational structure. Based on the experimental results proposed by industrial psychologists, this research is one step toward a quantitative study of organizational efficiency. Two major types of organizations, hierarchical (serial) and egalitarian (parallel), are investigated by applying simulation techniques. The variables controlled comprise organizational type, number of levels in a hierarchical structure, and number of participants. The research results are also applied to investigate the applicability of current design-to-manufacturing strategies, such as *simultaneous engineering* and *concurrent design* in firms. Suggestions on how to reduce the design-to-manufacturing time through appropriate organizational structures are presented following analysis of the simulation results.

Acknowledgements

I am indebted to several people for the intellectual contributions, support, and encouragement they have provided during the preparation of this thesis. Although the list is long, some must be mentioned individually.

In particular, I would like to thank my thesis chairman, Dr. JoAnne Freeman. We have worked closely during my period in the masters program, and she has been a constant source of encouragement and inspiration. My intellectual debt to her is great. I would also like to thank the other members of my committee, Dr. Marvin Agee, Dr. James Jucker, and Dr. Jeffrey Tew, all of whom have always been willing to discuss ideas and have provided invaluable comments in this work.

I don't know how to appreciate the generous help from friends in the Writing Center and in Computer Consulting Services, especially from the following individuals: , , , and . Editorial help from and from was indispensable for me to complete my thesis. Special thanks went to for her contagious cheerfulness which helped me think positively about people and things.

Lastly, I wish to acknowledge the motivation and support of my family throughout the masters program.

Table of Contents

List of Illustrations

List of Tables

Chapter 1. Introduction

1.1 Background

Recently, manufacturing strategy has been recognized as one way to regain a competitive advantage for American manufacturers in the world market. Work carried out by Porter (1985), Skinner (1985), and Wheelwright and Hayes (1984) has focused attention on the central role and potential importance of manufacturing; this work helps to explain the relative success of Japanese and German companies as well as highlighting areas for further research. However, Pendleburg (1987, p. 39) suggested that there remains a crucial area that does not receive sufficient attention: design and engineering, which not only mandate a majority of final product costs but also decide a company's future market success.

The work of Bikker and Heyden (1987, p. 1639) points out the role of design and engineering:

> Productivity of design has primarily to do with the results. It must be possible to fulfill all requirements of the customer, manufacturing and process planning. This includes the flexibility asked for by the customers. The costs and flowtime of the design and engineering process itself have to stay as low as possible.

Coincidentally, Mr. John Akers (1987), Chairman of IBM, emphasized that the top priority of his organization was to shorten the time from design to market (Pendlebury, 1987). The design-to-manufacturing interface plays a critical role in reducing this time. Many Japanese companies have placed priority on engineering-related issues, thereby putting design and engineering at the heart of their manufacturing strategy. George Stalk (1988) believes that time will be the next source of competitive advantage. He said, in a Harvard Business Review article (Stalk, 1988, p. 41), "As a strategic weapon, time is the equivalent of money, productivity, quality, even innovation."

Communication networks play an important role in the decision-making processes which directly affect the time taken for design and manufacturing. According to Leavitt (1978), the groups whose problems require the collation of information from all members may be classified into different basic types. Two that were discussed by him were (also see Figure 1):

1. The "star pattern," in which one position is highly centralized and the others relatively peripheral; and
2. The "circle pattern," in which each member has more than one source of information.

These patterns are also termed hierarchical and egalitarian organizational structures, respectively.

Leavitt summarized test results from experiments involving these two different groups and found that different group arrangements caused people to behave differently. Based on these experimental results, Leavitt concluded that the structure of communication in a group sometimes sets limits on the group's performance.

Leavitt's classification was used in modeling the product development process described in this thesis. In this research, a simulation model was proposed in which group structure and communication are simulated at the level which is responsible for product development. The participating departments are: marketing, design, and manufacturing engineering. The phases in the product development process are: conceptual design; basic design and prototype building; pilot production;

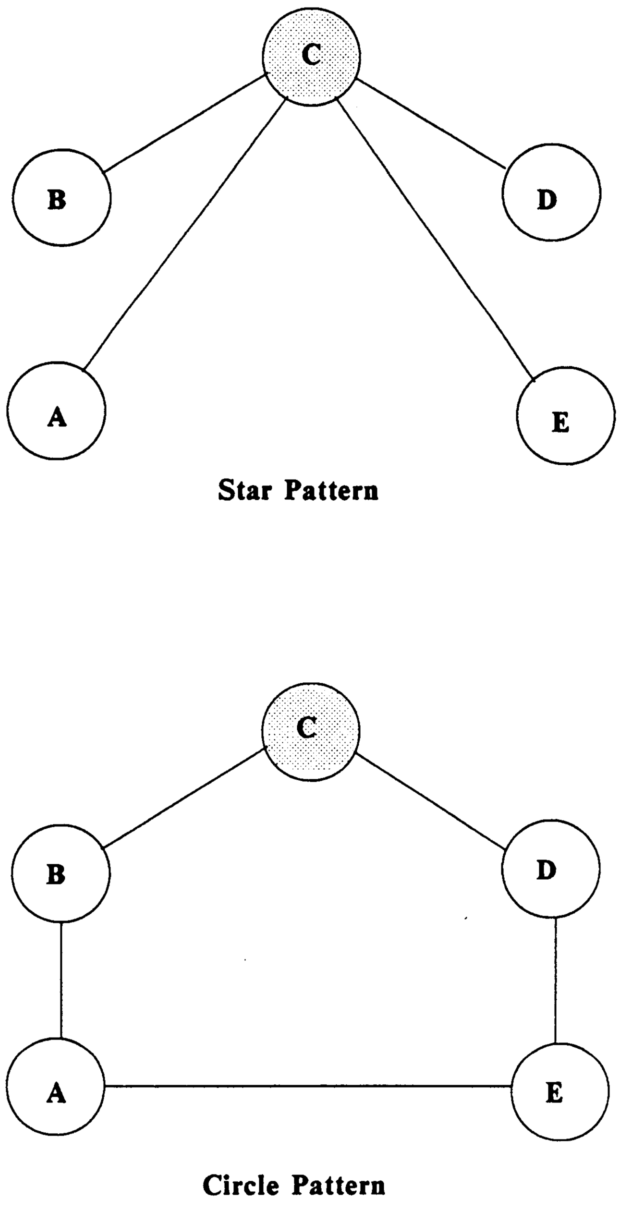


Figure 1. Two Possible Communication Types: From Leavitt, 1978, pp. 236-7.

and manufacturing introduction. From the simulation analysis, the assumption that the structure of a group affects the design-to-manufacture time was tested.

In this research, simulation modeling was applied to the communication channels through which the specifications and requirements of design are conceptualized, approved, and issued to production. In the model, each department is a node in which the the decision-making time used is determined. It is appropriate to think of a representative from each department (node) as a server of a specific design project. That is to say, the server (e.g., from marketing) participating in a specific design project is located at the node (e.g., marketing department), etc. The decision maker, at each stage of the product development process, acts like a "server" and the design projects are "customers." These stages are defined later in Chapter 3, Section 3. The transmission time between any two nodes is a delay time. For a highly centralized, or hierarchical structure, the servers are defined as serially related, with communication channels only open between the decision maker and subordinate department(s). In the decentralized, or egalitarian structure, the servers are parallelly related, and communication may take place freely among them. These two models are two extremes among many possible organizational settings. Most real organizations tend to combine these two basic types to form a mixed structure.

One of the underlying assumptions of this research was that product quality is developed from useful information aggregated during the product development process, an assumption based on Clark, et al. (1987, p. 5). In his paper entitled "Product Development in the World Auto Industry," Clark says:

> ... product development comprises activities that translate knowledge of market needs and technological opportunities into information for production. The information includes product concepts, styling models, specifications, layouts, prototypes, engineering drawings, process designs, tools and dies, equipment, and software. The product itself is thus a bundle of information embodied in materials.

Decision-making styles in varying structures of organizations have an effect on the design-to-market time which includes not only the sum of routing information up and down the structure but also the time consumed in the decision-making processes. A simple organization of three departments is used to explain the structural effect on information transmission time consumed in the design-to-market process (see Figure 2).

For simplicity, consider that only one department (e.g., manufacturing department) is going to request information from another one (e.g., design department). In the hierarchical (or serial) structure, the representative from the general manager's office acts as the medium who receives the requested information from the manufacturing engineering department, filters it, and then transfers it to the design department. To reply, the procedure is reversed; the return information is sent back to the manufacturing engineering department by design department via the representative from the general manager's office. The total number of links is four. In the egalitarian structure, the total number of links is only two, since departments may request information directly from each other (See Figure 3). In the worst case, the case in which each department needs information from all the others, there may be tremendous time consumed in the links in the hierarchical structure, while there is more direct provision of information in the egalitarian structure. The number of links is considered one measure of information transmission time.

From the results of the simulation study, suggestions are made for feasible organizational structures given an organization's requirements and objectives. If the bottleneck problems associated with inappropriate organizational communications could be solved more efficiently by designing better communication networks in organizations, the design-to-manufacture (and design-to-market) time would be shortened significantly, which would contribute to productivity improvement in the organization. Successfully applying the correct structure could help to facilitate a better manufacturing strategy for a manufacturing company.

1.2 Problem Statement

The problem defined in this research was to study quantitatively one of the many possible measures of a manufacturing organization — the efficiency measure. Among those factors affecting

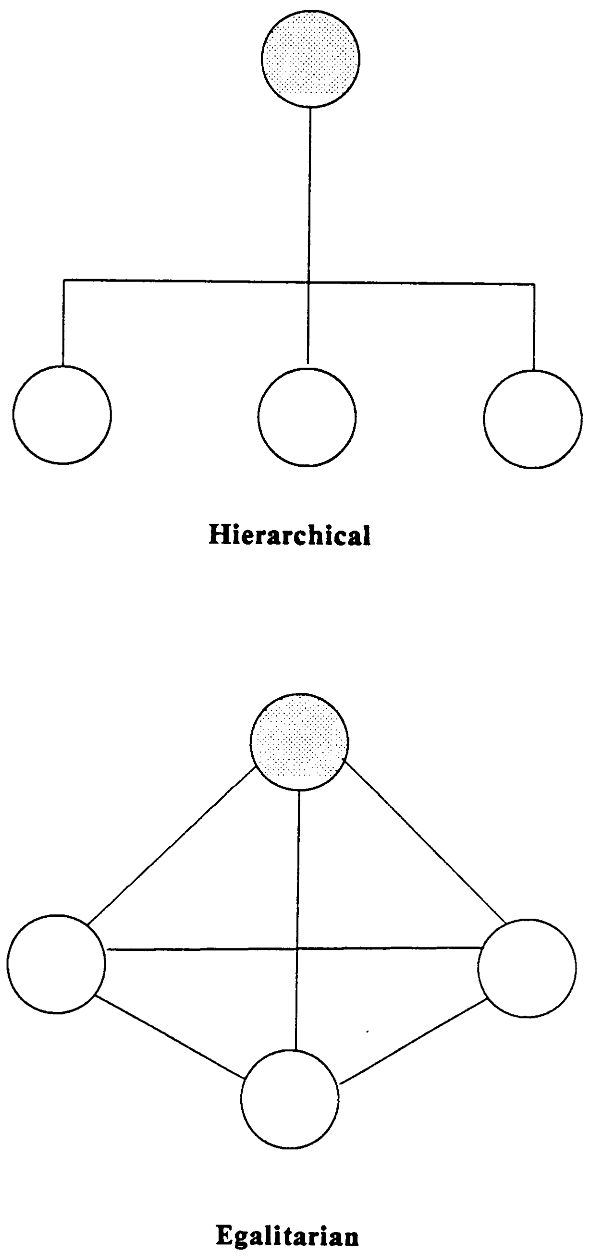
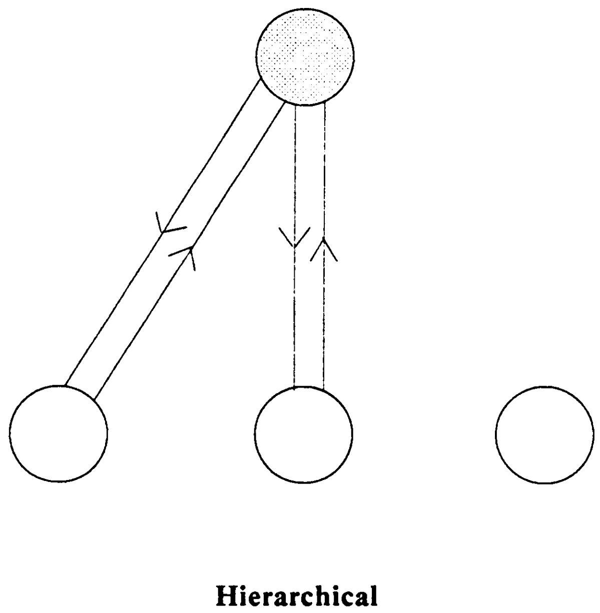


Figure 2. Two Simple Organizational Structures of Three Departments and One General Manager's Office.



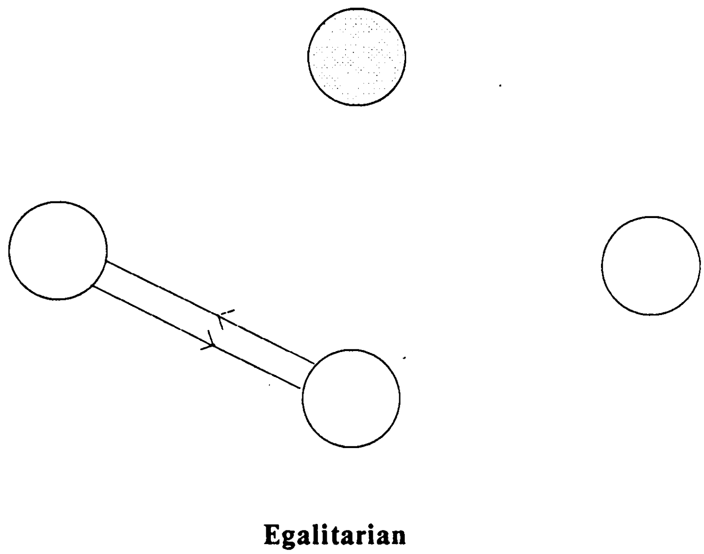


Figure 3. Information-Changing Links in Both Structures: The Structural Effect on Information Transmission Time Consumed in the Design-to-Market Process (n is the number of passes of information between two departments in a simple enquiring process)

the organizational efficiency, the organizational structure was the only factor considered in this research. There are many kinds of organizational structures. However, only two of them (i.e., hierarchical and egalitarian) were chosen for comparison. On the product side, time is the major strategic dimension considered among several possible (e.g., product quality).

1.2.1 The Functions of Departments in a Modern Manufacturing Organization

A responsibility center is an activity, task, or collection of activities controlled by a single individual (Moriarity and Allen, 1987). In general, for this research, there were four responsibility centers assumed to be involved in the (joint) decision-making process for product development in a typical manufacturing company. The responsibility centers involved are: program coordinator (representing the office of the general manager), marketing, design, and manufacturing engineering (other departments, such as personnel, accounting, and maintenance were not considered in this research). Each center has its own responsibilities. The job relationship between the preceding and succeeding centers explains the necessity of information transmission and sharing. To help the readers understand the necessity of information changing between departments in a manufacturing firm, typical functions (or responsibilities) of each (department) responsibility center are introduced as follows.

The functions of the program coordinator are (1) exchanging and filtering the information in the hierarchical organizational structure, or participating and coordinating the team in an egalitarian structure, which consists of representatives from each department; and (2) acting as the decision-making representative of the general manager, in either structure.

The functions of the marketing department are (1) marketing investigation, (2) conception of the competitive product, (3) thorough understanding of customers' preferences, and (4) forecasting the sales volume of the existing product and the product which is going to be sent to market.

The functions of the design department are (1) imaginative design of the product conceptualized by marketing people, and (2) prototype design.

The functions of the manufacturing engineering department are (1) manufacturability analysis, (2) layout design and/or re-design, (3) resource allocation, (4) profitability analysis of the potential sales forecasted by marketing, (5) process design and process planning, and (6) preparation for large-scale production.

1.2.2 The Sequence of Events for Two Structures

It is assumed that the sequence of events for product development begins with marketing, continues through design, and ends at manufacturing engineering. Hayes, et al. (1988, p. 276) described the new product development process as follows:

> 'Next generation' development projects are often complex collections of activities involving many people over several years. To further structure the discussion of these activities, we divide the life cycle of a product or process into eight phases.
>
> **Phases in the Life of a Product or Process**

Phase	*Primary Activity*
1	knowledge acquisition
2	concept investigation
3	basic design preparation
4	prototype building and testing
5	pilot production run
6	manufacturing introduction and ramp-up
7	ongoing enhancement
8	phase out

Regarding this eight-phase cycle, Hayes, et. al. (1988, p. 276) stated that,

> Development activities encompass the first six phases. They begin with the building of knowledge and the development of a concept. In the middle phase, engineers complete a design and translate it into prototypes. After testing and refining the design, the new product or process is introduced into pilot production and then ramped up for commercial use.

This process has been simplified to four representative phases to facilitate this research. They are conceptual design; basic design and prototype building; pilot production; and manufacturing introduction, as follows:

Phase	*Primary Activity*
1	Conceptual Design
2	Basic Design and Prototype Building
3	Pilot Production
4	Manufacturing Introduction

These phases will be used as the frames to model the product development process. The modeling processes are explained in Chapter Three. There is only one participative department in the hierarchical structure in each phase. However, there are three participative departments (with different amounts of involvement) in the egalitarian structure in each phase. Considering the randomness in the information-acquiring processes as well as the decreasing marginal rate in the information vs. time curve, one model is presented for each structure. The final objective was to compare the time consumed in two antithetic models (hierarchical and egalitarian).

1.2.3 The Importance of this Research

Leavitt (1978) summarized the test results of two different groups (one in a hierarchical structure and another in an egalitarian structure) and found that different organizational structures cause people to behave differently. Based on the experimental results, Leavitt (1978) concluded that the structure of the communication network in a group sometimes sets limits on the group's performance. His conclusion may be able to be generalized from small groups to larger organizations. Official communication networks are much like organization charts. There is likely to be a formal, officially charted organization, as well as an informal, uncharted organization. The formal organization and the official communication channels within it were formally considered in this thesis.

Different organizations may have different communication styles which are especially suitable to them. In the real world, the mixed-type of (hierarchical and egalitarian) organizational structures appear most often. In order to compare the efficiency of the antithetic communication styles (centralized vs. decentralized), a simulation model was applied to each of the structures with the same number of participative departments. In both models, the group structure was simulated at the production level, which is directly subordinate to the headquarter's manufacturing department, as well as its parallels — the design and marketing departments. By using the data (average time for a typical design) from the simulation study, the assumption that the structure of the group affects the design-to-manufacture time was tested.

The structure of an organization most likely has an effect on the total design-to-market time. Applying the simulation results, the comparisons of two antithetic organizational structures can be made on the condition of the assumptions assumed in this research. If one bottleneck problem — manufacturability — could be solved more efficiently by applying better communication channels in organizations, the design-to-manufacture (and design-to-market) time could be significantly shortened, which might contribute to productivity in the organization. Successfully applying the correct structure may well improve today's manufacturing industry. This simulation study is one step in the necessary process of researching how organizational structure affects design-to-manufacturing time.

1.2.4 Summary and Assumptions

The main difference in the two cases (i.e., hierarchical and egalitarian) is the amount of control that is available to pass or withhold information, and at what level that control resides. In the most extreme case of a pure hierarchy, the control resides only at the decision-maker level and no communication across departments is allowed. At the other extreme, the egalitarian case, communication may take place between departments without "consent," since consent is built into the structure by design.

One underlying assumption for this research was that product quality is developed from useful information aggregated during product development, before the production process. It was also assumed that the relationships between effort and time may be modeled mathematically. Among a lot of possible choices, the (negative) exponential function was chosen to represent the relationship between effort and time for two reasons: it is characterized by its marginal rate as well as its well-behaved mathematical nature. The complexity and the level of innovation of the program (of product design) will be reflected by the amount of information necessary to attain the program coordinator's minimum level of satisfaction to fire the sequence of events. A set of linear constraints was set accordingly for each phase of product design in each model.

The relationship between the mean value of quality of information and effort was assumed to follow a mathematical relationship. Quality of information was assumed to be a random variable with a truncated normal distribution, which changes with time. The truncated range of the mean value of quality of information was assumed in the range of 0 to 100 percent. A negative amount of information does not make sense, and 100 percent is the ceiling for the information available. The longer the time, the larger the mean value, and the smaller the variance of the distribution associated with the quality of information. That is to say, information improves with time, both in its expected value and its variance. Finally, it was assumed that product quality follows a direct relationship with the quality of information. These assumptions will be made more clear in Chapters 2 and 3.

In this research, simulation techniques were applied to different organizational settings by writing programs to test the time used under each set of assumptions. The programs were coded using Fortran and the International Mathematical and Statistical Library package. The objective was to compare the simulated decision-making times for both organizational settings.

1.3 The Objectives of This Research

The objectives of this research were:

1. To model the product development process;

2. To consider the organizational effects of the process;

3. To identify two antithetic organizational settings (hierarchical vs. egalitarian);

4. To embed the product development process in both structures;

5. To simulate and compare the design-to-market times consumed in both structures; and

6. To consider the simulation results for the purpose of commenting on the popular team approach in product development (i.e., "simultaneous engineering" and "concurrent design").

Chapter 2. Literature Review

2.1 Information: Definition and Measurement

2.1.1 Definition of Information

Based on the assumption that any final product is an aggregate of information accumulated in the design-to-premanufacturing phases, it is helpful to investigate various definitions of "information" at the beginning of this research.

Information is often analyzed with respect to meaning, origin, and value. Modern information theory adds another dimension, amount. The need for a measure of the amount of information arose in telecommunication and in the general treatment of control and communication (cybernetics). Once a precise technical definition had been developed, it was found that the domain of the definition of information was wide and even included biology (Quastler, 1987).

Caspari (1968) defined information as the screening, editing, and evaluation of data in the context of a particular decision-making process. "Data" was defined by Chavas (1984) as the result of an inquiry process (e.g., sampling or experimentation) concerning particular events (e.g., today's hog prices in Omaha, corn yield response to fertilizer applied in Iowa). By using written or spoken languages, the data can be transmitted as signals over space or time through particular communication devices, such as radio, telephone, or newspapers.

Coding is a branch of communication theory devoted to problem-solving. A unique feature of information theory is its use of a numerical measure of the amount of information gained when the contents of a message are learned. Information theory relies heavily on the mathematical science of probability. For this reason the term "information theory" is often applied loosely to other probabilistic studies in communication theory, such as signal detection, random noise, and prediction.

Considering the historical introduction of information and information theory, the suitable definition for this research is chosen. In this research, the definition of information elaborates on Caspari's definition: information is the sum of the intangible contributions (e.g., the price of a similar product from a competing peer), combined with other physical elements, in the final product.

2.1.2 Measurement of Information

The probability characteristic of entropy leads to its use in communication theory as a measure of information (Shannon, 1948). The absence of information about a situation is equivalent to an uncertainty associated with the nature of the situation. This uncertainty, designated H, is defined as the entropy of the information about the particular situation, Eq. (1),

$$H(p_1,p_2,\cdots,p_n) = -\sum_{k=1}^{n} p_k \cdot \log p_k \qquad (1)$$

where $p_1,p_2,\cdots,p_n$ are the probabilities of mutually exclusive events. In this equation, the logarithms are taken to an arbitrary but fixed base, and $p_k \cdot \log p_k$ is always equal to zero if $p_k = 0$. For example, if $p_1 = 1$ and all others p's are zero, the situation is completely predictable beforehand; there is no uncertainty and so the entropy is zero. In all other cases the entropy is positive.

In introducing entropy of an information space, C. E. Shannon (1948) described a source of information by its entropy H in bits per symbol. The ratio of the entropy of a source to the maximum rate of signaling that it can achieve with the same symbols is its relative entropy. One minus relative entropy is the redundancy of the source (Rockett, 1987).

The preceding introduction of the measurement of information is used more often in communication theory and is introduced for its historical value. Information measurement is a broad area, and there are many ways to measure it. In the study of information theory, entropy theory is used often. In this research, however, the measurement of information is a relatively subjective and macroscopic process based on the decision maker's own experience and judgment.

2.2 A Model of Product Development

2.2.1 The Conceptual Model

Clark, et al. (1987) proposed a model of product development in their paper entitled "Product Development in the Auto Industry." In that paper they wrote (p. 5):

> The unit of analysis in this study is the product development project.... We use the idea of information processing to organize the analysis. In this context product development comprises activities that translate knowledge of market needs and technological opportunities into information for production. The information includes product concepts, styling models, specifications, layouts, prototypes, engineering drawings, process designs, tools and dies, equipment, and software. The product itself is thus a bundle of information embodied in materials.

In this research, their model, especially the definition of product, was adopted. That is, the product, as well as its quality, was treated as the result of information processing. Materials, or physical resources for the final products, are ignored in the discussion hereafter.

2.2.2 Attributes Affecting a Product's Success

Agee (1989) benefited this research by providing the following attributes which affect the successfulness of new products in the market. As he suggested, the existing manufacturing firms must continually modify old products and/or develop new products to remain competitive in the marketplace. This is particularly true when a firm is involved in the world market. For new manufacturing firms, new products typically come into being by virtue of the development of some new product (e.g., microcomputers).

It seems that attributes which significantly affect a product's success in the marketplace are: (1) relevancy, (2) timeliness, (3) quality, and (4) selling price. These are not necessarily independent attributes and, in fact, quality and selling price are usually highly dependent. The customer may also judge that a product is not "relevant" if the selling price is too high.

Relevancy refers to whether the product has design features that meet particular customer needs/desires or not. The attribute, timeliness, has two dimensions — market introduction and lead time if the product is successful. Assuming a new product successfully meets customers' relevancy, quality, and selling price criteria, there is a high likelihood that competitive products will soon appear in the marketplace. Thus, the firm that first introduces the product should have a distinct advantage over competitors. The second dimension of timeliness is lead time, the time period from customer order to customer delivery. In today's society, whether from an individual or corporate perspective, people either expect immediate availability or, if not, a very fast response to their requests. That is, people expect very short delivery cycles.

Quality is a relative term and often has different meanings to different people. Further, a given product may be judged of excellent quality by one person and of poor quality by another person, depending upon expectations. Thus, a working definition of quality level is to state that a product has an acceptable quality level if it meets the customers' expectations. The product has high quality if expectations are excellent; poor quality if expectations are not met.

Operationally, product quality is typically defined in terms of meeting specifications or targets on certain characteristics. Such specifications are product dependent and therefore diverse and, from a global perspective, almost innumerable in quantity. As an example, a specification for a particular steel bar stock might be that it's tensile strength must be at least 60,000 lbs/in^2. Tensile strength is a specific measure of the bar stock's quality. The value of 60,000 lbs/in^2 serves as a reference point to judge, on a relative basis, whether a piece of the steel bar stock is of acceptable, low, or high quality.

For a given product, the customers' expectations may require that several specifications be met, perhaps pertaining to the general specification categories of strength, resistance, durability, ease of maintenance, appearance, etc. The individual specifications may have different priorities in the customer's view as well. Thus, quality cannot be defined in an absolute sense but the general meaning of the term is understood, and the importance of "acceptable" quality of product is well known in the manufacturing world.

As mentioned previously, the attribute of quality and selling price are related. Usually, the higher the quality, the higher the cost of production and hence, the higher the selling price. The challenge of manufacturing is to produce products of acceptable (or high) quality at the lowest cost possible. Assuming these four attributes, a goal of manufacturing is to produce products on a timely basis that are relevant, of acceptable or high quality, and that are competitively priced.

2.3 Current Studies on Organizational Effects in a Manufacturing Firm

Manufacturing strategy is one extension of the field of production and operations management. Manufacturing strategy is a discipline which helps a company to achieve its global optimum by making the best use of its overall resources and by applying trade-offs to its subordinating departments. To achieve that goal, the company will almost always need to apply the trade-off concept to its conflicting objectives of its subordinating departments. Manufacturing strategists consider at least three dimensions at the corporate level: capital (financial considerations), workforce (organizational considerations), and product and/or process development (technological considerations). Among the three dimensions, the organizational dimension was not, but is now, attracting more attention of the manufacturing strategists. In the following sections, the major emphasis is put on the consideration of the organizational effects on the efficiency of new product development in a manufacturing organization.

2.3.1 Organizational Impacts on Modern Manufacturing Firms

Organizational structure can affect a manufacturing firm in many ways (e.g., worker motivation, the accuracy and efficiency of information flows). From recent literature, it seems that efficiency is being paid more attention. It was the major goal of this research to consider the organizational effects on efficiency of new product development.

At the time IBM was being bothered by the time lag between the proposed (advertised) and the actual time for its new product to be on the market (Beckman and Jucker, 1988), Drucker (1988) advocated the adoption of a new organization for the competitive era. He forecasted that (ibid, p. 45) "The large business 20 years hence is more likely to resemble a hospital or a symphony (characterized by their simple organizational structures) than a typical manufacturing company (characterized by its multi-level, complicated organizational structure)." He went one step further (ibid, p. 46): "The best example of a large and successful information-based organization (has) no middle management at all." It is easy to understand his forecast just by counting the number of "links" in the information changing process of two organizational settings. The first organizational setting is "flat" — a two-level, three-department hierarchical structure where the decision maker is located at the first level and controls and filters all the information. In a "taller" organization, add one middle level with two people between the top level and the bottom level. It is easy to compare the number of links passed when a piece of information is transferred between the top and bottom levels. For the flat organizational setting, the number of links passed is two; for the tall organization, the number of links passed is four. The "flat" organization may be an alternative way to reduce the design-to-market time. However, in this research, the number of organizational levels is fixed to be two. Therefore, no further discussion on "flat" organizations will be addressed.

2.3.2 Team Approach in Modern Manufacturing Organizations

Recently, the team approach has been very popular in new product design. To understand the reason, the following illustration is given. In the new product design process, the marketing department is always involved at its early stage (e.g., conceptual design). Since the marketing department acts as the interface between the manufacturing firm and the customer, the performance of the marketing function should contribute directly to the satisfaction of the customer and the competitiveness of the manufacturer. Hence, the relationship between the marketing department and all its successors should be considered in order to guarantee the success and timeliness of the new product.

In his recent article, "Manufacturing by Design," Whitney (1988, p. 85) pointed out that:

> Multifunctional teams are currently the most effective way known to cut through barriers (long time, high cost, etc.) to good design. Teams can be surprisingly

small — as small as 4 members, though 20 members is typical in large projects — and they usually include every specialty in the company. Top executives should make their support and interest clear. Various names have been given to this team approach, like "simultaneous engineering" and "concurrent design." Different companies emphasize different strengths within the team. In many Japanese companies, teams like this have been functioning for so long that most of the employees cannot remember another way to design a product.

A Teamwork Application — Quality Function Deployment

Recently, in the paper entitled "Quality Function Deployment," Sullivan (1986) introduced a system which ensures that the customers' needs drive the product design and production process. Sullivan's system can be expressed as a series of questions (Hauser, 1988):

1. What do customers want?
2. Are all preferences equally important?
3. Will delivering perceived needs yield a competitive advantage?
4. How can we change the product?
5. How much do engineers influence customer-perceived qualities?
6. How does one engineering change affect other characteristics?

To answer those questions, communications among customers, the marketing domain, and the engineering domain (design and manufacturing engineering) are indispensable. For example, to answer Question Four, it is necessary to change the "what to do" information from the marketing domain to the knowledge of "how to do it" offered by the engineering domain. The importance of the inter-domain communication is one justification of the value of research on organizational efficiency.

For many years, Quality Function Deployment (QFD) has been a mechanism (or a philosophy) widely used by Japanese companies with the goal to bring new (and carryover) products to market sooner than the competition with lower cost and improved quality. In America, Ford Motor Co. and several supplier companies were pioneers in the development of QFD as an operating mechanism to transform customer expectations into specific design and manufacturing requirements.

Hauser (1988, p. 63), who introduced QFD to Ford and its supplier companies in 1984, said:

> QFD is a set of planning and communication routines, which focuses and coordinates skills within an organization, first to design, then to manufacture and market goods that customers want to purchase and will continue to purchase. The foundation of the "house of quality" (the synonym of QFD) is the belief that products should be designed to reflect customers' desires and tastes — so marketing people, design engineers, and manufacturing staff must work closely together from the time a product is first conceived.

From the preceding discussion about QFD, it is easy to find its contribution to the communication between pertinent departments, due to the fact that QFD considers product design as a team effort. Hence an appropriate question is, "What kind of organizational structure is most suitable for the required communication among the members in the organization?"

Another question arises, "Is it cost justifiable to satisfy all the customers' suggestions and preferences?" To answer this question, Parkinson's (1984, p. 66) citation of the product design criteria screening process used by a German company is given:

> The problem is to find the right combination of product features to meet perhaps 70% of the customer's needs. A machine which satisfies 100% of the customers' needs would be too costly to build, and so we have to compromise at say 70% of the needed features, and then add on special features to meet individual customer requirements. In design terms we have to think about three distinct sets of criteria: those which we must have, those which we would have, if possible, and those which it would be nice to have.

In this research, "those which we must have" were assumed to equal 60% of all the customers' requirements; "those which we would like to have" were assumed to equal an additional 20% of the customers′ requirements; "those which it would be nice to have" were assumed to equal the final 20% of all the customers′ requirements. In this research, 80% of all the customers′ requirements is assumed to be a necessity for customer satisfaction.

2.4 Communication among Individuals

2.4.1 The Definition of Communication Networks

Usually, an A-to-B conversation is thought of as direct; but many such communications, especially in organizations, are mediated through other people. One thing an organization chart is supposed to define is the channel or channels over which A can legitimately get a message through to B, and often that may be only through C and D. The defining set of a particular organization is called the *communication network*. A communication net is a group structure. The net defines how the group is "hung" together (Leavitt, 1988, p. 208). It was one of the objectives of this research to show that a particular communication network that an organization uses can have a lot to do with the speed (and accuracy) of all members′ communications.

2.4.2 The Characteristics of Communication Networks

The major characteristics of communication networks that might be considered are (1) the size of the loop (i.e., the amount of organizational space covered by given types of information); (2) the nature of the network, whether a simple repetitive pattern or a chain modification type; (3) the open or closed character of the network; (4) the efficiency of the network for its task; and (5) the fit between the network and the systemic function it serves (Katz, 1978). In this research, (1), (3), and

(4) will be discussed in more depth as factors of more importance, since the goal of this research is to test organizational efficiency.

There has been a considerable amount of research completed on communication networks, which are structured arrangements of a small number of individuals who are allowed to transmit information and communicate with one another only in a set and defined pattern. The research described below provides some additional insight into the communication process as modeled among individuals or their departments in a manufacturing organization.

Researchers asked the members of a network (Gannon, 1988) to solve a specific problem by communicating with one another only through pre-defined channels of communication. Researchers worked with four communication networks: (1) the wheel (or star) network, (2) the chain network, (3) the circle network, and (4) the completely connected network (see Figure 4).

In the *wheel network*, one member is at the center and four or more members are at each end of a spoke. This network is highly centralized, since the members at the end of the spokes can communicate only with the individual at the center and no one else.

In the *chain network*, two members serve as endpoints; they can communicate directly only with the persons next to them. The middle members serve as relay points to the individual in the center. In this situation the center person communicates directly with the two middle members but not with the end individuals. Thus, the chain network is also centralized but not as much as the wheel network since there are middle members who also have some responsibilities. In this research, the wheel network is similar to this writer's definition of centralized (i.e., hierarchical) network.

The *circle network* is somewhat decentralized, since each individual in it can communicate with the two other individuals immediately adjacent.

The *completely connected network*, also called the *all-channel network*, is highly decentralized. Each individual in the group can communicate directly with every other individual in the group. In this research, the all-channel network is similar to the decentralized (i.e., egalitarian) network by definition.

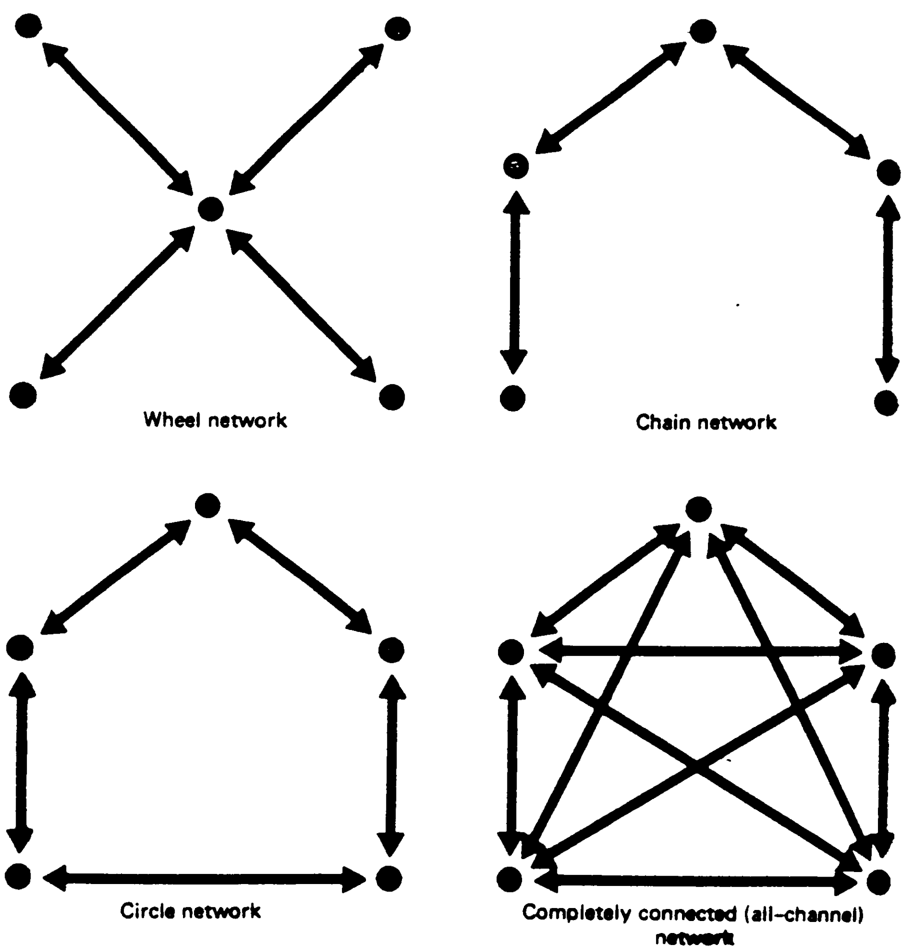


Figure 4. Types of Communication Networks: From Gannon, 1988, p. 310.

The research on highly centralized networks, such as the wheel and the chain, suggests that they are effective in solving routine problems that mainly involve collecting information (Costello and Zalkind, 1963). This seems logical, for the individual at the center of the wheel and chain networks is processing and weeding out the information the group generates and ignoring irrelevant communications. In addition, the leadership position of the central individual in the wheel and chain networks is strong, probably because that individual has the greatest chance of influencing the other members of the group. Finally, these groups structure their communication patterns very rapidly, since everyone quickly learns he or she must process information through the individual in the central position.

Decentralized networks, such as the all-channel and the circle, appear to be more appropriate when the group confronts a nonroutine or unstructured problem. The fact that individuals can communicate directly with each other means they are freer to express opinions and to generate a large number of solutions, many of which may be very creative and innovative. In the decentralized networks there is a higher level of satisfaction among the members of the groups than in centralized networks, probably because individuals are allowed to communicate with one another and to express their own points of view.

2.5 Networks in Organizations

The research findings described in the last section have not been generalized to an entire organization for two possible reasons: (1) the number of individuals who have participated in the communication network research is small; (2) it is difficult to do experiments in a medium-sized, let alone a large-scale, organization. However, a manager may apply these findings to the behavior of small work groups in his or her own organization. If the work is highly structured, such that the members of the group must perform it in a set and routine fashion, the manager should probably deal with a centralized network. If the manager directs the activities of a group whose work is nonroutine, a decentralized network might be appropriate. While all the properties of formal network models may not always exist in actual work groups, evidence suggests that they do occur frequently. For example, unskilled employees, who perform repetitive jobs on an assembly line, work in centralized networks since the pace of the assembly line allows only limited communication among individuals.

According to Leavitt (1978), researchers have further classified the groups whose problems require the collation of information from all members into two basic types: hierarchical and egalitarian. In Mintzberg's (1979) discussion of the issue of hierarchical centralization and egalitarian decentralization, he distinguished them exclusively in terms of power over the decisions made in the manufacturing organization. When all the power for decision making rests at a single point in the organization — ultimately in the hands of a single individual — the structure is called centralized; to the extent that the power is dispersed equally among many individuals, the structure is called egalitarian (or decentralized). In this research, Mintzberg's definitions of hierarchical and egalitarian structures are adopted. Not only because they were consistent with the classification system reported by Leavitt, but also for their obvious distinctions in terms of power.

2.6 Organizational Communication

While communication between individuals and within groups is of obvious significance, the flow of information through the various departments of an organization is also important. Modeling the information flow in a manufacturing organization is an emphasis of this research. Information in an organization usually moves both vertically and horizontally, between supervisor and subordinate and among peers.

It has been found that horizontal communication among equals or peers tends to predominate at the lower levels of the organization. In a study of 48 lower-echelon managers, A. K. Wickesberg (1968) showed that 67 percent of their communications was horizontal; only 33 percent was vertical, between supervisors and subordinates. Among first-line supervisors, these horizontal communications primarily focused on joint problem solving and the work flow (Simpson, 1959).

The communications at the supervisor's level are very specific and goal-oriented, normally directed at solving a particular problem. At higher organizational levels, managers have a greater variety of communications, many of which are not specifically job-related (Albaum, 1964). In this way, the manager is able to obtain current information on activities that may affect his or her own work.

Vertical communication in an organization is sometimes inhibited by the difference in status of the transmitter and the receiver. Also, the higher a person's status in the organization, the greater the distortion in the communications he or she receives (Barlund and Harland, 1963; Cohen, 1962). In some organizations, when consultants have been hired to solve specific problems, they have been unable to persuade subordinates to talk freely in the presence of their superiors. When, at the request of consultants, the superiors do not attend group sessions, the subordinates tend to be responsive and open about the organizational problems they face. This is especially true of ambitious subordinates. The more ambitious a subordinate is, the more likely he or she is to distort his or her communication to the superior (Read, 1962). This distortion is particularly pronounced when the subordinate distrusts the superior (Maier, Hoffman, and Read, 1963).

In some situations, the channels of communication become overloaded. The manager can sometimes solve this problem by delegating some of his or her tasks. An executive secretary, an assistant, or an entire staff could perform this function for the executive. Also, some organizations attack the overload problem by establishing an Office of the President in which two or more coequal chief executives divide their responsibilities so that no one is overworked. In other situations, the manager might ask his or her subordinates to complete all of the staff work on a project so that his or her function would be merely to approve the final report or product. Whatever the method, the objective is to reduce the amount of communication that must be channeled through a particular organizational position (Gannon, 1977).

It is clear from the above literature that communication can be enhanced or inhibited by organizational structure. In manufacturing organizations, unsatisfactory communication may affect the efficiency of new product development. Therefore, it is meaningful to consider different structures for modern manufacturing organizations to help ensure better communication.

In this research, the organizational communication considered is the communication between representatives from different departments in a manufacturing organization. For further research, the different communication types at different organizational levels could be included, but will not be addressed in this research.

2.7 Dimensions of Organizational Structure which Influence Communication

The structure of an organization may be considered its anatomy; it affects how all the parts interrelate in pursuit of the organization's goals. Structure can influence communication in the organization by limiting and guiding its flow. In fact, some authors (e.g., Roberts & O'Reilly, 1978) think of differences among organizations in terms of differences in communication structure. Within an organization, a main purpose of communication is to help maintain *coordination* among the parts. Depending on the organization's structure, communication can enhance coordination among the parts in different ways. Muchinsky (1987) identified three dimensions of organizational structure which influence communication. They are: (1) size, (2) centralized/decentralized shape, and (3) degree of uncertainty. Only size was considered in this research.

Size is probably the most obvious structural factor in an organization. The larger the size of the organization, the more levels and more types of communication will be necessary. This dimension becomes even more important in large organizations where inter-level communication is allowed, since the total number of links connecting any two individuals is increased by n when the size of the group is increased from n to (n + 1). In this research, the size of the organization was considered to be fixed (i.e., group of size four).

2.8 Control over the Decision Process

As shown in Figure 5, Mintzberg (1979) depicts the decision process as a series of steps over which an individual has more or less control. Given that a situation requires action, the first step is to *collect information* to pass on to the decision maker, without comment, about what can be done. A second step is to process that information to present *advice* to the decision maker about what should be done. A third step is to make the *choice,* that is, determine what is intended to be done. Fourth is to *authorize* what is intended to be done; and finally, to *execute* that which is actually to be done. The power of an individual is determined by his or her control over these various steps. Power is maximized — and the decision process most centralized — when the decision maker controls all the steps: collects information, analyzes it, makes the choice, personally authorizes action, and then executes it. As others persons control these steps, the decision maker loses power, and the process becomes more decentralized.

2.9 Case Studies on Team Approach in the Area of Design

In this section, two recent case studies (i.e., Taurus (Mishne, 1988) and PLUS (1988) are discussed. Both cases reported the use of the team approach in design-to-manufacturing processes in different manufacturing industries. The different results of the design process are featured here to consider whether the team approach is the panacea to shortening the design-to-manufacturing time.

In Mishne's paper (1988, pp. 47-48), entitled "A Passion for Perfection," he said the following:

> Ford Motor Co. took a $3 billion calculated risk on Taurus, but it was a risk that paid off handsomely. What's the key to this success story, that has other automakers rethinking the way they do business? It's simple — team work.

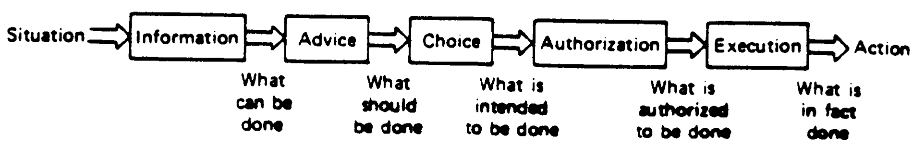


Figure 5. A Continuum of Control over the Decision Process: From Mintzberg, 1979, p. 188.

> The "Taurus" team followed a "program management" approach. Representatives from all the various units — planning, design, engineering, and manufacturing — worked together as a group. The team took final responsibility for the vehicle. Because all of the usually disjointed groups were intimately involved from the start, problems were resolved early on before they caused a crisis; for example, manufacturing suggested changes in design that resulted in higher productivity or better quality.

Finally, Taurus was a big success after a relatively long period of effort — 5 years. It is a successful example of the team approach in consumer products (e.g., automobiles). Will the team approach be so successful if it is adopted to produce high-tech products (e.g. electronics)?

Actually, another case study, "PLUS Development Corporation," reveals more information to answer this question. In this case, the PLUS development team believed that their expertise was in design and marketing and the PLUS managers decided to rely on outside vendors for components and manufacturing expertise. PLUS chose its Japanese manufacturing counterpart, Japan Electro-Mechanical Corporation (JEMCO), to develop the production process in manufacturing the miniaturized hard disk drive for the IBM PC. The PLUS engineers were responsible for product design and the JEMCO engineers addressed manufacturability. The following paragraph, which provides more information about JEMCO, was quoted from the original case (1988, pp. 66):

> JEMCO was solely a manufacturing company, receiving most of its product design from Japan Trading's central laboratories, and manufacturing for private label or for Japan Trading. JEMCO had no marketing function of its own. JEMCO's executives' management style featured team work and open communication and had successfully built their reputation as the premier electromechanical manufacturer in Japan.

During a long cooperation period, the PLUS team couldn't understand, at least initially, why the JEMCO engineers kept demanding so many details about how the design should work. Whereas PLUS designers were used to rough specifications (e.g., "less than 10 mm"), the JEMCO team asked for detailed precision (e.g., "9.8 mm"). PLUS engineers usually designed for functionality and then looked for manufacturing problems; the JEMCO team wanted to design parts and components to exact specifications, anticipating and solving problems before going into production. The JEMCO team's idea was that, if every part meets specifications, then every product assembled from those parts will work. Frequently, the JEMCO engineers called for design changes to enhance manufacturability, even if there was not a great cost savings to gain. The PLUS engineers were accustomed to the typical approach in U.S. companies, which was to do a design, make some mistakes, live with them, and learn for the next time.

One of the final results from JEMCO's approach was a quality product with a falling-behind schedule. Surprisingly, they found that another company advertised a competitive product updated for the new PC's. As stated by the president of PLUS (pp. 66-67), "We had expected a 9 to 12 month window with no product competition but that has been cut to two months."

The hard disk product manager said the following with regret (pp. 66-67):

> I'm in a state of shock to think that, after we invested 2 years and 20 million dollars in developing this product, another company can develop a competitive product in four months. This company (PPC) took fairly standard parts and copied our product idea. I think PPC is just the first of many companies that will follow with a similar product. I am very concerned that we become so enamored of our gold-plated technology that we missed the market opportunity. We could have had a product out similar to PPC's over a year ago.

After studying these two cases, readers may feel an irony that the same philosophy led to different results. However, if the top priority of the manufacturer (e.g., quality of final products in Taurus case; and reduced design-to-market time in PLUS Development case) is considered, the results are not surprising. One of the conclusions made by comparing these two cases was that the team approach in design may not be the panacea to all manufacturers.

2.10 Summary of the Literature Review

In this chapter, the literature pertaining to information and its definition and measurement has been reviewed. Stages in the model of product development proposed by Clark, et al, were outlined and simplified for further use. Current studies of organizational effects on manufacturing firms were reported and summarized. An intuitive comparison between "flat" and "tall" organizations, as well as the popular "team" approach in design with one application, was given to show the structural effects on organizational efficiency. The definition of "communication networks" and characteristics of communication networks in various structures were mentioned. In the section on organizational communication, three dimensions of organizational structure which influence communication were identified. Mintzberg's theory of control over the decision process was introduced to explain the differences between centralized and decentralized organizational structures from the "power" point of view. Finally, case studies describing two companies' experiences in design-to-manufacture efforts were described.

These ideas have helped to inform the modeling work, discussed next in Chapter Three.

Chapter 3. Problem Formulation — A Modeling Approach

3.1 Introduction

Considering the current range of studies in strategic management, it was found that more attention was paid to financial and technological issues than to organizational ones. In addition, experimentation about organizational efficiency performed by social psychologists was restricted to small groups of people instead of being at the level of a multi-echelon organization. Therefore, the writer applied several methodologies (e.g., operational research modeling techniques and simulation) introduced in industrial engineering to initiate a rudimentary quantitative study of organizational efficiency at the level of production. The participating departments considered in production were marketing, design, and manufacturing engineering.

The overall purpose of this research was to develop an initial framework for comparing communication time within two different organizational structures in a quantitative way. As mentioned in Chapter One, the pure hierarchical and the pure egalitarian structures were chosen for investigation.

The reader will also recall from Chapter One that, for purposes of this research, phases of developmental activities were defined to move a new product from conceptual design to manufacturing introduction (See Section 3.3 as well). In each phase, decisions must be made before proceeding to the next phase. Information must be acquired before the responsible decision-maker can make rational decisions. Thus, it is believed that the time required to make these various decisions is a function of the firm's communication network (or organizational structure) and the time required to acquire sufficient information at each decision point.

Of the attributes affecting a product's success, which were mentioned in Section 2.2.2, this research is primarily concerned with the attribute of timeliness and, in fact, will focus on only one dimension of timeliness. The literature reviewed emphasized the need to reduce the time from product design concept to customer delivery. This research will address only part of this production cycle. The research is also limited to the investigation of only one factor which can influence the length of the production cycle; namely, the firm's type of organizational structure and the effect this structure may have on communication and decision-making time.

This research is an application of simulation methodology to decision-making processes in communication channels through which the information for product development flows. Among several possible measures of organizational effectiveness and organizational efficiency, a single criterion — time — was used as the efficiency measure in this research. By comparing the time consumed for product development in two different structures, some insights into the popular "team" approach versus a more traditional approach in product design are provided.

It is the purpose of this chapter to explain the methodology used to estimate the decision-making time required to accomplish four production phases in each of two organizational structures. Three measures for assessing the effectiveness of communications within an organization will first be discussed. Then the four production phases will be briefly reviewed. Sections 3.4 and 3.5 contain a discussion about the decision-making process assumed for the pure hierarchical and pure egalitarian organizational structures, respectively. The models and philosophies relating information to the time required to make decisions in each organizational structure are discussed in Section 3.5.2.

In this chapter, the building block of the information-acquiring and decision-making processes for an individual decision-maker is first investigated. The modeling work is shown in Section 3.3. It was used to embed these processes in two antithetic structures introduced in Chapter Two — hierarchical and egalitarian structures.

3.2 Measures of an Organizational Communication Network

Three popular measures of the successfulness of organizational communication (Leavitt, 1978, 1988; Gannon, 1977, 1988) are: speed (efficiency), quality (reliability), and satisfaction (a psychological measure). The first measure (efficiency) refers to the time consumed in the design-to-premanufacturing stage, and was adopted as the single measure for this research. For this measure, simulation modeling was applied to test the efficiency of different organizational structures.

For the second measure, reliability refers to the "accuracy" of the information passed in a communication network. The reliability function and reliability measures are suggested to be addressed in further research. From the reliability model, the amount of distortion of the input signal should be detectable. One intuitive observation of this measure is: *The flatter the organization, the shorter the communication channel.* Therefore, less distortion is expected to appear in the communication network of a flat organization. That is to say, the flatter the organization, the higher the reliability of the communication network.

The third measure (satisfaction) has been extensively studied by researchers of psychology and should be summarized according to structure. In short, the more egalitarian the organization, the more participation will be felt by the participants; and the feeling of belonging to the environment will be developed (Leavitt, 1978; Baron, 1986). Finally, higher satisfaction will be observed among the group members in the network as a whole in an egalitarian structure. The third measure is the most difficult one on which to perform a quantitative analysis since it relates directly to the attributes of the human being and, hence, is difficult to model.

3.2.1 Speed (Efficiency) Analysis

"Efficiency" refers to the speediness of information transferred from the "raw material" to the final product. The efficiency measures were applied to organizations of different structures (i.e., hierarchical and egalitarian) in this research.

Readers may recall the "team" approach in design, which was first introduced in Section 2.3.2. Actually, teams may be considered as shadow organizations which change with the size of the firm and the complexity of the design project; a team approach is an example of the egalitarian model which is antithetic to the hierarchical model. Comparisons of the organizational efficiency between these two structures were made according to the simulation results.

3.2.2 Reliability (Accuracy) Analysis

"Reliability" refers to the accuracy of information transmitted from the source to the receiver, or at least the perceived accuracy — the extent to which the receiver perceives that the information is correct. In a sense, the accuracy of information can be thought of as its validity. In discussing accuracy, the term "distortion" should also be mentioned. Information distortion is the incorrect reproduction of objectively correct information.

Distortion reduces reliability. Distortion can be caused by either unconscious or deliberate alteration. All too often in an organization the same message is not received by all parties. After people "exchange notes" on a particular message, there often remain subtle differences in content (e.g., "Well, the way I heard it was ..."). Somewhere along the communication network distortion has occurred.

What causes distortion? A study by O'Reilly (1978) shows several correlates of information distortion. Senders suppress important but unfavorable information sent to superiors and accent favorable information about themselves. Subordinates often screen information before sending it upward to avoid upper-echelon overload, but deliberate distortion can have a negative effect (Athanassiades, 1973). This is especially true when important but unfavorable information is sent. Superiors may lose the ability to discriminate between the relevant and irrelevant with a consequent loss in decision-making performance. O'Reilly also found that low trust in the receiver results in greater suppression of information by senders, especially when the information reflects unfavorably on the sender.

If the original organization that the representative comes from follows centralized control, the information flow forms a "series system." In a *series system,* the reliability of the information can not be easily sustained (as suggested in the following example). But if the organization that the representative comes from follows an egalitarian type of control, the information flow forms a "parallel system" which sustains the reliability much better (as shown in the following example).

A simplified example borrowed from circuit analysis is the reliability of a two-component (of the same type) system. For the serial system, the reliability (counted as the probability of a signal going through) is $(1 - p)^2$. For the parallel system, the reliability is $(1 - p^2)$, where p is the probability of malfunction of one component in either system. Since p, a probability measure, is always located in the interval [0, 1], the reliability measure of a two-component serial system $(1 - p)^2$ is always smaller than or equal to that of a two-component parallel system $(1 - p^2)$.

The interested reader may read more in the area of system reliability. However, the reliability analysis introduced here was to show that the efficiency measure was not the only one that could be considered in structural effects on product development.

3.2.3 Satisfaction (Psychological) Analysis

Higher satisfaction has been observed among team members in egalitarian structures (Baron, 1983). Compared to the members in a hierarchical structure, the members in an egalitarian structure have more and better chances to participate in and contribute to the decision-making processes directly related to their work. This participative experience helps to make the members experience feelings of recognition and achievement. The works in social psychology (e.g., Baron, 1986), provide more information through the design and analysis of experiments. The satisfaction measure was introduced here to remind the reader that trade-offs among measures should be considered when a suitable organizational structure needs to be chosen.

Among the three measures, the efficiency measure will be investigated further in this research; the other two measures, though, are beyond the scope of this research and will not be addressed.

3.3 The Sequence of Events (Four Major Phases) in a Product Design Process

Eight phases in the life of a product or process were introduced in Chapter One. They were simplified to four representative phases to present a better picture of the job done in each phase as well as to indicate the responsible department(s) in each phase. The four representative phases are: conceptual design, basic design and prototype building, pilot production, and manufacturing introduction. A tabulated diagram of these four phases is as follows:

Phase	*Primary Activity*
1	Conceptual Design
2	Basic Design and Prototype Building
3	Pilot Production
4	Manufacturing Introduction

In the following two sections, detailed illustrations of decision-making processes (and participants) in each phase are provided for pure hierarchical and pure egalitarian structures respectively.

3.4 Decision-Making Phases in Two Antithetic Organizational Structures

The decision-making phases in two antithetic organizational structures are introduced next. The first case is associated with the pure hierarchical organizational structure; the second case is associated with the pure egalitarian structure.

Case One: Decision-Making Phases in a Pure Hierarchical Organizational Structure

The first case is the serial (hierarchical) decision-making model. In this case, prior experience and learning effects from the previous design projects are implicitly applied. There are four phases in this model with different departments responsible for them (see Figure 6).

In Phase One, the only people involved are the program coordinator and the marketing representative. The program coordinator gives an order to the marketing representative who is responsible for conceptual design. The marketing representative then begins to gather and analyze the information from the market, consulting firms, competing peers, and the offices in the marketing department. The marketing representative is also responsible for conception of the alternate product(s), and for forecasting the sales volume of the existing product (in inventory), as well as the product which is chosen to go market. Whenever the program coordinator thinks there is enough information (say, Q_1%, where the judgment is based on the program coordinator's prior experience), the project with the appropriate information (filtered and/or enriched by the program coordinator) will be transferred to the next department — the design department.

In Phase Two, the only people involved are the coordinator and the design representative. The design department will receive an order and the marketing information (in the form of a conceptual design) from the coordinator. The marketing information may also include customers' preferences, price suggestions, and the cost of similar competitive products. The design represen-

Phase	Primary Activity	Responsible Department
1	Conceptual Design	Marketing
2	Basic Design and Prototype Building	Design
3	Pilot Production	Design
4	Manufacturing Introduction	Manufacturing Engineering

Figure 6. A Simplified New Product Development Process for Both Structures

tative is concerned with the basic design, prototype building, material requirements, tolerance approximations, and other design details. Again, when the program coordinator thinks there is enough information (say, Q_2%), the project will be moved forward to the third phase.

The coordinator and (again) the design representative are involved in Phase Three. As in the first two phases, the design representative will receive an order and filtered information from the coordinator and will be responsible for pilot production. For Phase Three, Q_3% information is the minimum requirement to proceed to Phase Four. If more information is needed from the manufacturing engineering or marketing departments, the coordinator will act as the information exchanger.

The coordinator and the manufacturing engineer are involved in Phase Four. The manufacturing engineer is responsible for manufacturing introduction, including fixture and jig design, layout design and/or re-design, production planning, resource allocation, and scheduling work. If any information is needed from the design and marketing departments, the coordinator will act as the information exchanger. If the coordinator thinks that there has been enough information (e.g., Q_4%) generated for production purposes, the production process will then begin. The reader should recall that face-to-face communication between representatives of departments is prohibited in the pure hierarchical structure.

In the hierarchical model, only one of the three departments is directly involved in the information-acquiring and decision-making processes at each phase. In the tabulated diagram below, the symbol p_{ij} means fraction of involvement for phase i and department j (j = 1 represents the most involved department):

Phase	*Primary Activity*	*Involvement (Normalized value)*
1	Conceptual Design	Mktg (p_{11}), Desn (p_{12}), MfgE (p_{13}).
2	Prototype Building	Desn (p_{21}), Mktg (p_{22}), MfgE (p_{23}).
3	Pilot Production	Desn (p_{31}), MfgE (p_{32}), Mktg (p_{33}).
4	Manufacturing Intro.	MfgE (p_{41}), Desn (p_{42}), Mktg (p_{43}).

where

$$\sum_{j=1}^{3} p_{ij} = 1, \; i = 1, \ldots 4,$$

and

$$p_{i1} = 1; \; p_{i2} = 0 \text{ and } p_{i3} = 0$$

for $i = 1, \ldots 4$.

According to the preceding constraints, there is only one participating department in each phase in the hierarchical model; and the total involvement of each phase is normalized to be one. For example, marketing is the only department involved in the decision-making process in phase one; therefore $p_{11} = 1$.

<u>Case Two</u>: <u>Decision-Making Phases in a Pure Egalitarian Organizational Structure</u>

In the pure egalitarian structure, representatives from marketing, design, and manufacturing engineering work as a team. Although representatives from different departments have different amounts of involvement at different phases of product development, each of them is involved to some extent in all phases. In the tabulated diagram, the symbol p_{ij} means fraction of involvement for phase i and department j (j = 1 represents the most involved department):

Phase	*Primary Activity*	*Involvement (Normalized value)*
1	Conceptual Design	Mktg (p_{11}), Desn (p_{12}), MfgE (p_{13}).
2	Prototype Building	Desn (p_{21}), Mktg (p_{22}), MfgE (p_{23}).
3	Pilot Production	Desn (p_{31}), MfgE (p_{32}), Mktg (p_{33}).
4	Manufacturing Intro.	MfgE (p_{41}), Desn (p_{42}), Mktg (p_{43}).

where

$$\sum_{j=1}^{3} p_{ij} = 1, \; i = 1, \ldots 4,$$

and

$$p_{i1} > p_{i2} > p_{i3}$$

for $i = 1, \ldots 4$.

At each phase, the most involved department representative works as the coordinator in the team. The coordinator will continue to ask for information from other departments or their representatives until the most involved department representative thinks that "enough" (at least Q%) information has been acquired from each individual department. For example, at Phase One, manufacturing's involvement is p_{13}, and marketing will keep on asking the manufacturing representative for more specific information until $Q\% \cdot p_{13}$ (the weighted percent of perfect information originally expected by marketing representative from the manufacturing representative in Phase One) has been acquired. It was assumed that marketing will act as the coordinator of the first phase due to its primary involvement at this stage. The marketing representative will continue asking for information from design and manufacturing representatives (as well as from the marketing department). The enquiring processes will not stop until design, manufacturing, as well as marketing have cumulatively supplied Q% ($Q\% \cdot (p_{11} + p_{12} + p_{13}) = Q\%$) of the information asked for (by the marketing representative). After the project has moved to the next phase, the process repeats with the design representative as coordinator.

3.5 The Building Block of the Information-Acquiring and Decision-Making Processes

In order to perform the efficiency analysis (introduced in Section 3.2) systematically, it was appropriate to model the decision-making processes first.

3.5.1 The Flowchart of the Decision-Making Processes

It is assumed that there are three steps in a decision-making process:

1. The decision maker collects information from the suppliers of information.
2. The decision maker applies prior experience to judge the sufficiency of the gathered information.
3. The decision maker then makes one of the following choices:

    a. If the decision maker thinks that the information is sufficient (target value met), he or she will then make a decision and pass the gathered information as well as his or her decision to a successor; or

    b. If the decision maker thinks that the information is not sufficient, then he or she will ask for more information from the supplier. The loop then goes back to the first step (see Figure 7).

3.5.2 The Basic Relationship Between Perfect Information and Time in an Information-Acquiring Process

It is assumed that the percentage of perfect information follows an exponential function with time. Among many possible alternatives, one exponential function that shows this relationship is a memory-retrieval function discussed by Wickelgren (1987):

$$y = L \bullet (1 - e^{-R \bullet [\tau - t]})$$

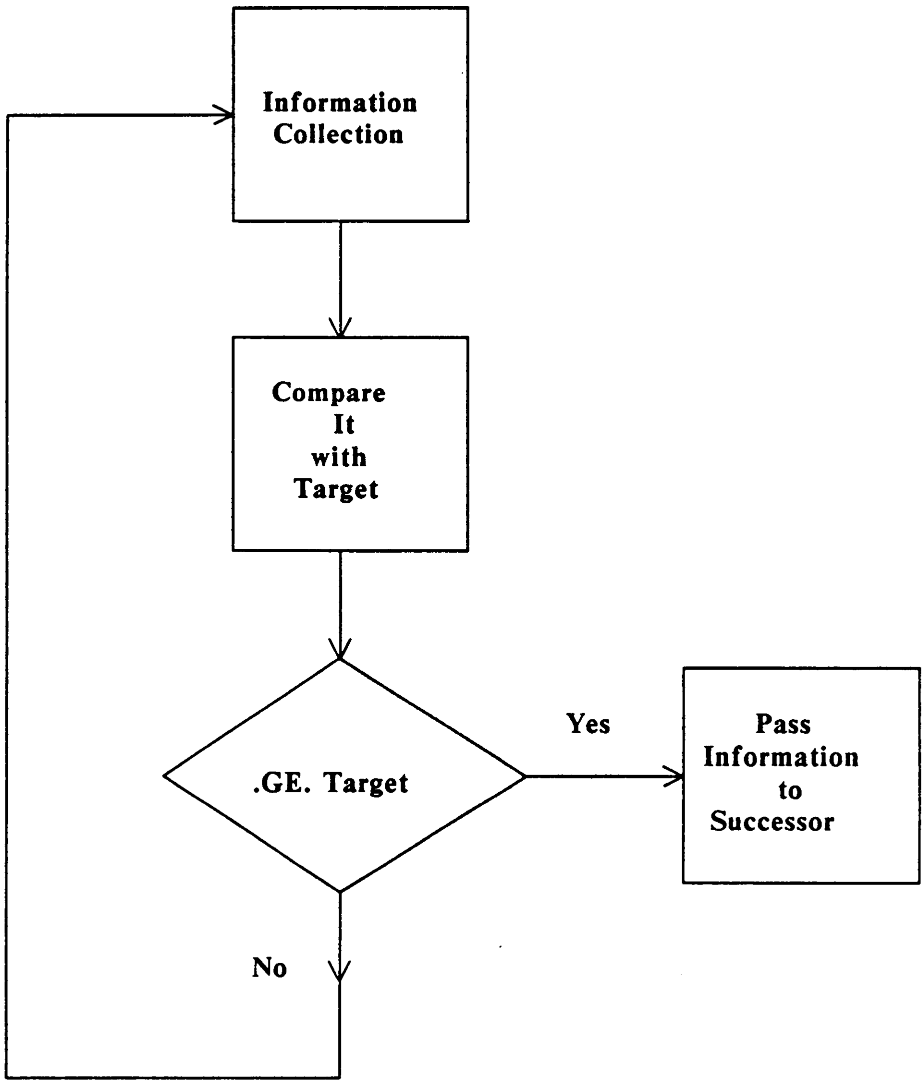


Figure 7. The Information-Acquiring Process

where y is the percentage of perfect information acquired, τ is the time elapsed, L and R are reserved parameters, and ℓ is the control variable for the time elapsed in the orientation stage (ℓ is assumed to be zero in this research). The reasons for choosing this curve are: this curve is mathematically well-behaved, and it exhibits a diminishing marginal rate of information obtained over time.

Information available from a decision maker (e.g., a manager) is directly related to his or her personal knowledge (e.g., in capital, labor, materials, or processes). Generally speaking, the value of his or her personal knowledge is implicitly shown by his or her position in the management hierarchy.

In light of the fact that decision makers at different management levels have different amounts of personal knowledge and responsibility, they must consider different numbers of production variables and should follow different information-versus-time curves. Several management levels with their major emphases in their decision making are classified as follows (see Table 1). In the table, C (or c), L (or l), and M (or m) represent capital, labor, and material respectively. Upper-case letters mean major emphasis, and lower case letters mean considerations of less importance. For a top-level manager, capital, labor, and material are all of primary importance in decision making. For a middle-level manager, labor and material are of primary importance in decision making; but major capital expenditure is not entirely decided by the decision maker. For a low-level manager, his or her major emphasis is mainly the materials required for production. Thus, if a low-level manager is asked some question about capital, he or she will not be expected to respond as well as (or as quick as) a manager at the top level. From this table, it is seen that managers at higher levels have more responsibilities. Therefore, managers at higher levels have more personal knowledge for higher level decision making and need more time to make those decisions. However, it is reasonable to consider different curves for different levels of management hierarchy only when the benefits of doing that justifies the extra efforts needed. In this research, only a single curve of a single management hierarchy is considered.

Table 1 was introduced to remind the reader that there were some undecided parameters in the equation introduced in Section 3.5.2. It is possible to attribute one parameter to the level of management hierarchy.

Management Hierarchy	Management Emphasis
Top level manager	(C, L, M)
Middle level manager	(c, L, M)
Low level manager	(c, l, M)

Table 1. Management Hierarchy and Management Emphasis

Figure 8 is a conceptual plot of the equation for y discussed previously. (From now on, X will represent this value, as a percent of perfect information.) Assume that a decision maker requests information from Department A at $t = t_1$; the percent of perfect information passed to the decision maker is likely to be small, say 20%. In Figure 8, it is assumed that the percent of perfect information received at any given time is a random variable having a truncated normal distribution. At different points in time, different normal distributions apply. That is, at time t_1, it is assumed the mean (or expected) value is 20% and the distribution has a large variance. Then, if Department A is queried at a later time, say t_2 , the percent of perfect information passed to the enquirer would be from a normal distribution with an expected value of 50%, and having a smaller variance than the normal distribution at time t_1. Similarly, information received at time t_3 would be from a normal distribution having an expected value of 80%, and having a smaller variance than the distribution at time t_2.

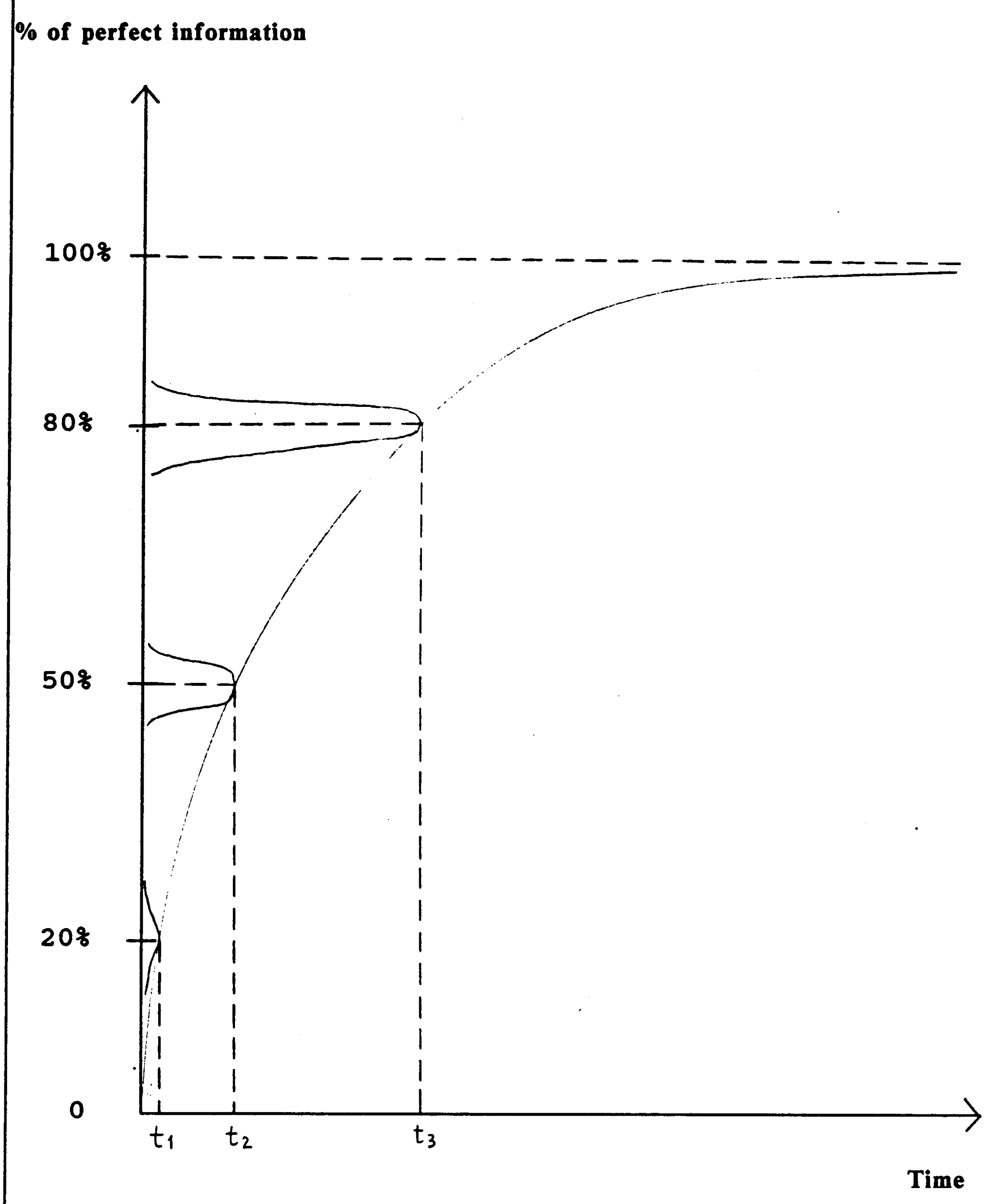


Figure 8. The Relationship between the Expected Percentage Values of Perfect Information and Time: The expected values of information are shown with their accompanying distributions

3.5.3 Embedding the Information-Acquiring Processes in Both Structures

Embedding the information-acquiring process in both structures, the following analysis can be performed. Figure 9 helps to explain the information-acquiring and decision-making processes.

In Figure 9, the first subscript of the symbol, U, is used to represent the structure type: egalitarian (1), or hierarchical (2). The second subscript is used to denote the nth distribution from which the sampling is made in the information-acquiring process. For example, U_{11} denotes the mean value of the first sampling distribution in the egalitarian model, and S_{23} means the standard deviation of the third sampling distribution in the hierarchical model.

According to the basic relationship between perfect information and time introduced in the last section, as well as the underlying assumption that the quality of the final product is directly proportional to the information acquired, the sampling process is performed. The first sampling distribution exhibits the lowest mean value ($\mu_{\bullet 1}$), and the highest standard deviation ($\sigma_{\bullet 1}$). The last sampling distribution exhibits the highest mean value ($\mu_{\bullet 3}$ for the egalitarian structure, and $\mu_{\bullet 6}$ for the hierarchical structure) and the lowest standard deviation ($\sigma_{\bullet 3}$ for the egalitarian structure, and $\sigma_{\bullet 6}$ for the hierarchical structure). It is assumed that perfect information is available in the long run from both structures ($\mu_{\bullet 3}$ in egalitarian $=$ $\mu_{\bullet 6}$ in hierarchical). Also it is assumed that, on the average, it will take twice as many iterations to acquire the same level of information in the hierarchical structure as compared to the egalitarian structure, since the latter has a better chance to get direct and firsthand (thus undistorted) information. If the average number of iterations to achieve the preset ideal amount of information in a typical hierarchical structure is 2n, then the number of iterations needed in a typical egalitarian structure will be n.

There are two parallel parts in Figure 9; the left-hand side is for the egalitarian structure and the right-hand side is for the hierarchical structure. The building block of the information acquiring and decision-making processes for the egalitarian structure is illustrated as follows (showing one phase only). The first three samplings (from truncated normal distributions having mean value μ_{11}) are made for the three participating departments, and the weighted average is calculated. If this

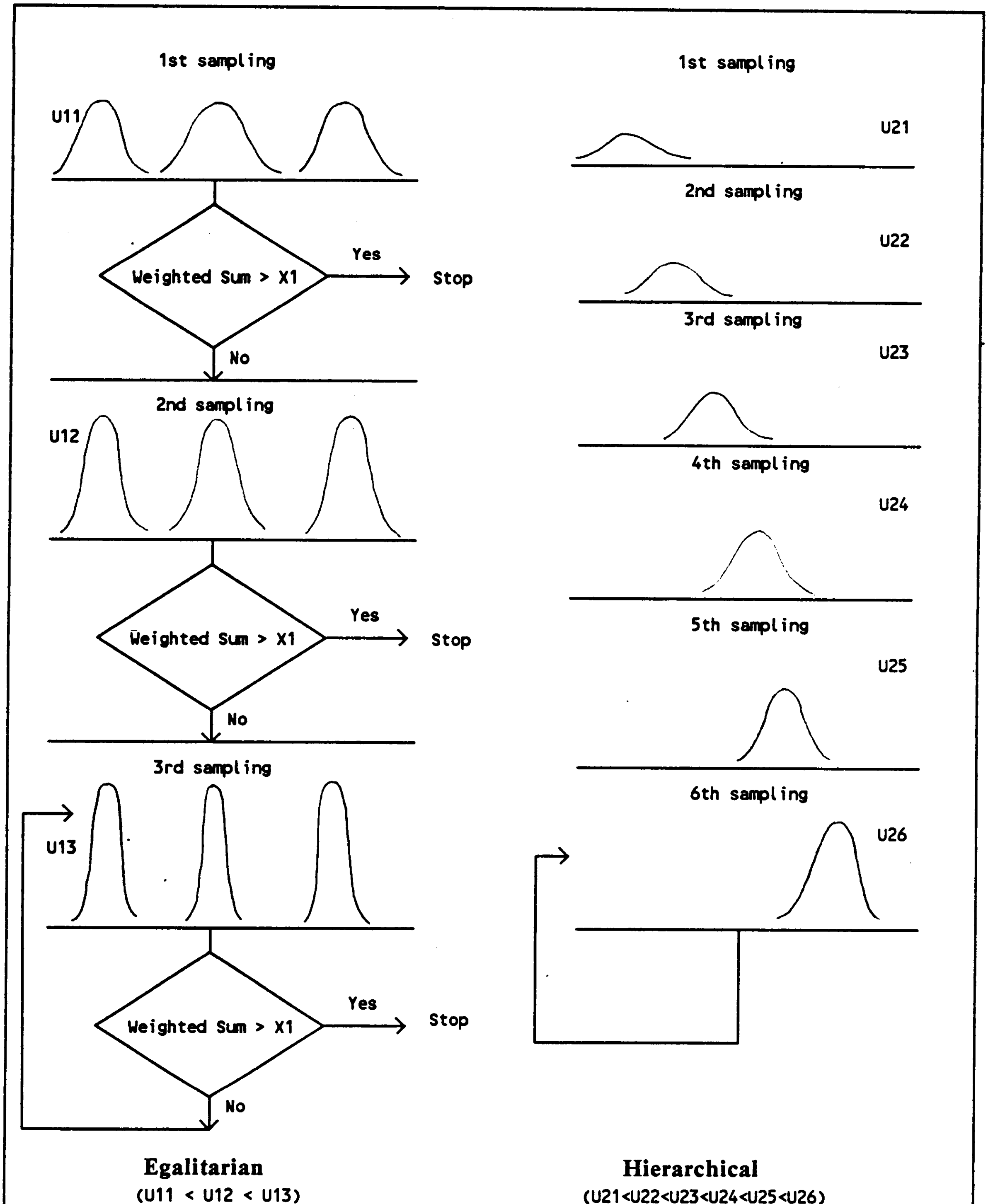


Figure 9. Building Block of the Information Acquiring and Decision-Making Processes: Egalitarian vs. Hierarchical, i.e., direct discussion vs. indirect information acquiring.

weighted value is greater than the preset target, X_1, the information-acquiring process is successfully completed, and enough information has been acquired for decision making for the phase in question. Hence, the flowchart suggests "stop." Otherwise, another three samplings are made from truncated normal distributions having improved mean value, μ_{12}, and the weighted average is again calculated. If the weighted value is greater than a preset target, X_1, the process stops (i.e., the whole process of the phase in question is complete). Otherwise, resampling will need to be made, etc. After the third iteration, however, the mean value of the information acquired is assumed to remain unimproved (at the value of μ_{13}), under the assumption that the cost for further data searching would exceed its value. The same reasoning can be applied to the information-acquiring and decision-making processes for the hierarchical structure. However, only one value is sampled at a time (since there is only one participating department in each phase); and the mean value of the information will remain unimproved after the sixth iteration in each phase. (This assumption could be modified in future research.)

The level of complexity of the product is defined in terms of the average number (n) of samplings. The classification is shown in Table 2. In this research, it is assumed that a product of middle level complexity (n = 3) is being considered.

Level of Complexity	Avg. # Samplings (n)
Low level	1 ~ 2
Middle level	3 ~ 4
High level	5 ~ 6

Table 2. The Classification of Product Complexity Level (in terms of the average number (n) of samplings)

Finally, in the simulation programs of this research, it is assumed that the hierarchical structure needs to be sampled six times to acquire the same amount of information which comes from the first three samplings made in the egalitarian structure. (80% information (as discussed in Section 2.3.2) is assumed to be the target value for reasonable decision-making use.)

As mentioned earlier in this section, the exponential relationship between the percent of perfect information and the time the information is received is a function of the parameters L, R, and t. Values for these parameters are unknown and, to the author's knowledge, have not been estimated by experimentation with human decision makers and reported in the literature. Thus, the author chose to approximate the exponential function by judgment and in the following way.

For the egalitarian organizational structure, it was assumed that the first query for information would be from a truncated normal distribution (of percent of perfect information) having a mean value, μ_{11} , equal to 20% and standard deviation, σ_{11} , equal to 80%. The first query would occur at t = two weeks. If a second query (sample) is necessary to reach a target value of X = 80% of perfect information, the normal distribution would have a mean value of μ_{12} = 50% and standard deviation of σ_{12} = 50%. This sampling would occur at time t = 4 weeks. The third and subsequent samples would be from a normal distribution with a mean value of μ_{13} = 80% and standard deviation of σ_{13} = 20%. All samples occur at two-week intervals.

For the hierarchical organizational structure, similar sampling distributions were assumed. However, it was reasoned that more sampling trials would be required, at two weeks intervals, to obtain approximately the same information as from the egalitarian structure. In fact, it was reasoned that the number of samples should be doubled (See Section 1.1 and Figure 3). The specific normal distributions assumed for the hierarchical structure were the following: μ_{21} = 10% and σ_{21} = 90%, μ_{22} = 24% and σ_{22} = 76%, μ_{23} = 38% and σ_{23} = 62%, μ_{24} = 52% and σ_{24} = 48%, μ_{25} = 66% and σ_{25} = 34%, and μ_{26} = 80% and σ_{26} = 20%. Samples beyond six would be from the last distribution.

The numerical values for these truncated normal distributions are summarized in Figure 10 and interpreted into a piecewise linear approximation to the exponential relationship, as shown in

Figure 11. (As the reader views Figure 11, it should be recalled that information requests occur at two weeks intervals).

Case One: Embedding the Information-Acquiring Processes to the Hierarchical Structure

For the hierarchical structure, the information source is unique for each department. Mainstream information comes from its predecessor in the sequence of events (marketing → design → manufacturing engineering). For example, a design representative acquires most of the information from a marketing representative. An implicit assumption suggests that each department could also acquire information from others which are not its immediate predecessor via the representative from the general manager's office. It is assumed that the first sampling will be made from the distribution with mean μ_{11} and standard deviation σ_{11}. A target value X_1 is first defined, after which the sample value x_1 from the truncated normal distribution (μ_{11}, σ_{11}) will be compared with the target value. If $x_1 < X_1$, then a resample will be made again after a certain time period (say, two weeks). The analogy between the computer simulation operation and a real decision-making process can be explained as follows. There is a minimum preset value of the amount of information that needs to be acquired from each department before proceeding to the next event in the sequence. This preset value is then used as the threshold by the program coordinator to make the decision on the flow of the sequence of events. The program coordinator has acquired the capability of judgment from his or her prior experience and/or other unspecified resources. If the information supplied by one of the departments (i.e., a sampled value x_1 from a simulation operation) is less than the preset value (the target value X_1), this department representative will be told to have the department work for two more weeks and supply the information again for evaluation. Meanwhile, the department continues to work and will have a better chance of getting a sample greater than X_1 after two weeks. The process will then proceed to the next distribution and the sampling will be made from the distribution with mean value μ_{12} and standard deviation σ_{12}. The sampling and evaluating

Egalitarian

Mean	Std. Dev.	Truncated Range of Means
$\mu_{11} = 20\%$	$\sigma_{11} = 80\%$	0% ~ 100%
$\mu_{12} = 50\%$	$\sigma_{12} = 50\%$	0% ~ 100%
$\mu_{13} = 80\%$	$\sigma_{13} = 20\%$	0% ~ 100%

Hierarchical

Mean	Std. Dev.	Truncated Range of Means
$\mu_{21} = 10\%$	$\sigma_{21} = 90\%$	0% ~ 100%
$\mu_{22} = 24\%$	$\sigma_{22} = 76\%$	0% ~ 100%
$\mu_{23} = 38\%$	$\sigma_{23} = 62\%$	0% ~ 100%
$\mu_{24} = 52\%$	$\sigma_{24} = 48\%$	0% ~ 100%
$\mu_{25} = 66\%$	$\sigma_{25} = 34\%$	0% ~ 100%
$\mu_{26} = 80\%$	$\sigma_{26} = 20\%$	0% ~ 100%

Figure 10. Numerical Values Used in the Illustration Example

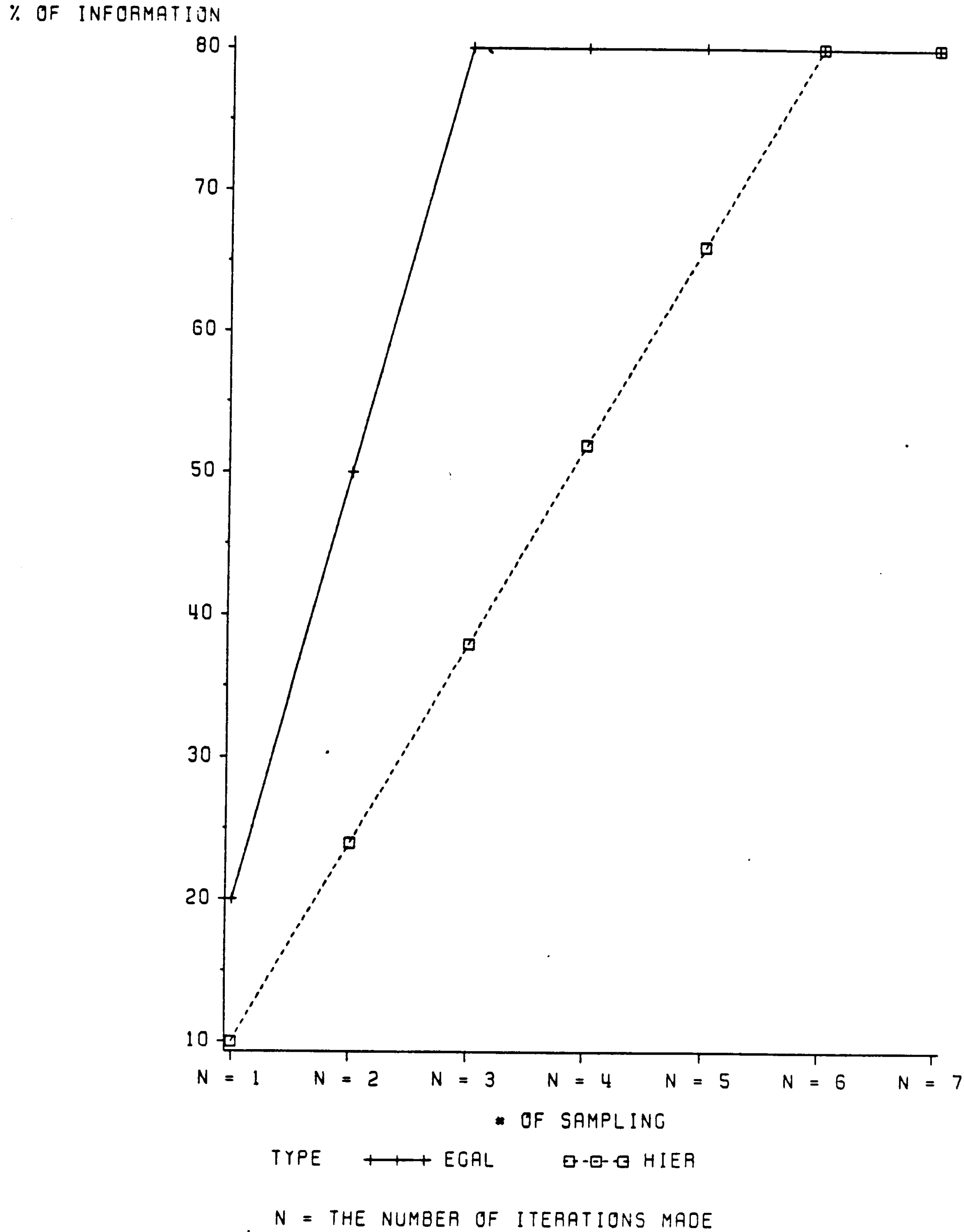


Figure 11. A Diagram of Percent of Information vs. Number of Samplings: Comparisons made between hierarchical and egalitarian structures.

process will continue until $x_1 > X_1$, and will then proceed to the next phase in a product development cycle, sampling until $x_2 > X_2$, $x_3 > X_3$, and $x_4 > X_4$, thereby completing the four phases.

Numerical Illustration of the Sampling Process for a Hierarchical Structure

As discussed in the last paragraph, the basic modelling work for simulating a hierarchical structure is now complete. In this section, the numerical illustration that was used for the simulation is presented to show exactly how the sampling is done in the program. It is assumed that at least 80% information (compared to 100% perfect information) is needed for satisfactory decision-making. When the representative of Department A asks another representative in Department B for information for the first time, it is expected that, on average, 10% information (compared to 100% perfect information) will be received via the representative from the general manager's office. If the information received from Department B the first time is higher than 80% (e.g., 83%), the enquiring process stops; otherwise the enquiring process will continue. Due to the learning process experienced by both departments during the product development process, it is expected that, on average, 24% information (compared to 100% perfect information) will be received via the representative from the general manager's office at the time of the second sampling. If the information received from Department B for the second time is higher than 80% (e.g., 81%), the enquiring process stops; otherwise the enquiring process will continue. Again, the learning effect will continue to raise the expected value of the amount of information received for decision making by 14%. If the information received from Department B for the third time is higher than 80% (e.g., 89%), the enquiring process stops; otherwise the enquiring process will continue. Similar processes will continue, and the mean value will increase at the rate of 14% per sampling until the mean value reaches 80% (at the sixth iteration). From this time on, it is assumed that the learning effect has achieved its plateau stage and no more significant improvement is to be made (i.e., the expected value of the amount of information received will stay at 80%), to reflect another popular criterion used in product development — stop investing in data searching when extra effort is no longer needed to meet the preset target. If the information received from Department B on the fourth sample is higher than 80% (e.g., 86%), the enquiring process stops; otherwise the enquiring process will not stop until the the information received from department B on the nth sample is higher than 80%. Of course, several samplings may have to be made before one sampled value greater than 80% is received. The enquiring process is then terminated.

<u>Case Two</u>: <u>Embedding the Information-Acquiring Processes in the Egalitarian Structure</u>

For the egalitarian structure, the same procedure is adopted with one exception. The exception is that, at each phase, the information comes from more than one source. Before the information from those sources is gathered, the information from each source will go through the same screening iterations as described in the hierarchical structure.

In a complete product development cycle, there are four screening processes to go through before x_4 in the egalitarian structure can be found. x_4, defined below, is the aggregate of information coming from multiple sources. In addition, x_i in the following constraints can only be attained under both of the following conditions:

1. All the components in each aggregate information term at each stage must exceed the target value X_i. For example, at Stage One, $x_{1mk} \geq X_1$, $x_{1d} \geq X_1$, and $x_{1me} \geq X_1$. The subscript mk represents marketing; d represents design; and me represents manufacturing engineering.

2. Each aggregate information term (x_i) must also exceed the target value X_i. For example, at stage one,

$$x_1 = p_{11} \cdot x_{1mk} + p_{12} \cdot x_{1d} + p_{13} \cdot x_{1me} \geq X_1$$

In mathematical terms, the following inequality constraints must be satisfied in order to end the simulation run. The p_{ij}'s were defined in Chapter 1, Section 2.

First, at Stage 1, the following criterion

$$x_1 = p_{11} \cdot x_{1mk} + p_{12} \cdot x_{1d} + p_{13} \cdot x_{1me} \geq X_1$$

should be satisfied before the beginning of Stage 2.

Similarly, at Stage 2, the following criterion

$$x_2 = p_{21} \cdot x_{1mk} + p_{22} \cdot x_{1d} + p_{23} \cdot x_{1me} \geq X_2$$

should be satisfied before the beginning of Stage 3.

Again, at Stage 3, the following criterion

$$x_3 = p_{31} \cdot x_{1mk} + p_{32} \cdot x_{1d} + p_{33} \cdot x_{1me} \geq X_3$$

should be satisfied before the beginning of Stage 4.

Finally, at Stage 4, the following criterion

$$x_4 = p_{41} \cdot x_{1mk} + p_{42} \cdot x_{1d} + p_{43} \cdot x_{1me} \geq X_4$$

should be satisfied to finish the simulation process.

Numerical Illustration of the Sampling Process for an Egalitarian Structure

At Stage 1, assume that x_{1mk} , x_{1d} , and x_{1me} are randomly sampled from a truncated normal distribution with mean value μ = 20%. If the smallest value of the triplet is greater than 80% (the sufficient condition), then the weighted information is greater than 80% (the necessary condition) and Stage 2 will then begin. Otherwise, another three values representing x_{1mk} , x_{1d} , and x_{1me} are sampled from a truncated normal distribution with improved mean value μ = 50%. (Recall that this represents sampling two weeks later.) If the smallest value of these three is greater than 80%, then the weighted information is greater than 80% and Stage 2 will then begin. Otherwise, another three values representing x_{1mk} , x_{1d} , and x_{1me} are sampled from a truncated normal distribution with improved mean value μ = 80%. If the smallest value of the triplet exceeds 80%, then the weighted information exceeds 80% and Stage 2 will then begin. Otherwise, another three values representing x_{1mk} , x_{1d} , and x_{1me} are sampled from a truncated normal distribution with the unimproved mean value μ = 80%. This resampling process will not stop until the smallest value among the triplet exceeds 80%. Whenever this terminating requirement is fulfilled, the second stage will then proceed.

The overall process will be complete when all four stages are finished.

3.5.4 Simulation Processes

The simulation programs for both structures were written by applying the processes illustrated in the numerical illustrations in Section 3.5.3. The program structure is further discussed in Chapter Four.

3.5.5 Final Comparisons to be Made Between the Two Structures

The total amount of time used to have the sample value exceed X_4 in the pure egalitarian structure was compared with that used to have the sample value exceed X_4 in the pure hierarchical structure. Conclusions were made on the features of the more efficient structure. The simulation was run 1,000 times to lessen the initial effects on the final result which was used for comparison.

In Section 4.2, 90% confidence intervals were calculated; other statistical analysis was performed for both structures to help explain the simulation results.

3.6 Summary of the Basic Assumptions Used for This Research

The basic assumptions of this research were that:

1. The product itself is a bundle of information embodied in materials;

2. The product quality is directly proportional to the amount of information acquired;

3. The mean value of the amount of information increases with time, but at a decreasing marginal rate;

4. The family of distributions of information has increasing mean value and decreasing standard deviation;

5. Samplings are made every two weeks;

6. By counting the number of information-changing links in both structures (see Figure 2), the ratio of the average number of iterations to achieve the (preset) ideal information distribution in hierarchical and egalitarian structures is 2:1; and

7. The increasing rate of mean values of information distribution (toward the preset upper limit) in hierarchical and egalitarian structures is 1:2, which ratio is the reciprocal of the rate of the average number of iterations to achieve the (preset) ideal information distribution in hierarchical and egalitarian structures.

3.7 The Conceptual Variables in This Research

The conceptual variables in this research were:

1. Organizational type: hierarchical and egalitarian;

2. Number of members in a group (working on one product) in a hierarchical organizational structure or the number of members in a team (working on one product) in an egalitarian organizational structure;

3. Number of hierarchical levels in an organization (which was assumed to be two in this research);

4. Level of complexity of the product (in terms of the average number (n) of samplings).

3.8 Outline and Stages of this Research

3.8.1 Summary of the Research Settings

The goal for this research was to compare the time consumed in the product development process in two antithetic organizational types. The complexity of the product was assumed to be in a middle range. The software tool used to accomplish the simulation processes and output comparisons was the Fortran 77 language with International Mathematical and Statistical Library (IMSL) routines.

The programming was applied in order to model and describe the product development stages in a multi-department organization. One IMSL routine, RNSET, was called to initialize a random seed for use in the IMSL random number generators. Another IMSL routine, DRNNOR, was called to generate pseudorandom numbers from a standard normal distribution.

3.8.2 The Stages of this Research

1. The First Stage — Formulate the Model.

   The conceptual model was built to reflect the theories proposed and field studies reported by the researchers in the area of manufacturing strategy and industrial psychology.

2. The Second Stage — Design the Experiment.

   The factors that were considered in the experimental design are: the number of hierarchical (serial) levels in the organization, the number of (parallel) departments incurred at a given hierarchical level, and the number of different organizational structures to be compared. In this research, the variables controlled included organizational type, number of hierarchical levels in the hierarchical structure (two levels), and number of participants (three departmental representatives and one coordinator from the general manager's office).

3. The Third Stage — Develop the Computer Programs.

   The controlled and dependent variables in the programs are tabulated in Table 3.

The controlled variables in the programs:	
Controlled Variable	Symbol
Organization type	H , E
# members	4
# levels	2
Level of complexity	middle; n = 3
Mean value of information	μ_i
Standard deviation of information	σ_i
(Target) total amount of information	Y_t

The dependent variables in the programs:	
Dependent Variable	Symbol
How long it takes for one cycle of product development	T_H , T_E

Table 3. Summary of the Controlled and Dependent Variables

3.9 Summary of Problem Formulation

In this chapter, the conceptual model was explained and the preparatory work for simulation was discussed. The reader may recall the examples introduced in Section 3.5.3 to envisage the simulation processes which are introduced in Chapter Four.

Chapter 4. Program Structure and Simulation Output Analysis

4.1 Program Structure

The conceptual models described in Chapter Three were exercised using simulation to compare the efficiency of two simple antithetic organizational structures. The programs were coded by using Fortran 77 with the International Mathematical and Statistical Library routines. There were three major parts of each program: random stream generation; random variates (from N(0,1)) generation; and the main program. The three parts are introduced below in order.

4.1.1 Random Stream Generation

The random stream was generated by calling IMSL routine, RNSET, which initializes a random seed for use in the IMSL random number generators. The random stream is used in the next step to generate random variates from N(0,1). These random numbers (X(K)) were kept for the use as described in Section 4.1.2.

4.1.2 Random Variates Generated from N(0,1)

The random variates from N(0,1) were generated by calling IMSL routine, DRNNOR, which generates pseudorandom numbers from a standard normal distribution. The random numbers X(K) generated were then transformed by the following formula: (X(K)*S) + U to represent the random number generated from the normal distribution with mean value U and standard deviation S (i.e., N(U,S)). The underlying principle is the formula for normalization: $Z = \frac{X - \mu}{\sigma}$. For example, for the standard normal distribution N(0,1), the Z value corresponding to an 80% probability is found to be 0.8418 (see Table A.3 in Walpole, 1985).

4.1.3 Main Program

The program flowcharts (showing one stage only) provide the necessary information to understand the program structure. The major difference between the two programs is:

- One sampled value is picked at a time for the hierarchical structure; whereas three sampled values were picked at a time for the egalitarian structure, with each value representing the information accumulated in one participative department.

For both structures

By following the numerical values that were listed in Figure 10, mean values and standard deviations of information distributions are shown to be increasing and decreasing respectively in each structure. The number of iterations by which the mean values increase toward the preset upper limit for the distributions in the egalitarian structure was assumed to be half as many as the number (of iterations) in the hierarchical structure.

For the hierarchical structure

It is assumed that the sampling is made every two weeks. That is, the coordinator or controlling manager enquires about the status of the project about every two weeks. (The time could be considered any period of time — two weeks were used here, for illustration purposes.) The first sampling is made from the distribution with the lowest mean value and the highest standard deviation. After the first sampling, another sampling is made from distributions with increasing mean values and decreasing standard deviations. The sampling terminates at the time when the first successful sampling is made. That is to say, whenever the sampled value is greater than the preset target value, the sampling process will be terminated. The operations are shown in the following flowchart (Figure 12).

As shown in Figure 12 and the program listing (Appendix A), 1000 random numbers are generated first, and C(11) is chosen as a controlling variable. The program will record that C1 = C11(I) and stop when C11(I) exceeds 1,000. If C11(I) is smaller than 5, then C10 = C11(I); otherwise let C10 = 5. C10 is used next to control U (the mean value) and S (the standard deviation) of the truncated normal distribution in question. From the equation, U=.14*(1+C10)-.04, C10=5 will set the upper limit of U to be 0.80. By using the transformation formula Y=(X(K)*S)+U, the random number (X(K)) generated from N(0,1) will be transferred to another random number (Y) as if Y was randomly generated from N(U,S) (S represents the standard deviation σ in the flowcharts and program listings.) If Y is greater than the preset target

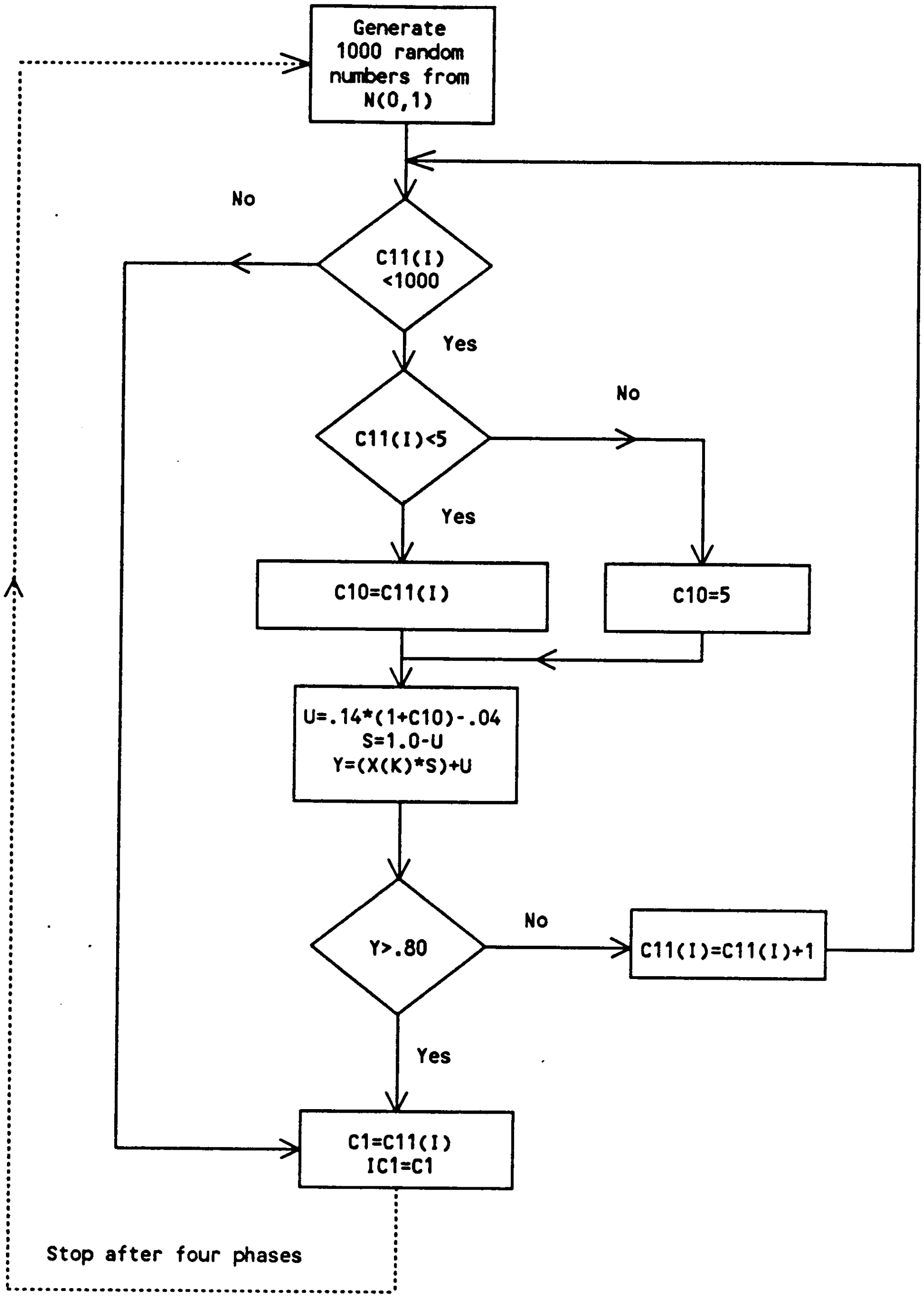


Figure 12. The Flowchart of Computer Operations for the Hierarchical Structure [showing one phase]

W (i.e., 0.8418*S + U) which corresponds to an 80% probability in the normal distribution N(U,S), the information acquiring process of the phase in question is complete, and the number of iterations is recorded as IC1; the program proceeds to the next phase. If Y is smaller than W, C11(I) will be increased by one and the program will go back to test if C11(I) < 1,000. If no, the program stops; if yes, C10 and U will be adjusted accordingly. Finally, the average of IC1, IC2, IC3, and IC4 is calculated and recorded as H(1). After running the complete program 1,000 times, the average of H(1), H(2),..., H(1,000) is calculated and stored for comparison.

For the egalitarian structure

Generally speaking, similar procedures were followed as those adopted in the hierarchical structure. The difference is that the decision-making processes in the egalitarian structure are joint processes. The emulated computer operation was arranged as follows. The computer program for the egalitarian structure was coded such that three sample values will be generated each time, with each value representing the information accumulated in one participative department. A sorting routine was used to rearrange the three sampled values in ascending order. The smallest value among the three is chosen to compare with the target value, since the smallest value will always represent the bottleneck department. If the smallest sampled value is less than the target value, three more numbers will be sampled from an improved distribution (i.e. a distribution with higher mean value and lower standard deviation) until the first successful triplet is found. The operations are shown in the flowchart in Figure 13.

The flowchart in Figure 13 is very similar to that in Figure 12. However, the possible values of U are set to be 20%, 50%, and 80% by using the iterative formula: U = .20 + (C10*.30). On the other hand, three random numbers are picked in order from N(0,1) and sorted. The smallest one, SS(1), is transformed to Y(I) by using the equation: Y(I) = (SS(I)*S) + U (S again represents the standard deviation σ in the flowcharts and program listings), Y(I) is used to represent the smallest random number among the triplet generated from N(U,S) of the Ith run of the simulation program.

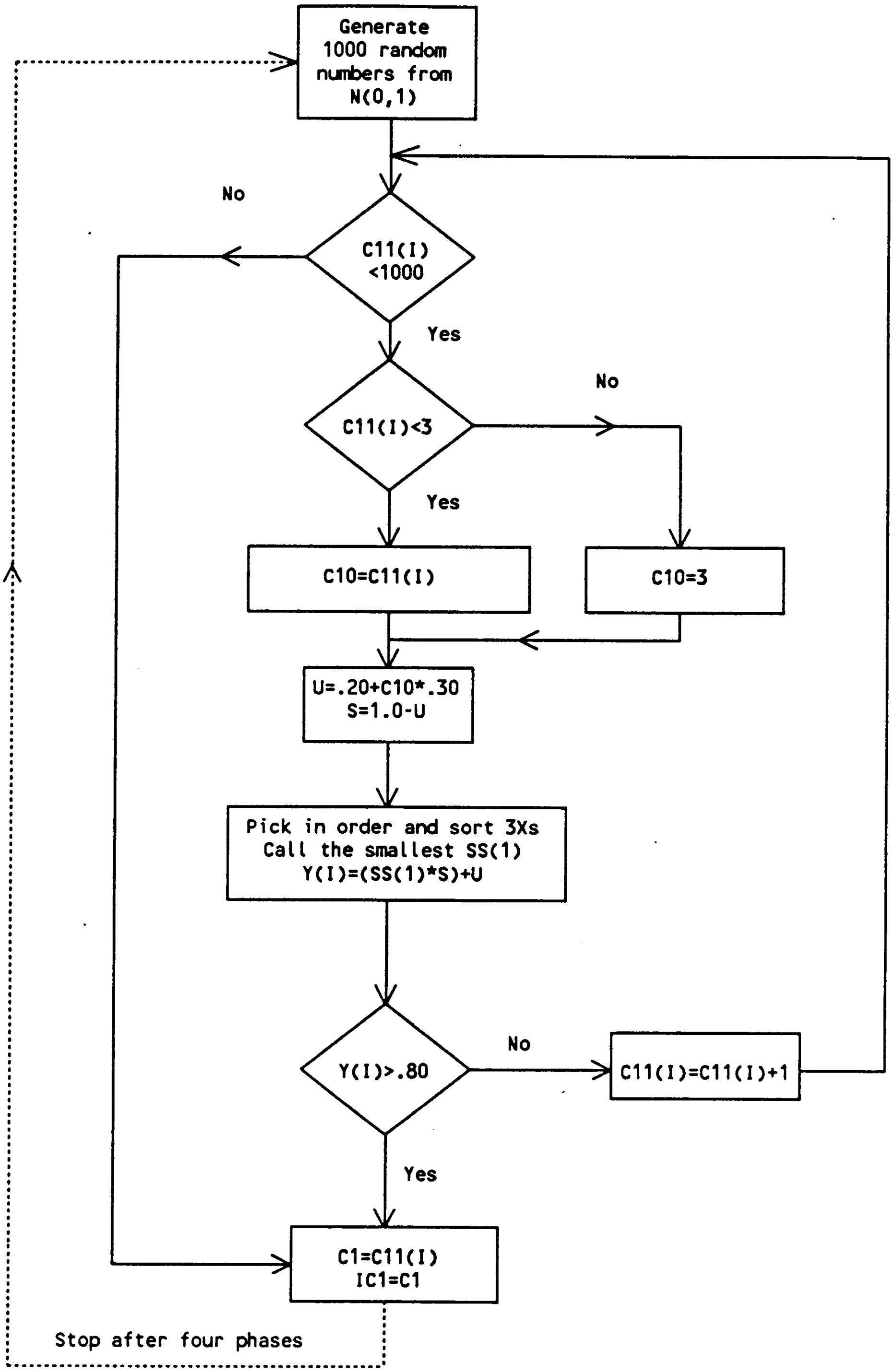


Figure 13. The Flowchart of Computer Operations for the Egalitarian Structure [showing one phase]

Y(I) is then used to compare with the value W (i.e., 0.8418*S + U). The other procedures are exactly the same as those described for the hierarchical structure in the flowchart (Figure 12).

4.2 Simulation Output Analysis

The simulation results are tabulated in Table 4 (100 runs) and Table 5 (1000 runs). Table 4 is shown for comparison purposes. The data shown in these tables suggest that a steady state may have not yet been achieved since the standard deviation didn't converge while the number of runs increased from 100 to 1000. However, in all four cases (100 and 1000 runs, for hierarchical and egalitarian structures, respectively), the numbers of samples are large enough ($n \geq 30$) to justify the use of the formula for finding the confidence interval for μ under the assumption that σ is known.

Simulation Results from 100 Runs		
Organization Type	Avg. # Samplings (Std. Deviation)	Avg. # Weeks Used in Design
Hierarchical	19.31 (9.54)	38.62
Egalitarian	15.86 (0.65)	31.72

Table 4. Simulation Results from 100 Simulation Runs

Simulation Results from 1,000 Runs		
Organization Type	Avg. # Samplings (Std. Deviation)	Avg. # Weeks Used in Design
Hierarchical	19.56 (9.03)	39.12
Egalitarian	15.81 (0.69)	31.62

Table 5. Simulation Results from 1,000 Simulation Runs

If $\overline{X}$ is the mean of a random sample of size n from a population with known variance σ^2, a $(1-\alpha)\cdot 100\%$ confidence interval for μ is given by

$$\overline{X} - Z_{\alpha/2}\cdot\frac{\sigma}{n^{1/2}} < \mu < \overline{X} + Z_{\alpha/2}\cdot\frac{\sigma}{n^{1/2}}$$

where $Z_{\alpha/2}$ is the Z value leaving an area of $\frac{\alpha}{2}$ to the right. To compute a $(1-\alpha)\cdot 100\%$ confidence interval for μ, it is assumed that σ is known. Since this is generally not the case, σ is replaced by the sample standard deviation s, provided $n \geq 30$ (Walpole and Myers, 1985).

The 90% confidence interval around μ for the 1,000 runs of the hierarchical structure is computed as follows.

$$19.56 - 1.645\cdot\frac{9.03}{1000^{1/2}} < \mu < 19.56 + 1.645\cdot\frac{9.03}{1000^{1/2}}$$

which reduces to

$$19.56 - 0.47 < \mu < 19.56 + 0.47$$

i.e.,

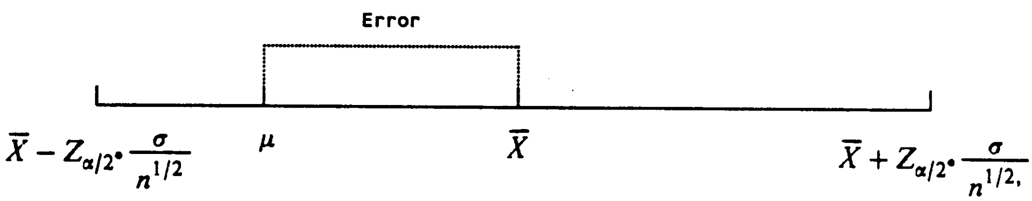


Figure 14. A Diagram of a Hypothetical Confidence Interval: μ is unknown; σ is known; sample size ≥ 30.

$$19.09<\mu<20.03$$

The 90% confidence interval around μ for the 1,000 runs of the egalitarian structure is computed as follows.

$$15.81 - 1.645 \cdot \frac{0.69}{1000^{1/2}} < \mu < 15.81 + 1.645 \cdot \frac{0.69}{1000^{1/2}}$$

which reduces to

$$15.81 - 0.04 < \mu < 15.81 + 0.04$$

i.e.,

$$15.77<\mu<15.85$$

The $(1\text{-}\alpha) \cdot 100\%$ confidence interval provides an estimate of the accuracy of the point estimate. If μ is actually the center value of the interval, then $\overline{X}$ estimates μ without error. Most of the time, however, $\overline{X}$ will not be exactly equal to μ and the point estimate is in error. The size of this error will be the absolute value of the difference between μ and $\overline{X}$, and users can be $(1\text{-}\alpha) \cdot 100\%$ confident that this difference will not exceeds $Z_{\alpha/2} \cdot \frac{\sigma}{n^{1/2}}$. This can be readily seen in a diagram of a hypothetical confidence interval, as in Figure 14.

Hence, if $\overline{X}$ is used as an estimate of μ, users can be $(1\text{-}\alpha) \cdot 100\%$ confident that the error will not exceed a specified amount e when the sample size is $n = \left[Z_{\alpha/2} \cdot \frac{\sigma}{e}\right]^2$. In the case of the simulated hierarchical structure, how large a sample is required if a user wants to be 90% confident that the estimate of μ is off by less than 0.5? $n = \left[1.645 \times \frac{9.03}{0.5}\right]^2 = 883$. Therefore, users can be 90% confident that a random sample of size 883 will provide an estimate $\overline{X}$ differing from μ by an amount less than 0.5.

Again, in the case of the simulated egalitarian structure, how large a sample is required if a user wants to be 90% confident that the estimate of μ is off by less than 0.5? $n = \left[1.645 \times \frac{0.69}{0.5}\right]^2 = 6$. Therefore, users can be 90% confident that a random sample of size 6 will provide an estimate $\overline{X}$ differing from μ by an amount less than 0.5. The reader may be surprised by the small sample needed for the egalitarian structure. However, based on the assumption that the mean value of its information distribution achieves 80% (identical to the preset target) only after three iterations, the small number found is not unexpected.

4.2.1 Output Analysis for the Hierarchical Structure

The average number of samplings from 1,000 runs for the hierarchical structure was 19.56. Since a fixed interval sampling (two weeks) was assumed, the product used here will take 39.12 weeks to be developed in the simulated hierarchical structure.

4.2.2 Output Analysis for the Egalitarian Structure

The average number of samplings from 1,000 runs for the egalitarian structure was 15.81. Since a fixed interval sampling (two weeks) is again assumed, the product will take 31.62 weeks to be developed in the simulated egalitarian structure.

4.2.3 Output Analysis for Both Structures

According to the simulation results for 1,000 runs, for a product with middle-level complexity (see Section 3.5), the time units consumed in the egalitarian structure (31.62 weeks) is 0.81 times as much as that consumed in the hierarchical structure (39.12 weeks). Based on the assumption that product quality is directly proportional to the amount of information acquired, the same level of quality was achieved by each structure since the same level of information was eventually achieved by both structures.

Based on the simulation results, the design-to-market time consumed in the simple egalitarian structure is seen as shorter statistically (compared to that of the simple hierarchical structure) and it appears to justify its feasibility of being used to solve the design-to-manufacturing interface problem. However, the assumptions of this research (which were outlined in Section 3.6) should be considered to explain the simulated results.

The following diagram (Figure 15) shows the relationship between the percent of information assumed for the nth sampling process and the number of samplings made (n). (In Figure 15, the number of iterations is N.) This figure can help to explain the simulation results of Section 4.2. It is seen that the egalitarian structure achieves a mean value $\mu = 80\%$ more quickly than the hierarchical structure. It takes three samplings for the egalitarian structure to achieve a normal distribution with an 80% mean value; however, it takes twice as many samplings (six samplings) for the hierarchical structure to achieve a normal distribution with an 80% mean value. This assumption, along with others outlined in Section 3.6, has fairly supported the simulation results listed in Tables 4 and 5, as well as the simulation output analysis performed in Section 4.2. A serious reader should not feel surprised about the comparative efficiency of the egalitarian structure suggested by the simulation results since it was assumed that it has a better chance to attain a high mean value sooner. The interested readers may also be curious about the suitable number of simulation runs; the number, NTIMES, shown in the programs (see Appendix A and B) was used as a parameter and it can be changed to any other reasonable integer. However, as shown in the statistical analysis in the last section, 1000 was a number big enough for a 90% confidence interval.

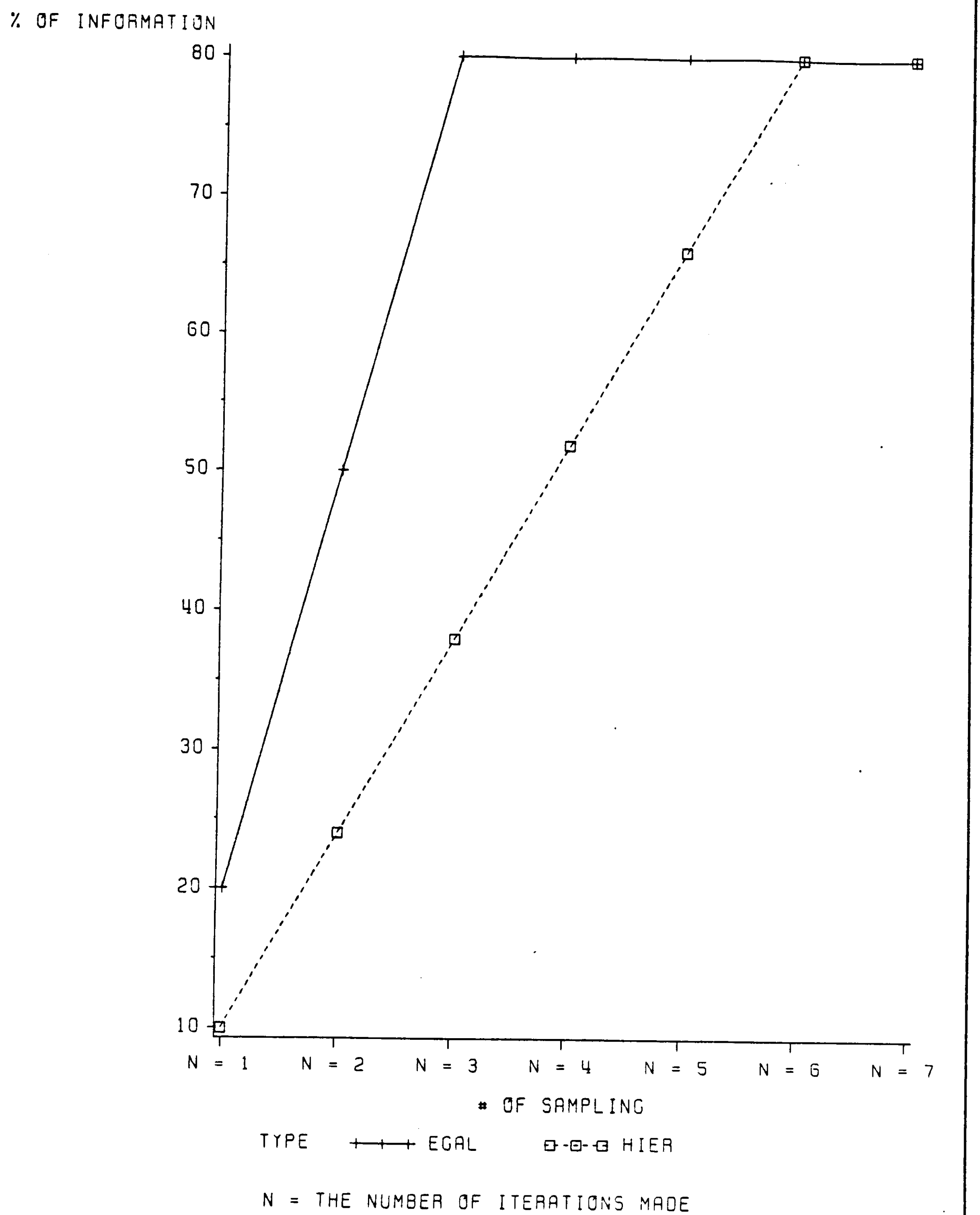


Figure 15. A Diagram of Percent of Information vs. Number of Samplings: Comparisons made between hierarchical and egalitarian structures.

Chapter 5. Summary and Conclusions

5.1 Summary

After performing the conceptual modeling, program execution, and output analysis, the goal of this research — comparing the efficiency of two simple antithetical organizational structures using simulation — was achieved. From the statistical analysis, it suggested that the egalitarian structure was more efficient under the assumptions of this research. However, the small sample needed for the egalitarian structure to achieve a 90% confidence interval suggested that the number of iterations assumed to achieve an 80% mean value may need to be increased for a meaningful comparison. This part is left for further research since some field study in a real manufacturing environment is needed.

In Section 5.2, some conclusions are reported. In Section 5.3, suggestions on further study are made.

5.2 Conclusions

From the analysis performed in this research, one suggestion on a competitive organizational structure is:

- For products (of middle level complexity) that are of a satisfactory quality, time is one of the most important priorities. The egalitarian structure appears to be suitable (especially for products with middle level complexity).

Actually, many companies have paid attention to the organizational effects on their competitiveness under global competition. IBM is a typical company which emphasizes the importance of short design-to-market time. There is no direct evidence that IBM did any revolutionary changes on their organizational structure to achieve that goal. However, Lei (1989) reported a recent change in IBM's strategic approach to simplify its product designs, which indirectly compensates for the organizational effects on the time issue in a traditional, multi-departmental organization by reducing the necessary communication among departments.

5.3 Suggestions for Further Research

Since high-tech and consumer products are products with different characteristics and are in different competitive environments with different priority settings, relationships between available information and final product quality need to be further investigated according to product type.

While considering the case studies (PLUS Development and Ford Taurus), some contrasting facts were observed. The first case considers the high-tech (sometimes synonymous with short-life) product design (hard disks); the second case is a typical example of a mature consumer product (cars). In the PLUS Development case (high-tech product design), the design and manufacturing departments had a close relationship, and the manufacturing department was demanding in regards to design details and tolerances. The high quality achieved in the final product was difficult to justify by the market loss, due to the amount of time elapsed. In the Ford Taurus case, the long time span (five years) and large investment (three billion dollars) were proven to be well rewarded. It is reasonable to include the type of product as one basic control variable to identify the strategic priorities for different products. In addition, these propositions are made for further investigation:

1. For the high-tech and/or innovative products, design-to-market time is the first priority for competitiveness; quality is the second priority. A more suitable organizational structure needs to be be chosen. (The more suitable organizational structure is hierarchical.)

2. For the consumer product with many established competitors, product quality is the most important priority; design-to-market time is the second priority (since the existing products could be used as the inventory). The more suitable organizational structure needs to be decided. (The more suitable organizational structure is egalitarian.)

3. Based on one of the assumptions of this research, any organizational or related changes which lead to minimizing the necessary organizational communications to sustain a certain level of information flow for satisfactory product quality should be seriously considered.

Suggestions for improving this research are as follows:

1. Some field study and working experience should enrich this conceptual model by helping to define the undefined variables L and R in the following formula:

$$y = L \bullet (1 - e^{-R \bullet [\tau - \text{ł}]})$$

introduced in Section 3.5.2.

2. Model and simulate the hybrid type of organization (transplant egalitarian teams into a hierarchical organization), since the hybrid type of organization is seen more often in the real world of manufacturing industry.

3. Consider continuous simulation instead of the discrete simulation approach for more flexible analysis.

4. Consider continuous improvement with an upper limit higher than 80% assumed in this research.

5. Consider the complex organizations with more levels and more departments; also consider different improvement rates for different departments at different levels.

In conclusion, it has been shown that a conceptual model of communication in two antithetic organizational structures can be modeled and tested even though human decision-making is a complicated process. However, conclusions about which structure is more efficient can not be made until more modeling and field work is undertaken. This is left for future research.

Bibliography

Adler, Paul S., 1988, The Managerial Challenges of Integrating CAD/CAM, Working Paper, Stanford University.

Agee, Marvin H., 1989, Personal Correspondence, Virginia Polytechnic Institute.

Albaum, G., 1964, Horizontal Information Flow: An Exploratory Study. *Academy of Management Journal,* **7**, pp. 21-33.

Athanassiades, J., 1973, The Distortion of Upward Communication in Hierarchical Organizations. *Academy of Management Journal,* **16**, pp. 207-226.

Barlund, D., and C. Harland, 1963, Propinquity and Prestige as Determinants of Communication Networks. *Sociometry,* **26**, pp. 467-479.

Baron, Robert A., 1986, *Behavior in Organizations: Understanding and Managing the Human Side of Work, Second Edition.* (Allyn and Bacon, Inc.).

Beckman, Sara L., and James V. Jucker, 1987, Achieving Flexibility in Manufacturing, Working Paper, Stanford University.

Bikker, H., and W. Heyden, 1987, Systematic Product-Breakdown and Documentation, Major Tools for Productivity Improvement. *International Journal of Production Research,* **25**, pp. 1635-1644.

Caspari, J. A., 1968, Fundamental Concepts of Information Theory. *Managerial Accounting,* **49**, pp. 8-10.

Chavas, Jean-Paul, and Rulon D. Pope, 1984, Information: Its Measurement and Valuation. *Amer. J. Agr. Econ.,* December 1984, pp. 705-710.

Clark, Kim B., W. Bruce Chew, and Takahiro Fujimoto, 1987, Product Development in the World Auto Industry. *Brookings Papers on Economic Activity,* **3**, pp. 729-771.

Cohen, A., 1962, Changing Small-Group Communication Networks. *Administrative Science Quarterly,* **6**, pp. 443-462.

Costello, T., and S. Zalkind, eds. 1963, *Psychology in Administration.* (Prentice-Hall).

Drucker, Peter E., 1988, The Coming of the New Organization. *Harvard Business Review,* January-February 1988, pp. 45-53.

Fine, Charles H., and Arnoldo C. Hax, 1984, Designing a Manufacturing Strategy. *Robotics & Computer-Integrated Manufacturing,* **1**, pp. 423-439.

Gannon, Martin J., 1977, *Management: An Organizational Perspective.* (Little, Brown and Company).

Gannon, Martin J., 1988, *Management: Managing for Result.* (Allyn and Bacon, Inc.).

Gerwin, D., and T. Leung, 1986, The Organizational Impacts of Flexible Manufacturing Systems. *Human Factors,* edited by T. Lupton (Springer-Verlag), pp. 157-170.

Hauser, John R., and Don Clausing, 1988, The House of Quality. *Harvard Business Review,* May-June 1988, pp. 63-73.

Hax, Arnoldo C., and Nicolas S. Majluf, 1984, *Strategic Management: An Integrative Perspective.* (Prentice-Hall).

Hayes, Robert, and Stephen C. Wheelwright, 1984, *Restoring Our Competitive Edge, Competing Through Manufacturing.* (John Wiley).

Hayes, Robert H., Stephen C. Wheelwright, and Kim B. Clark, 1988, *Dynamic Manufacturing: Creating The Learning Organization* (The Free Press).

Katz, Daniel, and Robert L. Kahn, 1978, *The Social Psychology of Organizations, Second Edition.*

Kleinrock, Leonard, 1960, *A Program for Testing Sequences of Random Numbers.* (Lincoln Laboratory, Massachusetts Institute of Technology), pp. 1-27.

Leavitt, Harold J., 1978, Communication Networks in Groups / Designs for Getting the Word Around. *Managerial Psychology, Fourth Edition.* (The University of Chicago Press), pp. 234-243.

Leavitt, Harold J., and Homa Bahrami, 1988, Communication Nets in Groups and Organizations: Who Can Talk to Whom about What? *Managerial Psychology: Managing Behavior in Organizations, Fifth Edition.* (The University of Chicago Press), pp. 208-216.

Lei, David, 1989, Strategies for Global Competition. *Long Range Planning,* **21**, pp. 102-109.

Maier, N., L. Hoffman, and W. Read, 1963, Superior-Subordinate Communication: The Relative Effectiveness of Managers Who Held Their Subordinates' Positions. *Personnel Psychology,* **16**, pp. 1-11.

Marschak, Thomas, and Stefan Reichelstein, December 1987, Network Mechanisms, Information Efficiency and Hierarchies. Working paper. (School of Business, University of California, Berkeley).

McGRAW-Hill Encyclopedia of Science & Technology, 1987, **9**, ICE-LEO, pp. 145-151.

McClelland, Marilyn K., 1984, Operations Management Model to Analyze Manufacturing Strategies. *ONR Technical Report #29.* (Office of Naval Research).

McClelland, Marilyn K., 1984, Operations Management Model to Analyze Manufacturing Strategies. *ONR Technical Report #29.* (Office of Naval Research).

Mintzberg, Henry, 1979, *The Structuring of Organizations: A Synthesis of the Research.* (Prentice-Hall).

Mishne, Patricia P., 1988, A Passion for Perfection. *Manufacturing Engineering,* November 1988, pp. 46-58.

Moriarity, Shane, and Carl P. Allen, 1987, *Cost Accounting, Second Edition.* (Harper & Row, Publishers).

Muchinsky, Paul M., 1987, *Psychology Applied to Work: An Introduction to Industrial and Organizational Psychology, Second Edition.* (The Dorsey Press).

O'Reilly, C. A., 1978, The Intentional Distortion of Information in Organizational Communication: A Laboratory and Field Approach. *Human Relations,* **31**, pp. 173-193.

Parkinson, Stephen T., 1984, *New Product Development in Engineering: A Comparison of the British and West German Machine Tool Industries.* (Cambridge University Press).

Pendlebury, A., 1987, Creating a Manufacturing Strategy to Suit Your Business. *Long Range Planning,* **20**, pp. 35-44.

"PLUS Development Corporation." Stanford Business School (S-PD-1).

"PLUS Development Corporation (B)." Stanford Business School (S-PD-1B).

Porter, Michael E., 1985, *Competitive Advantage.* (Free Press).

Power, Daniel J., Martin J. Gannon, Michael A. McGinnis, and David M. Schweiger, 1986, *Strategic Management Skills.* (Addison-Wesley).

Priest, John W., 1988, *Engineering Design for Producibility and Reliability.* (Marcel Dekker, Inc.)

Pritsker, A. A. B., 1986, *Introduction to Simulation and SLAM II, Third Edition.* (Halsted Press).

Quastler, Henry, 1987, Information Theory (Biology). *McGRAW-Hill Encyclopedia of Science & Technology, Sixth Edition,* 1987, **9**, ICE-LEO, pp. 149-151.

Read, W., 1962, Upward Communication in Industrial Hierarchies. *Human Relations,* **15**, pp. 3-15.

Rockett, Frank H., 1987, Measure of Information. *McGRAW-Hill Encyclopedia of Science & Technology, Sixth Edition,* 1987, **6**, ELE-EYE, pp. 378-379.

Shannon, Claude E., 1948, A Mathematical Theory of Communication, *Bell Syst. Tech. J.,* **27(3)**, pp. 379-423.

Shannon, Claude E., 1948, A Mathematical Theory of Communication, *Bell Syst. Tech. J.,* **27(4)**, pp. 623-656.

Shannon, Claude E., and Warren Weaver, 1975, *The Mathematical Theory of Communication, Sixteenth printing.* (University of Illinois Press).

Stalk, George, Jr., 1988, Time — The Next Source of Competitive Advantage. *Harvard Business Review,* July-August 1988, pp. 41-51.

Stoll, Henry W., 1988, Design for Manufacture. (Industrial Technology Institute).

Sullivan, Lawrence P., 1986, Quality Function Deployment. *Quality Progress,* June 1986, pp. 39-50.

Sullivan, Lawrence P., 1988, Policy Management Through Quality Function Deployment, *Quality Progress,* June 1988, pp. 18-20.

Urban, Glen L., and John R. Hauser, 1980, *Design and Marketing of New Products.* (Prentice-Hall).

Walpole, Ronald E., and Raymond H. Myers, 1985, *Probability and Statistics for Engineers and Scientists, Third Edition.* (Macmillan Publishing Company).

Whitney, Daniel E., 1988, Manufacturing by Design. *Harvard Business Review,* July-August 1988, pp. 83-91.

Wickelgren, Wayne A, 1987, Information Processing. *McGRAW-Hill Encyclopedia of Science & Technology, Sixth Edition,* 1987, **9**, ICE-LEO, pp. 143-146.

Wickesberg, A., 1968, Communications Network in the Business Organization Structure. *Academy of Management Journal,* **11**, pp. 253-262.

Zuboff, Shoshana, 1985, Technologies That Informate: Implications for Human Resource Management in the Computerized Industrial Workplace. *HRM Trends and Challenge,* edited by Walton, R. E., and Lawrence, P. R. (Harvard Business School Press).

Appendix A. Program Listing and Output Data for a Design Project in a Hierarchical Organizational Structure

The Hierarchical Model

```
***************            PROGRAM IDENTIFICATION            ***************
*                                                                          *
*      Program to count the averaged total number of samplings             *
*      which reveal the time units needed to achieve a certain             *
*      level of information for decision-making in a hierarchical          *
*      organizational structure.                                           *
*      Written by Ted Fu  01/03/89                      Rev. 07/19/89      *
*                                                                          *
****************************************************************************
*                                                                          *
*   This program                                                           *
*   A) Generates 1000 samples from a standard normal distribution by       *
*      calling IMSL routine RNNOR/DRNNOR                                   *
*   B) Using Y(N)=X(N)*S+U to trace the samples back to a Normal(U,S)      *
*      distribution                                                        *
*                                                                          *
****************************************************************************
*                                                                          *
*   Using IMSL routine RNSET                                               *
*                                                                          *
*   PURPOSE    Initialize a random seed for use in the IMSL random         *
*              number generators.                                          *
*   USAGE    - CALL RNSET (ISEED)                                          *
*                                                                          *
*   ARGUMENT                                                               *
*     ISEED - The seed of the random number generator.  (Input)            *
*             ISEED must be in the range (0, 2147483646).  If ISEED is     *
*             zero, a value is computed using the system clock; and        *
*             hence, the results of programs using the IMSL random         *
*             number generators will be different at different times.      *
*                                                                          *
****************************************************************************
*                                                                          *
*   Using IMSL routine RNNOR/DRNNOR                                        *
*                                                                          *
*   PURPOSE    Generate pseudorandom numbers from a standard normal        *
*              distribution                                                *
```

```
*                                                                         *
*  USAGE     CALL DRNNOR (NR,R)                                           *
*                                                                         *
*  ARGUMENTS                                                              *
*    NR    - Number of random numbers to generate                         *
*    R     - Vector of length NR containing the random standard           *
*            normal deviates.  (Output)                                   *
*                                                                         *
***************************************************************************
*                                                                         *
      IMPLICIT REAL*8 (D-G, O-Z)
      REAL YY1, YY2, YY3, YY4
      DOUBLE PRECISION HS, W
      INTEGER ISEED, K, M, N
      PARAMETER (M=100,N=1010,NTIMES=100)
      INTEGER C10, C12, C1, H(N)
      INTEGER C20, C22, C2
      INTEGER C30, C32, C3
      INTEGER C40, C42, C4
      DIMENSION T(M), R(N), X(N), C11(N), C21(N), C31(N), C41(N)
      DATA ISEED/123457/
      CALL RNSET (ISEED)
      C10=0
      C12=1
      C20=0
      C22=1
      C30=0
      C32=1
      C40=0
      C42=1
      PI=3.1415926D0
      DO 100 I=1, NTIMES
      C11(I)=0
      C21(I)=0
      C31(I)=0
      C41(I)=0
*STAGE 1*
*
      NR=1010
      CALL DRNNOR (NR,R)
*     CALL DSCAL (NR, S, R, 1)
```

```
*      CALL DADD (NR, U, R, 1)
*
       DO 5 J=1, 1010
          X(J)=R(J)
*      WRITE (9, *) X(J)
  5    CONTINUE
*
       DO 1111 K=1,N
       YY1=0.80D0
 11    IF (C11(I).GT.1000) THEN
          GO TO 14
       ENDIF
  2    IF (C11(I).LE.5) THEN
          C10=C11(I)
       ELSE
          C10=5
       ENDIF
*
       U=0.14D0*(1+C10)-0.04
       S=1.0D0-U
       W=.8418*S+U
*
       Y=(X(K)*S)+U
*      WRITE (6,*) Y, X(K), ISEED
*
       IF (Y.GT.W) GOTO 14
       C11(I)=C11(I)+1
1111   CONTINUE
*
 14    C1=C11(I)+C12
       IC1=C1
*      WRITE(11,*) IC1, 111
*      WRITE(6,*) IC1, 111
*STAGE 2*
*
       NR=1010
C      CALL RNSET (ISEED)
       CALL DRNNOR (NR,R)
C      CALL DSCAL (NR, S, R, 1)
C      CALL DADD (NR, U, R, 1)
C
```

```
      DO 6 J=1, 1010
         X(J)=R(J)
  6   CONTINUE
*
      DO 2222 K=1, N
      YY2=0.80D0
 22   IF (C21(I).GT.1000) THEN
         GO TO 28
      ENDIF
 29   IF (C21(I).LE.5) THEN
         C20=C21(I)
      ELSE
         C20=5
      ENDIF
*
      U=0.14D0*(1+C20)-0.04
      S=1.0D0-U
      W=.8418*S+U
*
      Y=(X(K)*S)+U
*
C     WRITE(6,*) Y, 222
      IF (Y.GT.W) GOTO 28
      C21(I)=C21(I)+1
2222  CONTINUE
*
 28   C2=C21(I)+C22
      IC2=C2
C     WRITE (6,*) IC2, 222
*STAGE 3*
*
      NR=1010
C     CALL RNSET (ISEED)
      CALL DRNNOR (NR,R)
C     CALL DSCAL (NR, S, R, 1)
C     CALL DADD (NR, U, R, 1)
C
      DO 7 J=1, 1010
         X(J)=R(J)
  7   CONTINUE
*
```

```
      DO 3333 K=1, N
      YY3=.80D0
  33  IF (C31(I).GT.1000) THEN
         GOTO 32
      ENDIF
  30  IF (C31(I).LE.5) THEN
         C30=C31(I)
      ELSE
         C30=5
      ENDIF
*
      U=0.14D0*(1+C30)-0.04
      S=1.0D0-U
      W=.8418*S+U
*
      Y=(X(K)*S)+U
      IF (Y.GT.W) GOTO 32
      C31(I)=C31(I)+1
3333  CONTINUE
*
  32  C3=C31(I)+C32
      IC3=C3
*     WRITE(6,*) IC3, 333
*STAGE 4*
*
      NR=1010
C     CALL RNSET (ISEED)
      CALL DRNNOR (NR,R)
C     CALL DSCAL (NR, S, R, 1)
C     CALL DADD (NR, U, R, 1)
C
      DO 9 J=1, 1010
         X(J)=R(J)
   9  CONTINUE
*
      DO 4444 K=1, N
      YY4=.80D0
  44  IF (C41(I).GT.1000) THEN
         GOTO 46
      ENDIF
  45  IF (C41(I).LE.5) THEN
```

```
         C40=C41(I)
      ELSE
         C40=5
      ENDIF
*
      U=0.14D0*(1+C40)-0.04
      S=1.0D0-U
      W=.8418*S+U
*
      Y=(X(K)*S)+U
*     WRITE(6,*) F, 444
      IF (Y.GT.W) GOTO 46
      C41(I)=C41(I)+1
4444  CONTINUE
*
  46  C4=C41(I)+C42
      IC4=C4
*     WRITE(9,*) IC4, 444
*********
      H(I)=IC1+IC2+IC3+IC4
      WRITE (9, *) H(I)
 100  CONTINUE
*
      SUM=0.0D0
      DO 110 J=1, NTIMES
         SUM=SUM+H(J)
*     WRITE(6,*) SUM, 444
 110  CONTINUE
*
      HS=SUM/DBLE(NTIMES)
      WRITE (9,130) HS
C     WRITE (6,*) HS
 130  FORMAT (1X,'THE AVERAGE IS ',F5.2)
      STOP
      END
```

Appendix B. Program Listing and Output Data for a Design Project in an Egalitarian Organizational Structure

The Egalitarian Model

```
***************          PROGRAM IDENTIFICATION          ***************
*                                                                      *
*       Program to count the averaged total number of samplings        *
*       which reveal the time units needed to achieve a certain        *
*       level of information (source of quality) in an egalitarian     *
*       organizational structure.                                      *
*       Written by Ted Fu  01/03/89                 Rev. 07/19/89      *
*                                                                      *
************************************************************************
*                                                                      *
*    This program                                                      *
*    A) Generates 1000 samples from a standard normal distribution by  *
*       calling IMSL routine RNNOR/DRNNOR                              *
*    B) Using Y(N)=X(N)*S+U to trace the samples back to a Normal(U,S) *
*       distribution                                                   *
*                                                                      *
************************************************************************
*                                                                      *
*    Using IMSL routine RNSET                                          *
*                                                                      *
*    PURPOSE   Initialize a random seed for use in the IMSL random     *
*              number generators.                                      *
*    USAGE    - CALL RNSET (ISEED)                                     *
*                                                                      *
*    ARGUMENT                                                          *
*      ISEED - The seed of the random number generator.  (Input)       *
*              ISEED must be in the range (0, 2147483646).  If ISEED is *
*              zero, a value is computed using the system clock; and   *
*              hence, the results of programs using the IMSL random    *
*              number generators will be different at different times. *
*                                                                      *
************************************************************************
*                                                                      *
*    Using IMSL routine RNNOR/DRNNOR                                   *
*                                                                      *
*    PURPOSE   Generate pseudorandom numbers from a standard normal    *
*              distribution                                            *
*                                                                      *
```

```
*   USAGE      CALL DRNNOR (NR,R)                                            *
*                                                                            *
*   ARGUMENTS                                                                *
*     NR     - Number of random numbers to generate                          *
*     R      - Vector of length NR containing the random standard            *
*              normal deviates.  (Output)                                    *
*                                                                            *
******************************************************************************
*                                                                            *
      IMPLICIT REAL*8 (D-G, O-Z)
      REAL YY1, YY2, YY3, YY4
      DOUBLE PRECISION HS, W
      INTEGER ISEED, K, M, N
      PARAMETER (M=100,NRAND=1010,NTIMES=1000)
      INTEGER C10, C12, C1, H(NRAND)
      INTEGER C20, C22, C2
      INTEGER C30, C32, C3
      INTEGER C40, C42, C4
      DIMENSION T(M), R(3), X(NRAND), Y(NRAND),Z(3),N(NRAND),SS(NRAND)
      DIMENSION C11(NRAND), C21(NRAND), C31(NRAND), C41(NRAND)
*     DIMENSION T(M), R(3), X(NRAND), Y(NRAND),Z(3),N(NRAND),SS(NRAND)
      DATA ISEED/123457/
      CALL RNSET (ISEED)
      C10=0
      C12=1
      C20=0
      C22=1
      C30=0
      C32=1
      C40=0
      C42=1
      PI=3.1415926D0
*
      NR=1010
      ISEED=123457
      DO 100 I=1, NTIMES
      C11(I)=0
      C21(I)=0
      C31(I)=0
      C41(I)=0
*
```

```
*STAGE 1*
*
      NR=1010
      CALL DRNNOR (NR,SS)
*
      DO 5 II=1, 1010
         X(II)=SS(II)
  5   CONTINUE
*
      DO 7 IA=1,1009,3
      YY1=0.8D0
      IF (C11(I).GT.1000) THEN
         GO TO 4
      ENDIF
      IF (C11(I).LE.3) THEN
         C10=C11(I)
      ELSE
         C10=3
      ENDIF
*
      U=0.20D0+C10*.30
      S=1.0D0-U
      W=.8418*S+U
*
******DO 7 IA=1,1009,3
         DO 17 J=IA,IA+2,1
 17      Z((J-IA)+1)=X(J)
         CALL SORT(Z,SS,3)
*        WRITE (6,*) SS(1), SS(2), SS(3)
      Y(I)=(SS(1)*S)+U
      IF (Y(I).GT.W) GOTO 4
         C11(I)=C11(I)+1
  7   CONTINUE
*
  4   C1=C11(I)+C12
      IC1=C1
*     WRITE (6,*) IC1, 111
*
*STAGE 2*
*
      NR=1010
```

```
      CALL DRNNOR (NR,SS)
*
      DO 6 II=1, 1010
         X(II)=SS(II)
  6   CONTINUE
*
      DO 14 IA=1,1009,3
      YY2=0.8D0
      IF (C21(I).GT.1000) THEN
         GO TO 8
      ENDIF
      IF (C21(I).LE.3) THEN
         C20=C21(I)
      ELSE
         C20=3
      ENDIF
*
      U=0.20D0+C20*.30
      S=1.0D0-U
      W=.8418*S+U
*
******DO 14 IA=1,1009,3
         DO 34 J=IA,IA+2,1
 34      Z((J-IA)+1)=X(J)
         CALL SORT(Z,SS,3)
*        WRITE (6,*) SS(1), SS(2), SS(3)
      Y(I)=(SS(1)*S)+U
      IF (Y(I).GT.W) GOTO 8
         C21(I)=C21(I)+1
 14     CONTINUE
*
  8   C2=C21(I)+C22
      IC2=C2
*     WRITE(6,*) IC2, 222
*
*STAGE 3*
*
      NR=1010
      CALL DRNNOR (NR,SS)
*
      DO 9 II=1, 1010
```

```
          X(II)=SS(II)
   9   CONTINUE
*
       DO 21 IA=1,1009,3
       YY3=0.8D0
       IF (C31(I).GT.1000) THEN
          GO TO 12
       ENDIF
       IF (C31(I).LE.3) THEN
          C30=C31(I)
       ELSE
          C30=3
       ENDIF
*
       U=0.20D0+C30*.30
       S=1.0D0-U
       W=.8418*S+U
*
******DO 21 IA=1,1009,3
          DO 51 J=IA,IA+2,1
 51       Z((J-IA)+1)=X(J)
          CALL SORT(Z,SS,3)
*         WRITE (6,*) SS(1), SS(2), SS(3)
       Y(I)=(SS(1)*S)+U
       IF (Y(I).GT.W) GOTO 12
          C31(I)=C31(I)+1
 21    CONTINUE
*
 12    C3=C31(I)+C32
       IC3=C3
*      WRITE(6,*) IC3, 333
*
*STAGE 4*
*
       NR=1010
       CALL DRNNOR (NR,SS)
*
       DO 19 II=1, 1010
          X(II)=SS(II)
 19    CONTINUE
*
```

```
        DO 28 IA=1,1009,3
        YY4=0.8D0
        IF (C41(I).GT.1000) THEN
           GO TO 16
        ENDIF
        IF (C41(I).LE.3) THEN
           C40=C41(I)
        ELSE
           C40=3
        ENDIF
*
        U=0.20D0+C40*.30
        S=1.0D0-U
        W=.8418*S+U
*
******DO 28 IA=1,1009,3
           DO 68 J=IA,IA+2,1
 68        Z((J-IA)+1)=X(J)
           CALL SORT(Z,SS,3)
*          WRITE (6,*) SS(1), SS(2), SS(3)
        Y(I)=(SS(1)*S)+U
        IF (Y(I).GT.W) GOTO 16
           C41(I)=C41(I)+1
 28       CONTINUE
*
 16     C4=C41(I)+C42
        IC4=C4
*       WRITE(6,*) IC4, 444
*---------------------------------------------------------------------
        H(I)=IC1+IC2+IC3+IC4
        WRITE (9,*) H(I)
 100    CONTINUE
*
        SUM=0.0D0
        DO 110 J=1, NTIMES
           SUM=SUM+H(J)
*       WRITE (6,*) H(J), SUM
 110    CONTINUE
*
        HS=SUM/DBLE(NTIMES)
```

```
      WRITE (9,130) HS
*     WRITE (6,*) HS
 130  FORMAT (1X,'THE AVERAGE IS ',F5.2)
      STOP
      END
*
*-------------------------------------------------------------------------
      SUBROUTINE SORT(SORTX,SORTY,N)
*
* THIS SUBROUTINE SORTS AN ARRAY X INTO AN ARRAY Y
* IN ASCENDING ORDER.  BOTH ARRAYS HAVE N VALUES.

      INTEGER  N, I
      REAL*8  SORTX(N),SORTY(N)
      LOGICAL  SORTED
*
      DO 10 I=1,N
         SORTY(I) = SORTX(I)
  10  CONTINUE
*
      SORTED = .FALSE.
  15  IF (.NOT.SORTED) THEN
         SORTED = .TRUE.
         DO 20 I=1,N-1
            IF (SORTY(I).GT.SORTY(I+1)) THEN
               TEMP = SORTY(I)
               SORTY(I) = SORTY(I+1)
               SORTY(I+1) = TEMP
               SORTED = .FALSE.
            ENDIF
  20  CONTINUE
      GO TO 15
      ENDIF
*
      RETURN
      END
```

The two page vita has been removed from the scanned document. Page 1 of 2

The two page vita has been removed from the scanned document. Page 2 of 2