# ANALYSIS OF MANAGEMENT INFORMATION SYSTEMS BY SIMULATION

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Ronald Eugene Hillblom

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RONALD EUGENE HILLBLOM

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Approved

John G. Coulson
Chairman

Russell L. Keernan

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# CHAPTER I

# INTRODUCTION

Information, both internal and external, provides the basis for management decisions in planning, directing, and controlling the functions of a business. In today's dynamic and complex business world, management has an increasing need for effective management information systems to improve their decision-making capability.

In an article entitled "Management in the 1980's," Harold Leavitt and Thomas Whisler speculate on the effect of what they call "information technology" on management. To quote:

> Over the last decade a new technology has begun to take hold in American business, one so new that its significance is still difficult to evaluate. While many aspects of this technology are uncertain, it seems clear that it will move into the managerial scene rapidly, with definite and far-reaching impact on managerial organization. . . .
>
> The new technology does not yet have a single established name. We shall call it <u>information technology</u>. It is composed of several related parts. One includes techniques for processing large amounts of information rapidly, and it is epitomized by the high-speed computer. A second part centers around the application of statistical and mathematical methods to decision-making problems; it is represented by techniques like mathematical programming, and by methodologies like operations research. A third

> part is in the offing, though its applications have not yet emerged very clearly; it consists of the simulation of higher-order thinking through computer programs.[1]

They conclude that management today is entering into a new and third industrial technology of the twentieth century. The first technology, scientific management, was instrumental in shaping to a great extent the design of industrial organizations. The second influential technology, participative management, came about after World War II, overtaking and displacing scientific management to a great extent. These two technologies have both survived for the reason that scientific management concentrated on the hourly worker, while participative management is generally aimed one level higher, at middle managers. Now, the new information technology has direct implications for middle management as well as top management.

A management information system is necessarily tailored to the specific requirements of the individual firm. Such an endeavor requires the application of information technology and systems methodology. The theory of systems planning or systems engineering has developed, in the last two decades, in recognition of the importance of the interaction between the components of a system. In systems

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[1]Harold Leavitt and Thomas Whisler, "Management In The 1980's," Harvard Business Review, XXXVI, No. 5 (November-December, 1958), pp. 41-42.

theory as applied to business systems, the firm cannot be studied merely as a collection of independent functional activities, but as a system of interconnected and related subsystems. The over-all performance of the business system is related to the degree of integration and control achieved between subsystems.[2]

The ultimate goal of a management information system is to provide all levels of management with adequate information for planning and decision-making needs. The information requirements for any one level of management are determined both by the organizational structure and the over-all goals of the firm.

A successful management information system is dependent upon careful analyzing, designing, and planning under the leadership of top management.

## Statement of the Problem

In the past, management has largely failed to exploit the capabilities of modern data processing equipment and the technology of operations research and systems planning. It has been the experience of many companies that the potential of data processing equipment, especially the computer, has consistently surpassed their ability to use

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[2]Stanford L. Optner, Systems Analysis for Business Management (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1960), pp. 12-13.

it. The potential of quantitative techniques from operations research and systems planning has been realized only in limited cases, due largely to the lack of communication between the technician and management.

Historically, management has considered the use of data processing systems only for cost displacement, the replacement of clerks to save money. A very common goal of such an "application" is the implementation of a mechanization program within a functional area with minimum investment of time, effort, and money. The potential benefits of a management information system would never be realized if cost-reduction were to remain the dominant criteria for the use of data processing systems. Measures of performance of an information system that assists management in the control of a business as it operates in a dynamic environment are intangible and not directly related to cost. The important measure is the effect of the information system on the over-all operation of the business. Management must rely on the techniques of the systems designer to provide a basis for analysis and evaluation of performance.

This study is designed to provide information about the basic characteristics of a management information system and to present a technique for the analysis of such a system. One of the basic tools of operations research and systems engineering is simulation which has already found numerous business applications.[3]

Simulation of a management information system and its related operating system promises to provide a method for the analysis and evaluation of many of the "intangible" aspects of the information system in terms of its contribution to the dynamic control of the business.

## Limitations of the Study

This study is limited to the consideration of management information systems typically found in the manufacturing industry. The model used to illustrate the simulation technique is limited to a simple, hypothetical manufacturing firm. The detailed analysis required by modeling and the computer time required to simulate the model made it infeasible to attempt a broader scope of study in the available time.

## Importance of the Problem

The increasing complexity of modern business demands the development of better techniques for managerial decision-making. There is a pressing need to shift the emphasis in data processing from volume record keeping to the development of management information for planning and

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[3]Elwood S. Buffa, Models for Production and Operations Management (New York: John Wiley & Sons, Inc., 1963), pp. 505-506.

control.

Management information necessary to evaluate alternative paths of action can be very costly. In fact, management information systems can be a major portion of a company's operating cost. It is estimated that in American industry today, the gathering, storing, manipulating, and organizing of information for management costs as much or more than does direct factory labor.[4]

The effectiveness of management decision-making is dependent upon the quality and timeliness of information. Therefore, the performance of the information system is of importance to the economic health of a business.

## Methodology

The methods for obtaining the information utilized in the preparation of this thesis were two: (1) a search through the available literature; and (2) the design and simulation of a manufacturing information model.

The review of the literature disclosed that there are few books written specifically on the subject of management information systems. The notable exception is the work of James D. Gallagher with the American Management Association which analyzes the organizational problems in

[4]Marshall K. Evans and Lou H. Hague, "Master Plan for Information Systems," Harvard Business Review, XL, No. 1 (January-February, 1962), p. 92.

installing an electronic management information system.[5] The American Management Association has made additional contributions to the subject in the form of special reports and bulletins. Periodicals, particularly the technical journals such as Management Science and Operations Research, were excellent sources of information on techniques of simulation and decision-making.

The manufacturing information model developed in this study was based in part on the model described by Boyd and Krasnow.[6] The parameters and decision rules used in the model were arbitrarily conceived as to achieve a "reasonable" operating situation that would demonstrate the use of simulation in the analysis of an information system. Simulation of the model was accomplished by the use of the IBM General Purpose Systems Simulator which was chosen as a matter of convenience over any other possible simulator. The description of the model in simulator language is shown in Appendix A.[7]

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[5]See James D. Gallagher, Management Information Systems and the Computer (New York: American Management Association, Inc., 1961).

[6]D. F. Boyd and H. S. Krasnow, "Economic Evaluation of Management Information Systems," IBM Systems Journal, II (March, 1963), pp. 2-23.

[7]For a detailed description of the simulator language, see International Business Machines Corporation, General Purpose Systems Simulator, a reference manual (1963).

The actual simulation runs were made on a IBM 7044 Computer and required approximately twenty to thirty minutes of machine time to complete each run. Output from the simulator has not been included as part of the thesis due to volume and lack of readability.

## Definition of Terms

Due to the broad usage of words and terms found in the literature, it is necessary to provide some definitions for clarity and understanding.

### Data

Howard Levin defines data as facts or statistics which are unrelated and uninterpreted.[8] In an information system, data are the source documents entering the system that have not yet been processed or interpreted by the data processing system for management reporting.

### Data Processing

The term "Data Processing" is used to denote the system of equipment, including the computer and all of its associated peripheral equipment, and people required to process data for management reporting. Data processing is an integral part of the management information system.

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[8]Howard S. Levin, Office Work and Automation (New York: John Wiley & Sons, Inc., 1956), p. 122.

## Decision-making

Management decision-making is commonly accepted as the process of selecting between alternate paths of action. Its importance in the information system depends on the characteristic of being programmable; a decision may be programmable or nonprogrammable. In reality, the decision process is a spectrum from one extreme to the other. Decisions are programmed to the extent that they are repetitive and routine, to the extent that a definite procedure has been worked out for handling them. Decisions are nonprogrammed to the extent that they are novel, unstructured, and consequential.[9]

## Feedback

In systems theory the concept of servo-mechanisms (or information-feedback) is a most important foundation for the analysis of the effect of time delays, amplification, and structure in a system such as a manufacturing firm. An information-feedback system exists whenever the environment leads to a decision that results in action which affects the environment and thereby influences future decisions.[10]

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[9]Herbert A. Simon, The New Science of Management Decision (New York: Harper & Row, 1960), pp. 5-6.

[10]Jay W. Forrester, Industrial Dynamics (New York: John Wiley & Sons, Inc., 1961), p. 14.

## Forecasting

The term "forecast" is used to indicate the process of projecting the past (historical data) into the future. In contrast, management's evaluation of the factors that modify the forecast is considered "prediction."[11] Forecasting techniques are routine procedures that are easily programmed while predictions are judgement procedures that are not so programmable.

## Information

Mr. Levin has also defined "information" as the knowledge derived from the organization and analysis of data.[12] Information for management decision-making, then, is generated in the information system by data processing from source data and files of historical data and information.

## Model

The concept of a "model" as well as that of "feedback" is a most important foundation of systems theory. A well stated definition of a model by Mr. Deacon, Jr., is:

> A "model" is an artifical representation of a system, process, organism, or environment designed to incorporate certain features of that system,

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[11] Robert G. Brown, Statistical Forecasting for Inventory Control (New York: McGraw-Hill, Inc., 1959), p. 3.

[12] Levin, loc. cit.

> process, organism or environment according to the purposes which it is intended to serve.[13]

For this study the model is an artifical representation of a manufacturing firm.

Simulation

The wide use of simulation in different fields of endeavor has given various interpretations to its meaning. For the purpose of this thesis, the definition by Deacon is used:

> "Simulation," as a general field of activity, has to do with the design, building, manipulation and study of models. "A simulation" or "simulation exercise" is an experiment performed upon a model.[14]

In this study an analysis of the information system is made by the simulation of the manufacturing model.

Systems Planning

In the past two decades, the formal awareness of the interactions between the parts of physical systems has led to the development of the field of "systems engineering." However, there seems to be no widely accepted field of general systems theory as applied to the complex business systems. The term "systems planning" as defined by

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[13]Amos R. Deacon, Jr., "Introduction," *Simulation and Gaming: A Symposium,* American Management Association Report No. 55 (New York: American Management Assn., Inc., 1961), p. 6.

[14]*Ibid*.

Ream is used to denote the application of systems theory in the analysis, design, and development of business operating systems.[15]

## Organization of the Thesis

The remainder of this thesis is organized in the following manner.

In Chapter II, the basic characteristics of management information systems are presented. First, the impact of the growth of data processing on the development of integrated information systems is discussed. This is followed by the effect on the organizational structure of a business as it develops larger and more costly business information systems. Next, the effect of decision theory on management decision-making is covered. Emphasis is placed on the expected impact of "programming" lower-level management decisions. Then, the importance of the roles played by systems planning and operations research is discussed in relation to their contribution to the development of management information systems. Finally, the use of simulation as a tool of the systems planner for the design, analysis, and evaluation of business systems is described.

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[15]Norman J. Ream, "The Organizational Relationships of Operations Research, Systems Planning, and Data Processing," The Changing Dimension of Office Management, American Management Association Report No. 41 (New York: American Management Assn., Inc., 1961), p. 98.

Chapter III describes the method of creating a model of a business system under study. The concept of the information-feedback system is discussed as a basis for an underlying structure to integrate the separate facets of the management process. Next, the factory as a system is described in terms of its subsystems; (1) physical, (2) informational, and (3) environmental. Lastly, the role of the systems planner as the experimenter making the analysis or evaluation of the model is discussed.

Chapter IV describes the specific model used in this thesis to illustrate the analysis of an information system by simulation. First, the physical manufacturing system is exaimed in terms of its products, facilities, and resources. The information system is next described according to the functional areas composing the system. Finally, the interaction of the environment with the physical and informational systems is covered.

In Chapter V, the two simulation runs that were made to analyze and evaluate the manufacturing model are discussed in detail. Several measures of performance are shown graphically. First, the parameters of the model are covered. Then, the use of variations in the demand pattern to test the control capabilities of the information is discussed. Lastly, the results from the two simulation runs are presented.

Chapter VI essentially summarizes the findings of previous chapters. Some conclusions concerning the future of management information systems and the use of simulation are advanced.

# CHAPTER II

## BASIC CHARACTERISTICS OF A MANAGEMENT INFORMATION SYSTEM

The dynamics of modern business, shorter lead-time requirements, increased number and complexity of products, wider geographic distribution of products, and larger potential risks in decision-making have given rise to the need for information which quickly shows management the impact of decisions and provides the means for rapid response to changing conditions. The growing complexity both of the business enterprise and its internal management environment, and of economic, governmental, and social climate in which it exists have provided impetus to the development of "information technology."

Management informational needs cannot be answered by mechanization or data processing alone. The basic problem is the development of an integrated management structure to realize overall corporate objectives. This was emphasized by Peter F. Drucker when he wrote:

> We need to know how to 'translate' from business needs, business results and business decisions into functional capacity and specialized effort. There

is, after all, no functional decision, there is not even functional data, just as there is not functional profit, no functional loss, no functional investment, no functional risk, no functional customer, no functional product and no functional image of a company. There is only a unified company product, risk, investment, and so on, hence only company performance and company results. Yet at the same time the work obviously has to be done by people each of whom has to be specialized. Hence for a decision to be possible, we must be able to integrate divergent individual knowledges and capacities into one organization potential; and for a decision to be effective, we must be able to translate it into a diversity of individual and expert, yet focused effort.[1]

To adequately discuss the characteristics of a management information system, the impact of data processing, the changing corporate organizational structure, the increasingly complex management decision-making problem, and the role of the systems planner and operations research must be described.

## Impact of Data Processing

The impact of data processing can best be shown by reviewing its growth in the past decade. During the period from April, 1951, when the world's first large-scale data processing system was installed by the United States Bureau of the Census, to the first of 1961, over 10,000 computer systems were installed for the use of government and industry. At the same time related peripheral input-output,

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[1]Peter F. Drucker, "Long-Range Planning, Challenge to Management Science," Management Science, V, No. 3 (April, 1959), pp. 247-248.

display, and communication equipment were installed.

For the most part, these computer systems were installed for "specific applications" within a functional area of a business; their use was identified and justified to handle a specified functional task. The use of data processing equipment has historically been for clerical cost-reduction by the application of the equipment to the same problem by handling the data more rapidly, accurately and at a lower cost.

Faced with increasingly more complex operating problems, management has recently paid more concern to the integration of old applications into a single processing system. This has introduced new concepts of organization structure, reduced duplication of effort, and generated sizable cost savings, and, perhaps the most important of all, provided the capability of programming low-level managerial decision-making. In industry, the emphasis has been on the development of inventory and production control systems. Such systems, though limited in scope, begin to approximate management information systems, since they do produce documents for the use in current operations and also information for planning and control. The use of data processing for operational control purposes does represent an advantageous use of equipment and personnel and can provide the base for developing and implementing a more sophisticated management information system.[2]

As data processing has grown in its use, management has begun to visualize the opportunity to reduce to orderly relationships the functions of the business and to provide integrated information systems to handle many of the activities which involve not only clerical work but also some lower-level managerial decisions.

The impact of data processing on management and on organizational structures has been of major consequence. Hardly ever before has there been a single factor that has had the powerful effect on the business world that data processing has had over the past decade and is expected to have in the coming decade.[3]

## The Changing Organizational Structure

The structure of an organization and its information requirements are closely linked as the structure reflects the organizational processes of decision-making and flows of information used to make decisions. The technology of working out decisions on predetermined and programmed rules implies changes in content of many managerial

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[2]James D. Gallagher, Management Information Systems and the Computer (New York: American Management Assn., Inc., 1961), p. 34.

[3]Gabriel N. Stilian, "EDP and Profit Making," Control Through Information, American Management Association Bulletin No. 24 (New York: American Management Assn., Inc., 1963), pp. 42-44.

jobs and in structural characteristics of the business organization.

When one considers the impact of a management information system across all functional areas of a business, it becomes evident that it is necessary that a top management function has to be added to the corporate organization structure which can implement, direct, coordinate, communicate, and integrate the informational flow to all levels of the corporate structure. In addition, the development of the top management function is a most important factor in influencing others within the corporate body to think in terms of an ultimate management information system.

When data processing was first used in industry, the equipment was almost invariably placed under the control of the financial officer for accounting applications. However, the range of applications were soon found to far exceed the limits of the accounting system. The management of the data processing service within a company has extended far beyond the technical problems of converting older methods to a computer or of providing machine time for various parts of the corporation that have their own programs. The attention of management has begun to shift from data processing itself to the integrated systems that data processing equipment make possible.

In companies with extensive computer experience, several shifts in organizational structure have typically occurred. Almost without exception, responsibility for the data processing function has risen in importance within the accounting organization. The establishment of a separate data processing department has been only the first step. Usually the increasingly technical capability required to take advantage of the rapidly growing potential in integrated information systems has soon led to the creation of a key position near the top of the financial structure.

Lately, some corporations have decided that the task of designing and operating the management information system is one that deserves a top level position outside the financial organization structure. There is emerging a new kind of corporate staff concerned exclusively with systems and analytical methods for decision-making. "Management service" is a name frequently used to describe this new function.[4]

### Improved Management Decision-Making

The primary function of management is to make the decisions that determine the future course of action for the business over the short and long term. These decisions have to do with every conceivable organizational and

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[4]Douglas J. Axsmith, "A Management Look at Data Processing: Promise, Problem, and Profit," <u>Total Systems</u> (Detroit: American Data Processing, Inc., 1962), p. 10.

physical problem; they may deal with markets and marketing channels, financial planning, personnel procurement policies, alternative plans for expanding production facilities, policies for material procurement, labor control and so on. More often than not the decisions involved cut across functional lines.

Decision theory is directed toward determing how rational decisions ought to be made. It attempts to establish a logical framework for decision that correlates science and the world of models with the real world for various alternative lines of action. These decisions are concerned with every thing that takes place in the organization. For day-to-day operating or repetitive decisions, a set of decision rules make possible continuity and smooth operations, for example the decision rule which determines the amount of material to be ordered at one time. Larger-scale decisions, such as the determination of an over-all plan for expansion, or the decision to float a new bond issue, employ the same general concepts of decision theory, but occur only occasionally.

In making decisions, the manager selects from a set of alternatives what is considered to be the best course of action. To judge which of the alternatives is best, however, he must have criteria and values that measure the relative worth of the alternatives, and a system for forecasting the performance of the alternative courses of action. These elements, taken together, form the basis for a decision criterion which balances the desirable and undesirable characteristics of the alternatives. The difficulties come in establishing the comparability of the various criteria that may conflict and in determing the future performance of the alternate paths of action.

Science in management has grown rapidly, yet poor communication between the management scientist and the operating management tends to introduce a lag in the actual use of known methods, as in the case of decision theory. One strong branch of management science view management in its decision-making function, attempting to reduce as many decisions as possible to a set of automatic decision rules programmable on a computer. This development is directed toward the determination of how decisions ought to be made.

Models and model building are integral parts of formal decision theory. Models are the mechanism by which predictions of performance of a process or system are made and they may be the basis of valuable control mechanisms. When criteria and values tend to be objective and when the models are good predictors, decisions based on them seem scientific, almost automatic. On the other hand, when criteria and values are vague and where quantitative aspects of models can account for only a portion of the problem, decisions rest heavily on judgement and experience.[5]

The nature of managerial decision-making, the degree to which it can be programmed, is a major consideration in the design of an information system. Low-level, repetitive, and routine decisions have already been replaced in the information system by computer programmed instructions. It is in the area of novel, unstructured decisions that procedural techniques have yet to be developed.

An effective management information system improves the managerial decision-making by: (1) timeliness of information, (2) quality of information, (3) wider range of alternatives, and (4) paths of action oriented to the over-all goals of the business.

## The Role of Systems Planning and Operations Research

In the past few years there has been rapid and extensive progress in the application of quantitative techniques to the analysis of management information problems. Considerable confusion does exist today as to the role of systems planning and operations research as they relate to

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[5]Elwood S. Buffa, Models for Production and Operations Management (New York: John Wiley & Sons, Inc., 1963), pp. 6-12.

the development of information systems. Are systems planning (often referred to as systems engineering or systems analysis) and operations research the same or are they different?

"Operations research" has been defined as "a scientific methodology--analytical, experimental, quantitative--which, by assessing the over-all implications of various alternative courses of action in a management system, provides an improved basis for management decisions."[6] In contrast, "systems planning" has been defined as "that staff work which is concerned with research, analysis, development, simplification, and establishment of operating systems and procedures."[7]

Systems planning at the very least employs the techniques of operations research. It has adopted many of the statistical techniques of operations research and as a result a large number of business problems have been exposed to solution via the "scientific method."

Systems planning tends to be business oriented to

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[6]John W. Pocock, "Operations Research: A Challenge to Management," Operations Research: A Basic Approach, American Management Association Special Report No. 13 (New York: American Management Assn., Inc., 1956), p. 9.

[7]Norman J. Ream, "The Organizational Relationships of Operations Research, Systems Planning, and Data Processing," The Changing Dimensions of Office Management, American Management Association Report No. 41 (New York: American Management Assn., Inc., 1961), p. 98.

better communicate with management. The great expectations of operations research have to some extent fallen into the gulf that exists between the scientific and business worlds. The complexity of problem solving tools, the vocabulary of mathematics, and the inability to translate these into simple ideas has contributed to lower realization of operations research programs, Thus, the business trained systems planner may be called upon to bring the tools of operations research to management's attention, to bridge the gap of communication.[8]

Systems planning in business may or may not be applied through the use of mathematical techniques. Systems planning and operations research share a common methodology by defining an objective method of problem solving. However, though they may seem quite similar in many respects there are distinct differences.

Operations research is usually concerned with the operation of an existing system, including both men and machines. Typically, operations research looks at military operations, supermarkets, factories, farms, etc., and exaims specific functions within these operations such as inventory control, distribution of raw and finished materials, waiting lines and advertising. The objective is to

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[8]Stanford L. Optner, Systems Analysis for Business Management (New Jersey: Prentice-Hall, Inc., 1960), pp. 162-166.

optimize, or to make better use of materials, energies, people and machines already in existence and at hand.

In contrast, systems planning emphasizes the planning and design of new systems to better perform existing operations or to implement operations, functions or services never before performed. The concern is with the system as a whole and not particularly the optimization of any one part. In recent years, the systems planner has gained considerable skill and experience in the development and installation of source data-acquisition, data-transmission, and data processing systems.

For the development of the complete, integrated management information system, the team approach with top management, operations research, and systems planning working effectively together presents the most promising method to attack and solve the informational problem.[9]

## Use of Simulation for Analysis

Simulation is a powerful technique for the study of management systems, whether of their design and evaluation or in search for fundamental principles. The use of simulation has grown rapidly in recent years largely because of the availability of electronic computers.

Some operations research people make a sharp

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[9]Gallagher, loc. cit., p. 39.

distinction between simulation and mathematical analysis. Mathematical analysis has proben to be a powerful technique for many problem areas. Yet it has been found to be inadequate for general analytical solutions to situations as complex as are encountered in business. The alternative is the experimental approach or the use of simulation.

To use simulation it is necessary to construct a detailed model of the business system to be studied. Such a model is a detailed description that tells how the conditions at one point in time lead to subsequent conditions at later points in time. The behavior of the model is observed, and experiments are conducted to answer specific questions about the system that is represented by the model.

With simulation models, the effects of many alternate policies can be determined without tampering with the actual physical system. The result is that there is no risk of upsetting the existing system with changes that have no assurance they would be beneficial. In a very real sense then, the common reference to simulation as management's laboratory is true.

Simulation models of operations systems have been growing rapidly and promise to become a dominant technique for assisting management in the decision-making process for day-to-day problems, as well as for comparing basic alternatives of operating policy.[10]

Business and industry have already made important applications of the simulation technique, ranging from models of relatively simple waiting line situations, to models of integrated systems of production. In general, simulation is useful in situations where mathematical analysis is either too complex or too costly. Quite often, however, it is found that the problem faced is incredibly complex, because of a maze of interacting variables, or where the problem itself may be relatively simple in structure, but involves a projection of mathematical analysis into unkown areas. An example of the latter would be a simple waiting line model where the nature of the distribution of arrivals for service times does not fit the standard ones for which analytical solutions have been worked out. Simulation, then, provides an approach to many problems which could not be solved by other known techniques.

Simulation models lend themselves most readily to large, very complex problems involving subtle interrelationships that are difficult to visualize and measure. They are most applicable when the cost and profit implications of a given situation are large, and when the mass of information needed to make a decision can be quantified,

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[10]Buffa, loc. cit., p. 505.

put into numbers, or set within limits.

Simulation has already been demonstrated as a most valuable technique in the analysis of the dynamic behavior of a firm.[11] Simulation also promises to be an extremely valuable technique in the analysis and evaluation of a management information system maintaining control over the firm as it operates in a changing environment.

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[11]Jay W. Forrester, Industrial Dynamics (New York: John Wiley & Sons, Inc., 1961), pp. 13-19.

# CHAPTER III

## DESCRIPTION OF THE METHOD OF ANALYSIS

Historically, the use of data processing has been directed at mechanizing a specific functional area such as a payroll application in the accounting department. The same approach can be found in the manufacturing area where material control, inventory control, and scheduling are often treated as independent applications. In the development of an integrated information system, each functional area cannot be considered as individual and independent applications, but they must be conceived as a total integrated system. First, input data must be converted into information necessary for the planning of materials, manpower, and facilities. Second, the planning information must be communicated to the operating levels for action. Finally, the performance of the functional areas must be processed for evaluation and decision-making to feedback into the planning cycle for dynamic response to changing conditions.

Because of the dynamic character of a business, it is extremely difficult to measure the contribution of its information system in assisting management to maintain control over the firm while operating in a changing environment. A basic premise for the analysis and evaluation of an information system is that better information will lead to better control which in turn will yield improved performance of the business. The control objective of the firm is to respond to the environmental demands in an economically efficient but competitive manner. The effectiveness of the information system in satisfying this objective may be based on the analysis of:

1. The accuracy, completeness, and timeliness with which the demand is satisfied.
2. An accounting measurement of the financial performance of the firm over a period of time in the face of changing demand.

Such measures, being more complex, are more difficult to estimate than the notion of cost displacement and requires an adequate model of the firm itself. Through simulation of the model the intangible contributions of the information system can be estimated.

The feasibility of using simulation for the analysis of an information system is best demonstrated by its application to a hypothetical firm. For this purpose a model of a manufacturing firm, which includes the basic functions of forecasting, material control, inventory control, and scheduling, is proposed. It is assumed that the data processing part of the information system processes data in "batches" as opposed to "on-line" processing where the data are processed as they occur. In other words, the processing of data is done on a cycle (e.g., one, two, or four weeks) and the data for the cycle are processed at one time in a batch.

## The Information-Feedback System

The concept of an information-feedback system is a principal basis for an underlying structure to integrate the separate facets of the management process. It deals with the effect of time delays, amplification and structure as they relate to the dynamic behavior of a system.

Forrester defines an information-feedback system as:

> An information-feedback system exists when-ever the environment leads to a decision that results in action which affects the environment and thereby influences future decisions.[1]

The study of feedback systems deals with the way information is used for the purpose of control. It helps to understand how the amount of corrective action and the time delays in interconnected subsystems can lead to ineffective operating performance.

Information-feedback systems owe their behavior to three characteristics--structure, delays and amplification.

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[1]Jay W. Forrester, Industrial Dynamics (New York: John Wiley & Sons, Inc., 1961), p. 14.

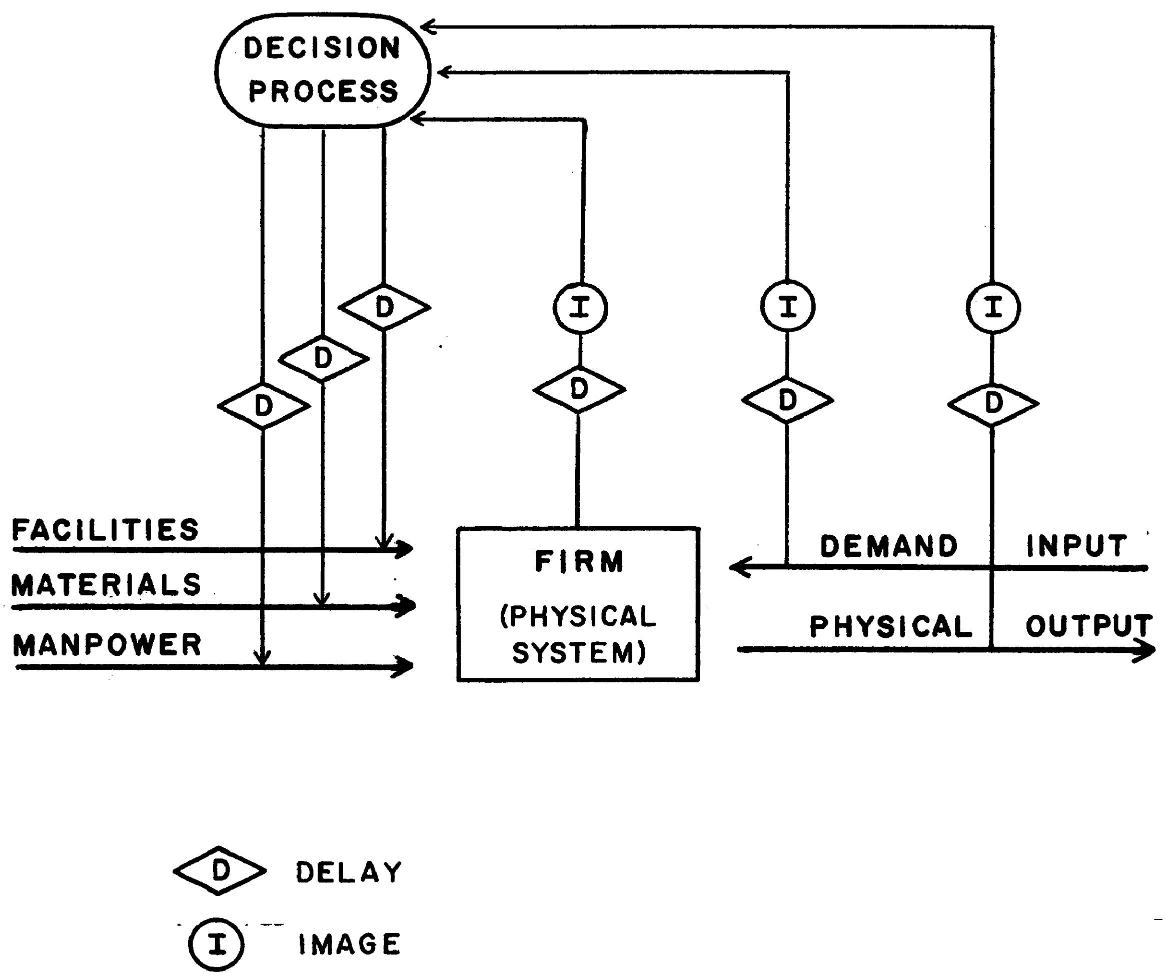
The structure of a system tells how the parts are related to one another. Delays always exist in the availability of information, in making decisions based on the information, and in taking action on the decisions. Amplification usually exists througout such systems, especially in the decision-making processes of industrial systems. Amplification is manifested when an action is more forceful than might at first seem to be implied by the information inputs to the decision process.

In the operation of a manufacturing firm there are many feedback mechanisms employed. An example of a physical feedback system is a thermostat that receives temperature information and decides to start the furnace; this causes the temperature to rise until the temperature information tells the thermostat to stop the furnace. An example of a business feedback system is where orders and inventory levels initiate manufacturing decisions that fill the orders, correct inventories, and lead to new manufacturing decisions based on new orders. Both of the examples are information-feedback control loops. The regenerative process is continuous, and new results lead to new decisions which keep the system in continuous motion.

The diagram in Figure 1 illustrates the concept of an information-feedback system as applied to a manufacturing firm. Management decisions are based on information

FIGURE 1

THE INFORMATION-FEEDBACK SYSTEM



regarding the rate of demand, the rate of output, and the performance of the firm. The decision process, after some time delay, makes changes in the facilities, materials and manpower available to the firm which affect the physical output. The loop is closed with the demand to the firm reacting to both the change in output and external environmental factors.

The general concepts of information-feedback systems are essential because such systems exhibit behavior as a whole which is not evident from examination of the parts separately. The pattern of system interconnection, the amplification caused by decisions and policy, the delays in actions, and the distortion in information flows combine to determine the over-all performance.[2]

## The Manufacturing System

A model is defined by stating its boundaries and its subsystems. The boundary concept makes it possible to define any on-going (non-static) process as a system. It further enables the systems planner to look at the problem as a whole, and set the framework for later looking at the parts (the subsystems) in something close to their correct relationship. A model is only useful when it accurately

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[2] Stanford L. Optner, Systems Analysis for Business Management (New Jersey: Prentice-Hall, Inc., 1960), pp. 17-19.

duplicates the behavior of the real world system. If a model does not accomplish this, it is useful only insofar as it provides information and insight into the development of a new model.

To define the boundaries of the manufacturing information model, its subsystems must be discussed.

Physical System

A basic manufacturing firm performs an economic function upon which its existence is based. A minimal set of activities is required in order to perform this function. The set of activities and its interrelationships compose the "physical system" which is the physical subsystem of the model.

In a manufacturing firm the elements of the physical system are the production processes and the resources which produce the end product. Typically, the manufacturing production process is "job shop" in nature, where products are fabricated and assembled intermittently in batches. The resources include all the facilities, materials and manpower required to affect the physical output from the production process.

A total representation of the manufacturing firm requires, in addition to the physical system, a second part defined as the "information system."

Information System

The information system encompasses all activities of the physical system whose direct or indirect function is to control the physical system. The information system is broader in concept than any existing data processing system, the latter serving as a component of the former. The information system can be represented by the following basic elements and their interrelationships.

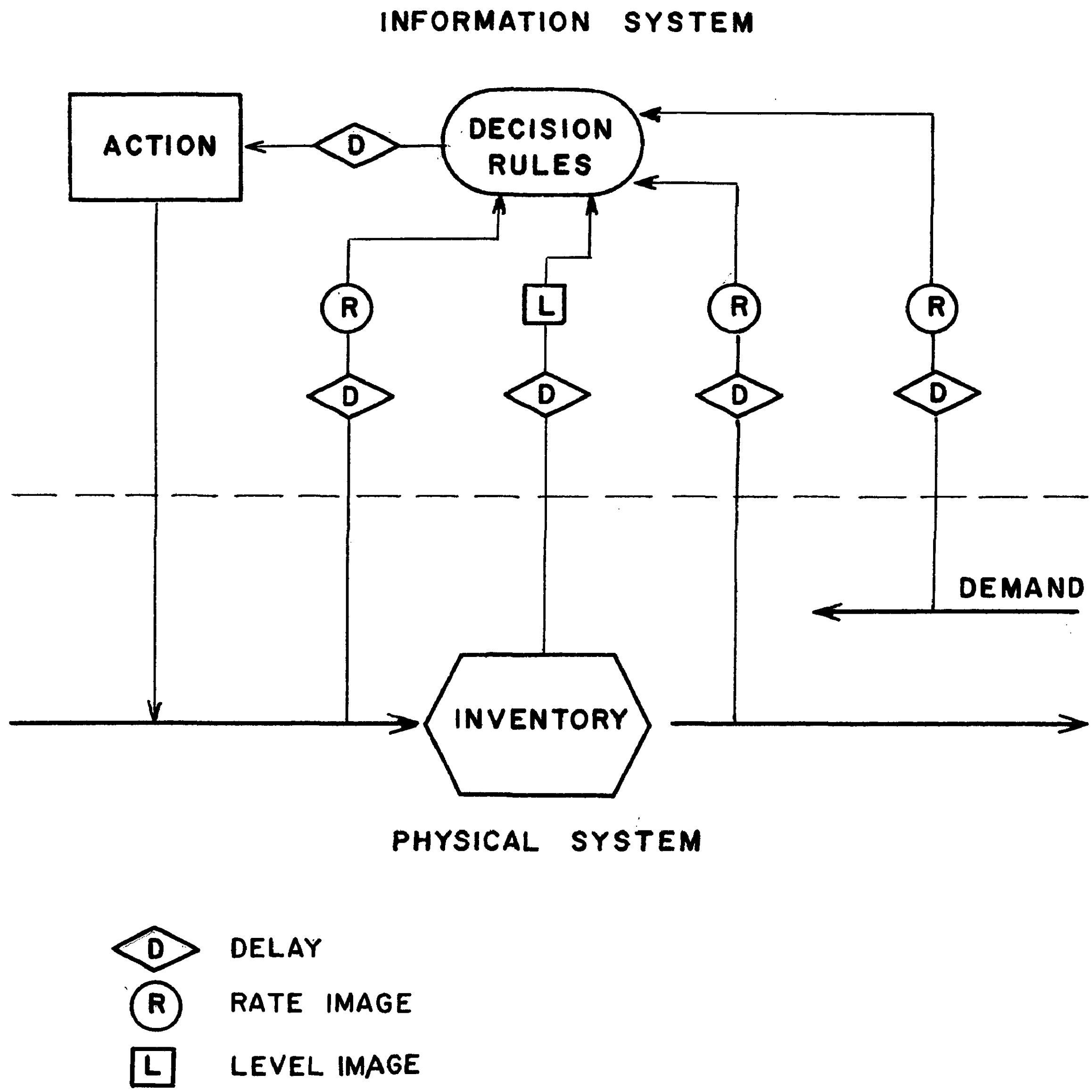
Sensor.--This type of element originates all data input to the information system. It includes both manual and machine-generated input. It reports the occurrence of an event within the physical system (or perhaps within the environment). A segment of a physical system is shown in Figure 2. Sensors record all possible events, the receipt of material into inventory, disbursements from inventory, and the receipt of orders (demand) for inventory.

Input transmission.--Sensed data are subject to delay and/or distortion during transmission. All delays associated with input are assumed to occur at this point (i.e., sensing alone is complete, accurate and instantaneous).

Image.--The end result of data input and most conventional processing, whether machine or manual, is an image. In Figure 2, the image of the true inventory is the

FIGURE 2

SEGMENT OF THE MANUFACTURING MODEL



inventory record. Images can be classified as levels (e.g., inventory) or rates (e.g., the arrival rate of inventory requisitions). With appropriate sensors, images can be provided which describe any activity within the physical system. However, they are distorted as a result of input transmission delays and may be biased by the random or systematic loss of sensed data during transmission.

Decision process.--The decision process is a crucial element of the information system. The term is used in the broadest possible sense to encompass all management decision-making related to the control of the physical system. Decision process can function with the aid of much or little information; with information which is accurate or distorted, timely or outdated. The information upon which the decision process depends (all of the information available to it) is contained in images. The decision process has no direct contact either with the physical system or the environment. In Figure 2, the decision to order additional material for inventory utilizes images of current demand rates and the level of inventory. Some part of the decision process may be "programmable" as computer instructions.

Output transmission.--The result of a decision is a command which will ultimately produce some change in the activities of the physical system. A single time delay is associated with both the decision-making process and the transmission of its commands. In Figure 2, the command is in the form of an order for additional material. More generally, commands take the form of an adjustment to the resources committed within the physical system. Typically, manpower would be reassigned to compensate for a change in the demand mix.

## Environment System

In addition to representing the firm in terms of the physical and information subsystems, a complete model requires explicit recognition of the interaction with its environment. In particular, it recognizes certain basic requirements (demands) which the environment places upon it and which it undertakes to satisfy. One basic measurement of the performance of the firm is the adequacy with which it satisfies these demands. The environment may also provide information inputs to the information system relevant to the future demand pattern.

For the purposes of model building, the boundary between the firm and its environment is somewhat arbitrary. The crucial distinction is between that which can and that which cannot be controlled by the firm. The former is classified within the physical system; the latter within the environment.

The environment, in the case of a manufacturing model, represents the broad economic, social, governmental, and physical factors which have an effect (input) on the business system.

## The Role of the Experimenter

It is the function of the experimenter (usually the systems planner) to define the system, build the model, and perform the simulation studies. The experimenter exerts control over the simulation by setting the parameters for the physical system, the information system and the environment.

There are any number of measures of the performance of an operating firm and its information system (e.g., inventory levels, manpower utilization, shipments, customer order cycle time). In order to record the results of each simulation run, comprehensive observations regarding the performance of the simulated firm must be made. The reporting mechanism for accomplishing the observations has been designated the "accounting reports" because of the parallel to the role of financial accounting for performance evaluation. Cost is an important element of performance and must necessarily be considered in any over-all analysis and evaluation of the business system.

Conventional accounting procedures have been introduced for the purpose of measuring the performance of both the physical system and its information system. The model is designed to produce reports that show data concerning the operation of the model, including data which are entirely independent of cost. It is assumed that no errors or time delays are introduced by the reporting scheme. In this sense the accounting report is perfect and provides an accurate and unbiased appraisal of the performance of the firm.

The final evaluation of the performance of the information system must include the cost of changing the parameters of the system. In other words, an improvement in the performance of the information system will normally cost more because of increased usage of data processing equipment and personnel. This cost must be balanced by the increased performance of the firm both in profit and better service.

# CHAPTER IV

## A HYPOTHETICAL MANUFACTURING INFORMATION MODEL

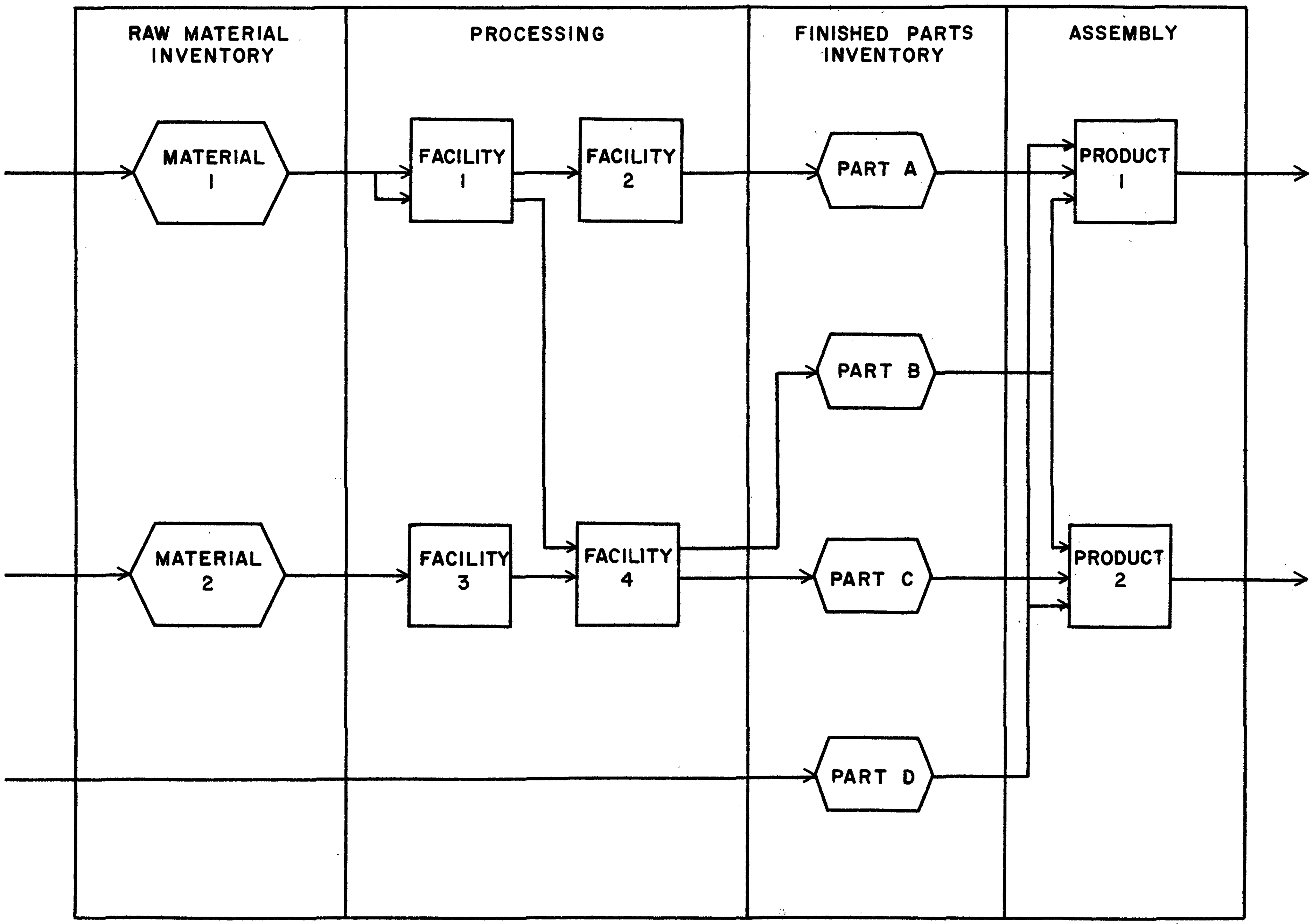
To demonstrate the technique of using simulation for the analysis and evaluation of an information system, a model of a simple, hypothetical manufacturing firm was created. The model incorporates the typical data processing applications of forecasting, inventory planning, material planning, and scheduling. The model is completely arbitrary and could be readily extended or curtailed. The information delays and implementation delays are typically those found in a data processing system where data are processed in "batches."

### The Physical System

The simple manufacturing firm shown in Figure 3 incorporates as much as possible of the dynamic complexity found in a typical manufacturing operation within a nominally simple model. Thus a basic assumption is made that the general dynamic characteristics of a system can be adequately represented without the introduction of the large number of individual elements actually present.

FIGURE 3

THE PHYSICAL SYSTEM



The specific firm manufactures two end products, designated as Products 1 and 2. The firm assembles and ships both products to customer order. Four finished parts (Parts A, B, C, D) provide all of the components for the assembled products, in accordance with the Bills of Material shown in Table 1.

TABLE 1

BILLS OF MATERIAL

| Part | A | B | C | D |
|---|---|---|---|---|
| Product 1 | 1 | 1 | | 1 |
| Product 2 | | 1 | 2 | 1 |

Parts B and D are common to both products, introducing a conflict situation (with its related decision problems) of the type often found in practice.

The activities of the physical system are distributed over four stages of manufacturing: (1) material control, (2) parts processing (fabrication), (3) inventory control, and (4) assembly and shipping. This introduces much of the dynamic complexity of the model, since overall response is dependent upon actions taken somewhat independently within each stage. Effective control does require planning to coordinate the activities with different stages.

The scale of an activity (e.g., time to perform, rate of occurrence, etc.) is either dependent upon other activities and therefore determined by the simulation (for example, the number of parts in inventory); or it is a parameter of the physical system controllable by the systems planner (for example, the time to assemble one unit of Product 1). In the latter case, the value may be specified determinately as a constant or a function, or stochastically as a random function.

The performance of an activity requires the commitment of one or more resources. Several activities have been structured so that they compete for the same resources, thereby creating typical conflict situations which can only be resolved by rational decisions. The resources available in the model are:

Processing manpower.--Men within the process stage are entirely interchangeable, and may work on any valid operation or remain idle.

Assembly manpower.--Men within the assembly stage may assemble orders for either product. However, no transfer of men between the assembly and processing stage is permitted.

Processing facilities.--Each facility within the processing operation commits one man and one unit of facility to the process of one part. The facility units require setup time each time a different part is to be processed on that unit.

Material.--The finished parts used in the assembly of the two products are fabricated from two raw materials and one purchased part. Two of the finished parts (Part A and Part B) compete for Raw Material 1. Part C is fabricated from Raw Material 2. Part D is purchased in bulk quantity as a finished part.

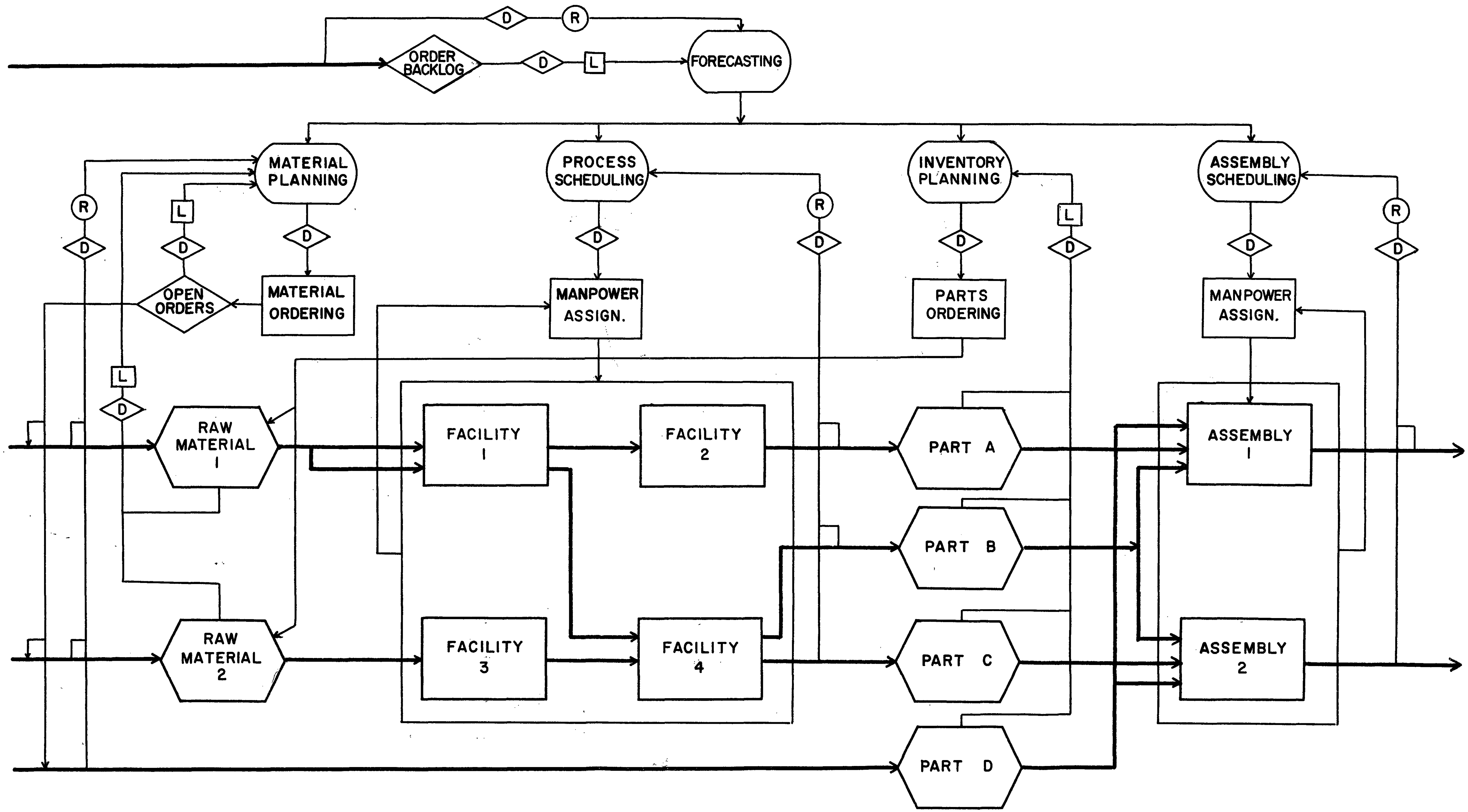
## The Information System

The prime objective in constructing the information system is to provide sufficient capability to permit effective dynamic control over the physical system. Within this context, the emphasis is placed upon building a conventional structure which could plausibly incorporate a range of data processing equipment. Since each data processing system has its own information processing capabilities, the degree of effective control that could be attained would vary with the range of equipment. In Figure 4, a schematic of the complete model depicting, among other things, all of the major features of a basic manufacturing information system.

Hierarchical aspects of an information system in the large firm are included. Decision-making occurs at various levels within the organization with considerable interaction between levels. Operational control, at the lowest level, responds to events on a fairly rapid time scale, in a highly constrained manner. At a higher level,

FIGURE 4

SCHEMATIC OF THE MODEL



tactical decisions are taken whose effect may be only indirect, leading to direct action at the operational level. These decisions are less frequent than those at the operational level, as well as more complex.

The physical system, as previously described, is also included in Figure 4. In the model, sensors are included at all points on the interfaces between the four stages of manufacture, and on the interface within the environment. The sensors are assumed to exert no direct influence on the physical system. It is indicated that this generates a reasonable amount of data for this type of system. Additional sensors, placed within each stage (e.g., recording material movement between operations in processing), would suggest a rather highly advanced information system involving the use of source data-acquisition equipment. Fewer sensors, placed only at the interface with the environment (e.g., recording orders and shipments) would probably not permit effective control over the physical system.

The precise configuration shown in Figure 4 is arbitrary, and could be readily extended or curtailed. When a real model is developed, it is needless to say that the sensors would be placed to reflect the actual occurrence of data input into the information system.

Figure 4 also indicates delays associated with the information transmission and processing, the resulting images of the sensed data, and the decision processes which utilize these images.

Decision rules are themselves parameters of the information system, in the sense that they can be individually detached and replaced. However, only one set of decision rules are used in the model. These are designed to achieve reasonable control even under fairly poor information flow conditions. In practice, of course, the decision processes and the quality of the information flow are highly related. Improved flow may be ineffective if not accompanied by improvements in decision-making (e.g., utlization of mathematical techniques) may well be impractical without parallel improvements in information flow.

The set of decision rules formulated for the model relate to forecasting, material planning, inventory planning, and manpower assignment (scheduling).

## Forecasting

Forecasting is the process which permits the model to adjust to, and perhaps anticipate, systematic changes in the demand for a product. Forecasting involves the use of historical data and a management judgement factor to produce new forecasts. Exponential smoothing is the method employed in the model to generate forecasts of future product demand. It is a special form of moving average developed by operations research for use in computer processing.[1]

The crucial element in creating a plan for the use of materials and resources is a projection of shipping requirements for the next planning period, based on the forecast of product demand and the current backlog of orders. Shipping requirements are established by distributing the backlog in an exponential manner to the scheduling periods. This places most of the backlog in the current scheduling period with decreasing proportions in succeeding scheduling periods.

Once shipping requirements have been established, they are used as the planning base for material planning, inventory planning, and scheduling. An assembly plan for manpower is produced from the shipping requirements by adjusting for assembly lead time. The plans for material planning, inventory planning, and scheduling are generated from the assembly plan by the necessary parts explosions, lead times, and scrap loss adjustments.

## Material Planning

The raw material and purchased part requirements provide the basis for ordering raw material and purchased

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[1] R. G. Brown, Statistical Forecasting for Inventory Control (New York: McGraw-Hill Co., 1959), p. 13.

part. Orders are placed periodically, at a time determined by the availability of a new forecast. This time is later than the nominal date of the forecast, due to the delays found in the information system. Before ordering, therefore, the forecast must be updated for material and parts received since the start of the period, and for any currently open orders.

For raw material, allowance is made for the possibility of receiving defective material. The actual order quantity is determined so as to cover requirements through an entire period plus safety stock.

Purchased Part D is ordered in bulk quantities of 500 parts in order to take advantage of quantity pricing. The decision to order more of Part D is based on availability of a new forecast, lead time, parts on order, and the current number of parts in stock.

## Inventory Planning

Although the firm assembles and ships products to customer order, parts are fabricated to inventory requirements. From the forecast and lead time for each part, the model calculates the minimum stock level, the reorder point, and the reorder quantity. This information is used in the inventory control function to maintain the inventory of parts at a minimum level and yet service the customer. In addition, the inventory control function adjusts the order quantity for scrap allowance.

Scheduling

In the processing stage, the shipping requirements are used once each week to generate a scheduled load. The requirements are first adjusted for parts produced since the beginning of the planning cycle, and are then extended in accordance with the work content (standard processing time) remaining in the period for each production operation. The available work force is then assigned to each operation (part to be processed on a facility) in proportion to the computed work loads and subject to the physical limitations set by the facility capacities.

Existing setups are not considered in arriving at the scheduling decision. The implementation of the decision permits reassigned men to complete the operation on which they are currently engaged before moving to a new assignment.

In the assembly stage, the assignment procedure is identical except that there are no facility constraints to be observed. Idle men are transferred to the alternate product unless idleness is observed for both products.

## Environment System

The interactions between the firm and its environment within the model are limited. This is far from a practical situation where many environmental influences such as governmental, social, economic, and competition to a large degree restrain the performance of the business. However, the experimenter must define the boundaries of the system to be studied. Boundaries include or limit the area of feasible study which, for this model, have been defined as:

Customer orders.--Orders are the demand input to the physical system. The properties of an order are: it is for a single product; it is held within the system until filled; it specifies the quantity (number of units) required.

Product shipments.--Shipments are an output of the physical system. No partical shipments are made. Orders are shipped as soon as completed.

Purchase orders.--A purchase order is an output of the information system. Each order is for a single raw material or purchased part, specifying the quantity of material or parts desired.

Receipt of material and parts.--The raw material and purchased part are inputs to the physical system. The environment imposes a delay (lead time) upon the filling of purchase orders. At the end of this delay, the material or part is entered into the physical system where it is inspected for defective material or parts. The defectives are removed and the remaining material or parts are entered into their respective inventories.

## The Selection of Parameters

A model of a firm has two interfaces: (1) one with its environment, and (2) one with the experimenter (the systems planner). The experimenter exerts control over the simulation by setting parameters for the physical system, the information system, and the environment. He is also free to independently set the cost elements (e.g., labor rates, material prices, product prices) of the accounting structure, which govern the level of financial results. The major controllable variables of the model are summarized in Table 2. For stochastic variables the parameters are in the form of probability distributions.

In addition to direct variation of system parameters, the experimenter may introduce more basic changes. Decision rules can be modified or entirely replaced without disturbing other parts of the model. It is also possible, though not quite as straight-forward, to modify the structure of the physical system. For example, the flow of parts in the processing stage could be changed, or the material usage specifications could be altered.

TABLE 2

PARAMETERS CONTROLLED BY THE EXPERIMENTER

| Subsystem | Parameter | Stochastic |
|---|---|---|
| Physical | Setup times | Yes |
| | Processing times | Yes |
| | Assembly times | Yes |
| | Rejection rates | Yes |
| | Size of work force | No |
| | Facility capacities | No |
| Information | Input transmission delay | Yes |
| | Command delays | Yes |
| | Length of planning period | No |
| | Forecasting smoothing constant | No |
| | Backlog distribution constant | No |
| | Processing lead time | No |
| | Assembly lead time | No |
| | Inventory safety stock | No |
| | Direct labor standards | No |
| | Scrap allowance | No |
| Environment | Purchase order lead time | Yes |
| | Customer order arrival rate | Yes |
| | Customer order quantity | Yes |

In the analysis of an information system, the parameters that are of concern are those which have been chosen to be modified to measure their effect on the model. The actual numerical values of both the parameters and the measures of performance are relatively unimportant since the concern is not with absolute values (simulation is a probabilistic technique), but rather the concern is with the change that occurs from one simulation run to another.

# CHAPTER V

## SIMULATION OF THE HYPOTHETICAL MODEL

In simulation, the experimental approach that is chosen depends entirely upon what one desires to learn about the model. It is possible to vary the parameters of the information processing system in order to evaluate the relative worth of a spectrum of data processing capabilities; or evaluate alternative decision processes. Alternatively, one can vary the parameters of the physical system to suggest the range of industry characteristics for which a given information handling capability is worth while. As in all simulation work, a systematic approach to experimentation is desirable. In particular, statistically designed experiments offer the best prospect of achieving soundly based conclusions at minimum cost in computer time.

For this study it is assumed that the systems planner is analysing a proposed improvement (the procurement of additional or new data processing equipment) in the information system. Essentially, the question to be answered is whether the anticipated change would significantly improve the performance of the business. If a significant improvement in performance is indicated, it is then necessary to compare the cost of the proposed change against the predicted performance.

The final evaluation of the results from simulation is a management function. Such a management decision would necessarily include their evaluation of outside factors (largely environmental) as well as the simulated improvement in service to the customer, control of facilities and resources, and cost of operation. However, the knowledge gained by the systems planner from the simulation study would provide a sound base for management's decision.

To demonstrate the technique of analyzing an information system through simulation, actual simulation of the manufacturing model was accomplished by the use of the IBM General Purpose Systems Simulator. The model as described in the simulator language is shown in Appendix A. It is indicated from the detail necessary to describe the relatively simple model that the systems planner must intimately know the business system to model it. Output from the simulation has not been included as part of this thesis due to the large volume and lack of a readible format.

Simulation of the manufacturing model was accomplished in two runs. The output from the first run represents the performance of the existing information system while the output from the second run represents that of the proposed system.

## The Information Parameters

The two simulation runs are based on manipulating two aspects of the information system; (1) the length of the planning cycle together with a related implementation delay; and (2) the magnitude of information transmission delays.

The model contains a series of decision rule algorithms beginning with the generation of a demand forecast and continuing on through material planning, inventory planning, and scheduling. These algorithms are applied periodically and new plans and schedules are generated based on the sensing of new demand information as well as the performance information of the physical system. These algorithms closely parallel typical planning and scheduling sequences in a real manufacturing firm.

TABLE 3

FORECASTING CYCLES

| Characteristic | Run 1 | Run 2 |
|---|---|---|
| Length of period | 4 weeks | 2 weeks |
| Implementation delay | 5 days | 3 days |

Table 3 shows the characteristics of the two forecasting cycles used in the two simulation runs. The slow cycle (Run 1) corresponds to every-four-weeks, and the fast cycle (Run 2) to every-two-weeks forecasting and planning. The implementation delay (output transmission delay) represents the time lags between the availability of the new forecast information and actually putting the plan into action.

The second aspect of the information system chosen for manipulation was that of information time lags (input transmission delay). The information system senses through more or less distorted images. A principal distorting influence is that of information delays. For example, it may be necessary to write today's purchase orders based on last week's inventory figures.

TABLE 4

INFORMATION DELAYS

| Information category | Run 1 | Run 2 |
|---|---|---|
| Incoming orders for products | 5 days | 2 days |
| Product shipments | 2 | 1 |
| Raw material receipts | 3 | 1 |
| Raw material into process | 2 | 1 |
| Finished parts movement into inventory | 2 | 1 |
| Finished parts movement into assembly | 3 | 1 |

Two sets of such delays were used in the simulation runs as indicated in Table 4. In the first run, incoming orders and shipping and receiving status are sensed through a one-week time lag. The in-plant movements are sensed through a two- and three-day delay as shown. In the second run, the one-week delay for incoming orders is reduced to two days. The in-plant delays are reduced to one day.

Thus, it can be seen that the second simulation run represents a major improvement in the delays of the information system. On the surface, one would expect a corresponding improvement in the over-all performance of the firm. The actual improvement is predicted from the output of the simulation runs.

## Varying the Demand Pattern

The activity which initiates the internal functioning of the model is the stream of incoming orders for the two products. This demand pattern provides the means for loading and testing the management control capabilities of the model. One of the prime functions of management is, in a broad sense, to respond in an effective way to the demand pattern. As previously noted, the purpose of this study is to determine whether significant differences in performance would result from changes in selected parameters of the information system. In order to amplify any such differences, a severe response requirement is placed on the model by the demand pattern. This is accomplished by imposing an abrupt change in the product demand levels.

The initial demand level for Product 1 is established at the average rate of seventeen units per week, and for Product 2, fifty-five units per week. At the end of the first four weeks of simulated operation, Product 1 demand is raised abruptly to an average of fifty-one per week, while Product 2 demand is dropped to nineteen per week. The demands are left at these levels for the remainder of the run.

The model is initialized by providing an initial stock of raw materials and finished parts and simulating the operation of the firm for several weeks. This allows the model to adjust itself to the parameters in use.

The forecasting function is initialized by providing "historical" demand levels which reflect the initial demand mix. The effect of the initializing is to put the model in a condition of having operated for an extended period of time at the initial demand mix and of having no expectation the levels would change.

The abrupt change in the demand mix presents three major problems:

1. The nature of the change in demand must be assessed and extrapolated in the form of new forecasts.
2. Raw material orders must be initiated to rebalance the raw material inventory to meet

the new demand mix.

3. Manpower assignments in the facilities must be shifted in order to supply the finished parts inventory with the new mix of finished parts for assembly.

It seems apparent that the logistics of Product 1 present a more critical problem than those of Product 2. At the time of abrupt change in demand levels, the supply of stocks necessary to support Product 1 is effectively tripled whereas the supply of stocks necessary to support Product 2 is reduced to about a third.

## The Accounting Parameters

The output from the model results in a very complete set of data describing the behavior of the physical system during the course of the simulation. At the end of each weekly reporting cycle, all pertinent physical data are produced including manpower distribution, facility queues, order backlogs, and product shipments.

The parameters of the accounting framework include a set of standard costs for the evaluation of finished products and all raw material and in-process inventories. The values of the accounting parameters selected for the simulation runs are shown in Table 5.

At the end of the weekly reporting cycle, the pertinent physical rates and levels are reported for use in

TABLE 5

ACCOUNTING PARAMETERS

| Category | Detail | Value |
|---|---|---|
| Product selling prices | Product 1 | $250 |
| | Product 2 | 375 |
| Raw material costs | Raw Material 1 | $ 25 |
| | Raw Material 2 | 40 |
| Purchased part cost | Part D | $ 1 |
| Direct labor standards | Wage rate | $3.00/hr. |
| | Standard hours | |
| | Facility 1, Part A | 5 hrs. |
| | Facility 1, Part B | 4 hrs. |
| | Facility 2, Part A | 10 hrs. |
| | Facility 3, Part C | 1 hr. |
| | Facility 4, Part B | 2 hrs. |
| | Facility 4, Part C | 3 hrs. |
| Standard burden | Burden rate | 70% |
| Fixed costs | Depreciation charge | $4,000/mo. |
| | Selling and admin. | 5,000/mo. |

creating a financial statement. For the two simulation runs, only the profit and loss statement has been prepared for graphical presentation. Other accounting reports (cash flow, balance sheet) could readily be prepared for management's analysis and evaluation.

Table 6 shows the form of the financial statement used to produce weekly profit and loss statements from the output of the two simulation runs. Accounting statements are not readily produced as direct output from the simula-

TABLE 6

THE FINANCIAL STATEMENT

| | | |
|---|---|---|
| Manufacturing expense statement | | |
| Raw material purchased | $ xxxx | |
| Purchased part expense | xxxx | |
| Direct labor expense | xxxx | |
| Indirect expense | xxxx | |
| Depreciation | xxxx | |
| Total expense | | $xxxxx |
| Deduct inventory changes | | |
| Change in raw material inventory | $ xxxx | |
| Change in in-process inventory | xxxx | |
| Change in finished parts inventory | xxxx | |
| Change in assembly inventory | xxxx | |
| Net change in inventories | | xxxxx |
| Cost of goods sold | | $xxxxx |
| Income statement | | |
| Sales | | $xxxxx |
| Deduct: | | |
| Standard cost of goods sold | $ xxxx | |
| Manufacturing cost variance | xxx | |
| Cost of goods sold | | xxxxx |
| Gross profit on sales | | xxxxx |
| Less selling and admin. expense | | xxxxx |
| Net profit/loss on operations | | $xxxxx |

tor due to the lack of report generating capability.

## Results of the Simulation Runs

Due to the fact that there are many possible measures of the performance of an operating firm and that the hypothetical model is only for illustration purposes, a few of the more important measures have been chosen to be presented. These are shown in graphical form.

### Physical Performance

One of the more direct indications of the response of the physical system to the variation in product demand is shown by a comparison of the actual shipments of the finished products with their demand pattern. Figures 5 and 6 show the comparisons for Runs 1 and 2, respectively. The product demand patterns are shown as distributions with average demand and associated limits. The distributions appear skewed which can be attributed to the variation of the number of units per customer order.

In both runs the form of the shipment curves are quite similar. In the fifth week, when the abrupt change in demand pattern is applied, shipments for Product 1 respond rapidly to the increased demand level. This rapid response reflects the fact that for this firm assembly is done on a "to-order" basis. However, the response level cannot be maintained due to the depletion of finished parts

FIGURE 5

PRODUCT DEMAND AND SHIPMENT
(Run 1)

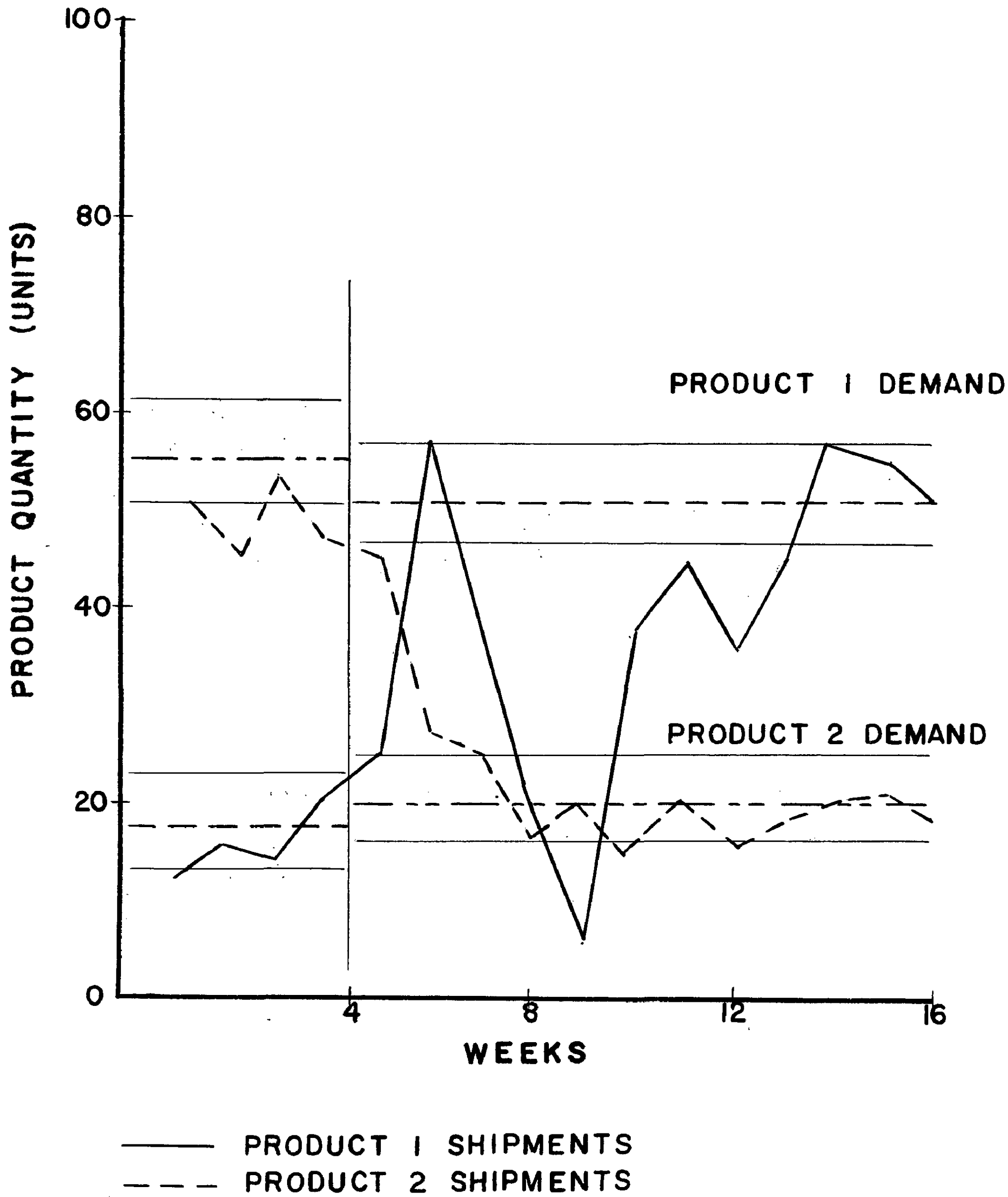
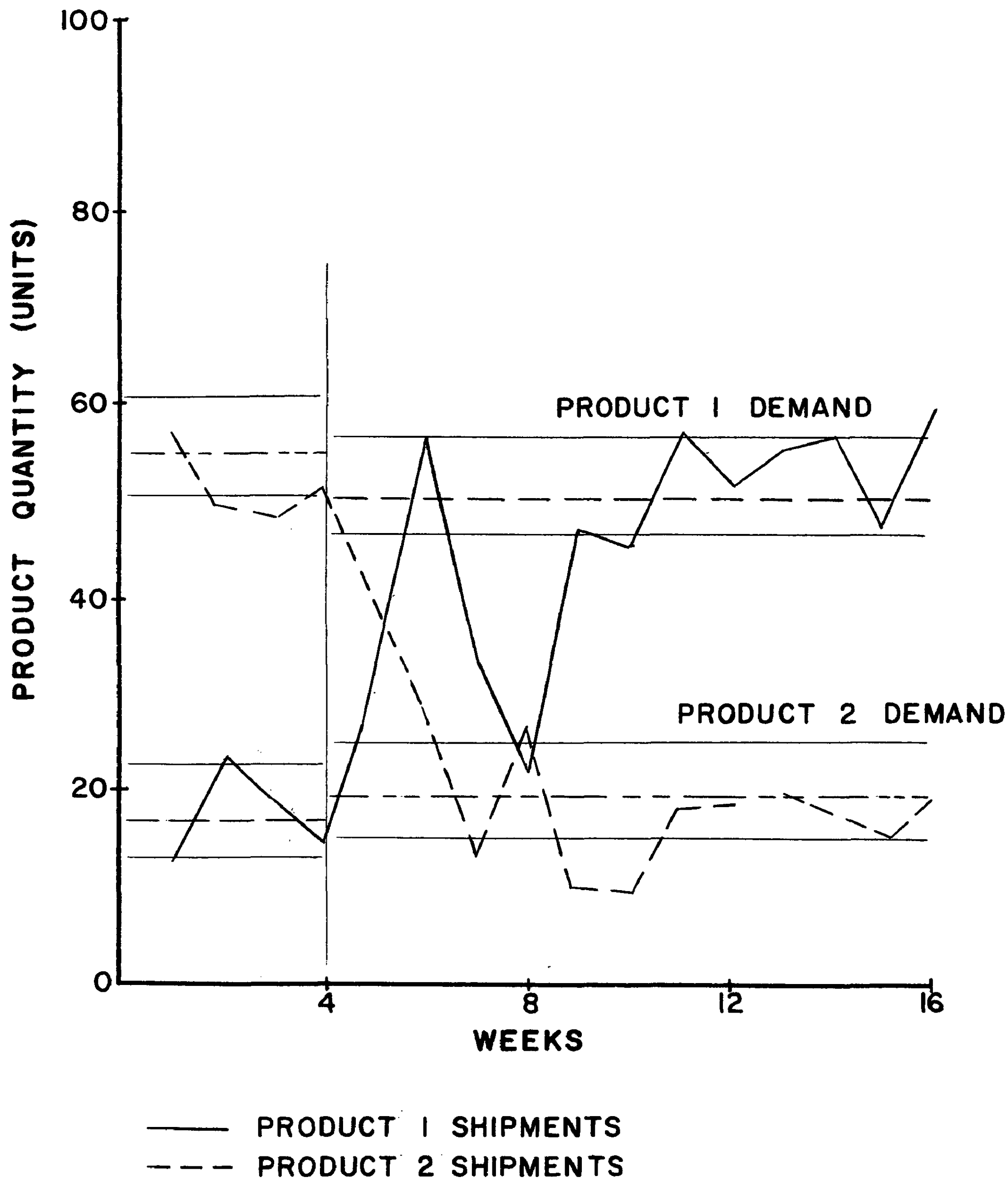


FIGURE 6

PRODUCT DEMAND AND SHIPMENT
(Run 2)



and raw material inventory which is pointed out in subsequent graphs. Shipments build up again after the eighth and ninth weeks as the forecasting and planning decision rules adjust to the new demand levels.

The pattern of Product 2 shipments reflect the easier response problem posed by the decrease in its demand.

Product 1 shipments in Run 2 indicate a faster response to the change in demand which is reflected by a significant difference between Product 1 backlogs of Runs 1 and 2. Figures 7 and 8 display the backlogs for Products 1 and 2 as created in Runs 1 and 2. These indicate the relationship between the demand and the shipping patterns.

The backlog, unfilled orders, for Run 1 show a rather stable pattern for the four week period before the change in demand levels. At the end of the fifth week, an abrupt rise in unfilled orders for Product 1 is started and continues until the thirteenth week. At that time the backlog begins to decrease. In contrast, the backlog for Product 2 decreases until it levels off at about ten units which represents a near minimum level for the assembly time built in the model. Essentially the same curves are observed in Run 2 with the exception that the backlog for Product 1 levels off sooner indicating a more rapid response to changing demand.

For a manufacturing firm of the type represented,

FIGURE 7

BACKLOG OF ORDERS
(Run 1)

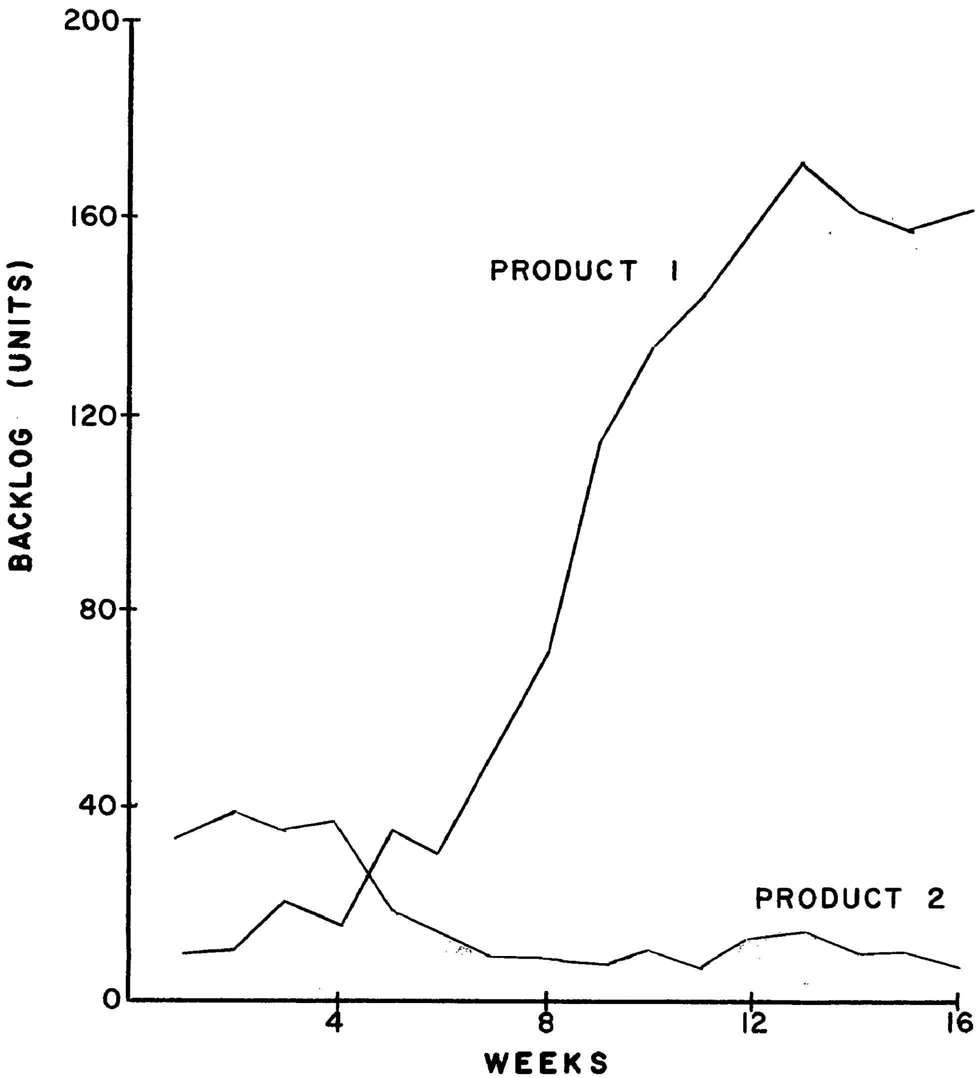
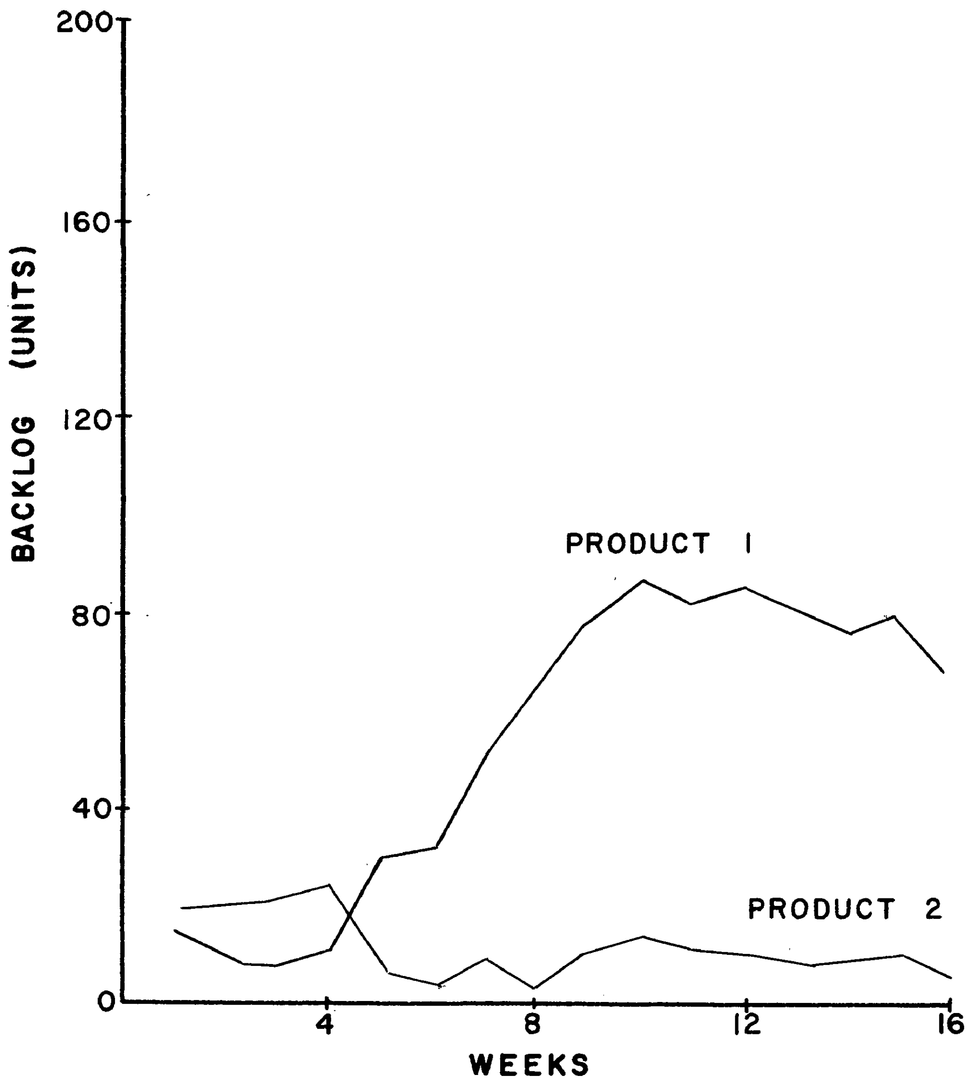


FIGURE 8

BACKLOG OF ORDERS
(Run 2)



one of the best single measurements of performance is that of customer order cycle time, i.e., time from receipt of an order to the shipment of the order. Figures 9 and 10 show in histogram form the order cycle times for the 16-week period of simulation of both runs. In Run 1, the average cycle time for Product 1 is 13.4 days. The distribution, however, is a bimodal one with the left portion representing delivery performance during the first four weeks. The right portion, with an average of about 17 days, represents the performance after the change in demand pattern occurred. Such a distribution reflects the deterioration in delivery performance that is related to the increasing backlog level. If one were to plot the average delivery time for each week, a significant trend to the right (longer delivery) would be observed. In contrast, the average order cycle time for Product 2 is 5.2 days which represents close to maximum delivery performance for the assembly processing and material moving times specified in the model.

In Run 2, Figure 10, the histograms for both Products are quite similar to Run 1 except that the bimodal distribution for Product 1 is not as distinct. The average cycle time for Product 1 is 12.1 days and 4.4 days for Product 2 which represents a significant improvement over the cycle times of Run 1.

The explanation for the decline in Product 1

FIGURE 9

ORDER LIFE CYCLE
(Run 1)

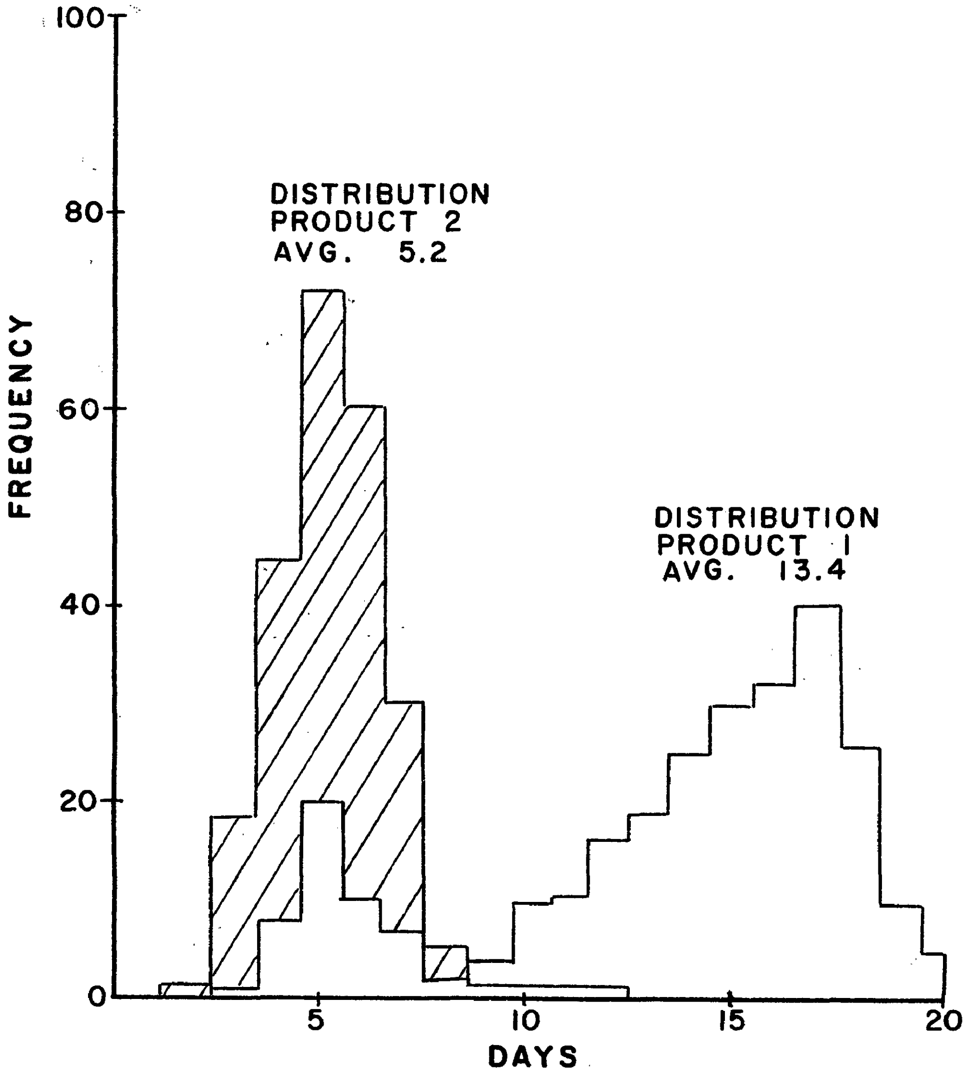
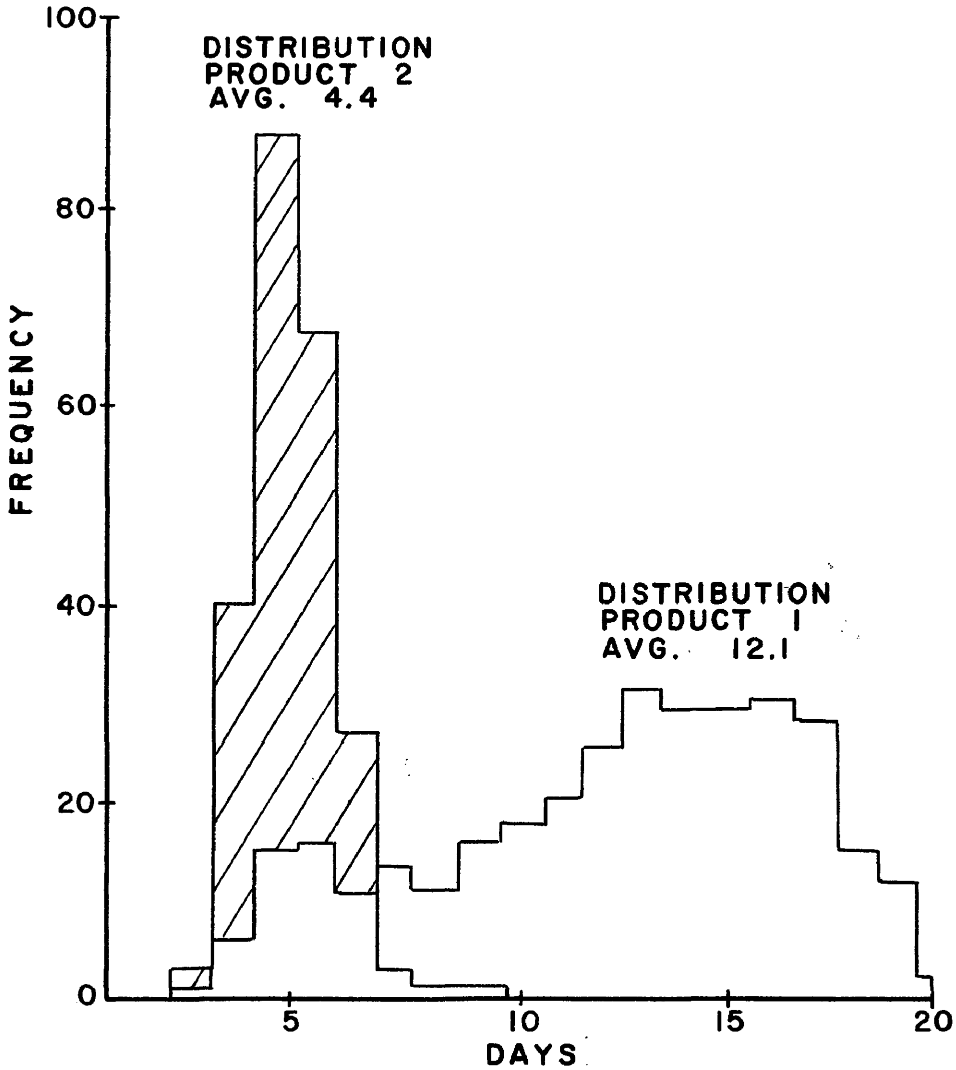


FIGURE 10

ORDER LIFE CYCLE
(Run 2)



shipments (after responding to the demand change) can be found by observing the finished parts and raw material inventories as shown in Figures 11, 12, 13, and 14. During Run 1, as shown in Figure 11, the inventory of Part A is rapidly reduced to zero after the fourth week when the demand change is applied. The increase in demand level for Product 1 effectively triples the consumption of Part A. The impact of such "stock-outage" is to reduce shipments of Product 1 (see Figure 5) and increase the backlog (see Figure 7). Part B inventory remains stable since a significant change has not taken place in the demand for this part. Part C inventory rapidly increases after the fourth week due to the greatly reduced demand level for Product 2. Part D, which is ordered in bulk quantities, exhibits an inventory pattern typical of parts purchased in fixed amounts.

During Run 2, as shown in Figure 12, the inventories follow much the same pattern as in Run 1 with the exception of Parts A and C. The higher inventory level for Part A and the lower inventory level for Part C reflect the better control response of the information system for the second run. In other words, the more rapid recovery of Part A inventory during Run 2 provides a significant improvement in Product 1 shipments while the more rapid adjustment to Part C demand reduces the inventory level and

FIGURE 11

FINISHED PARTS INVENTORIES
(Run 1)

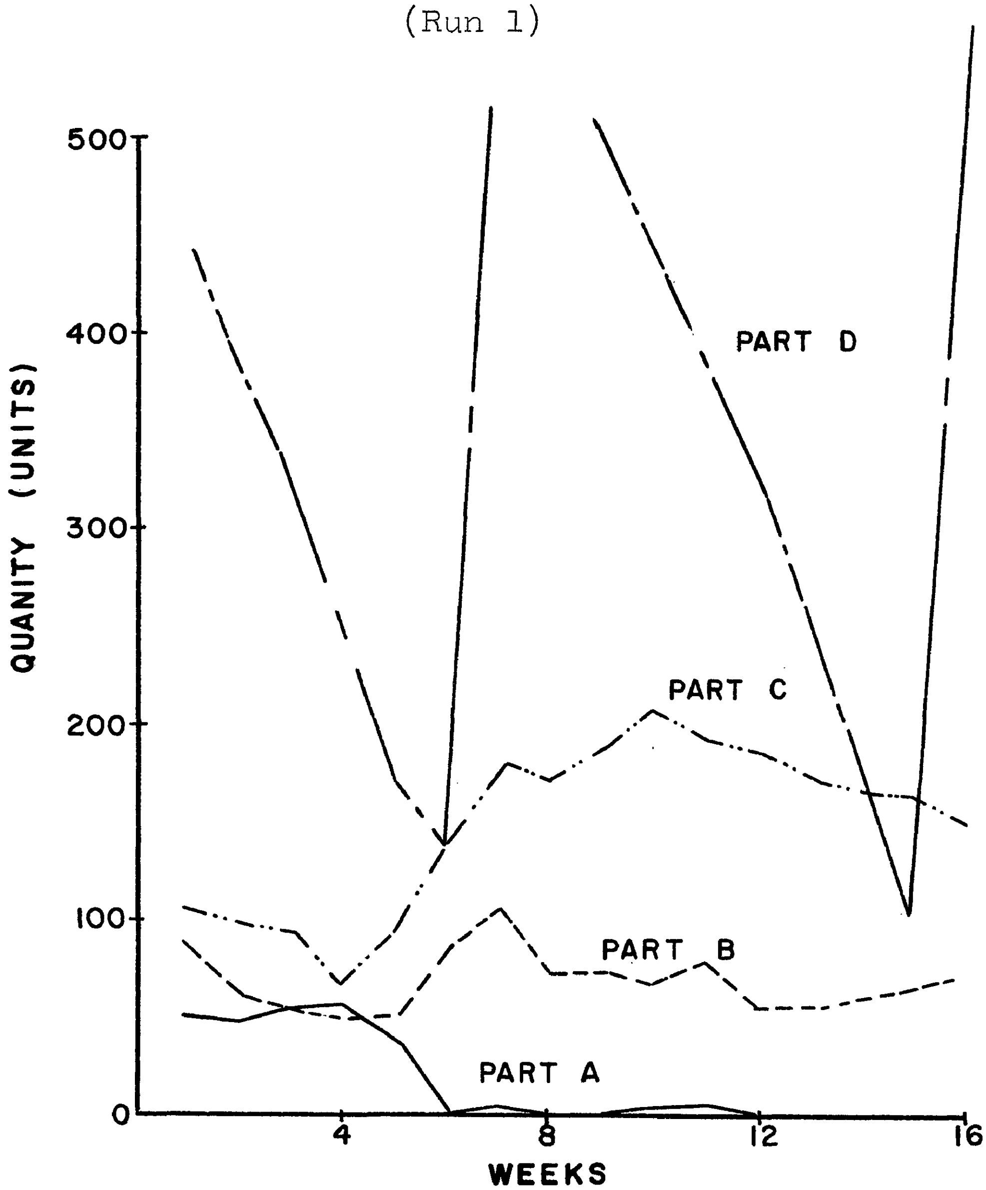


FIGURE 12

FINISHED PARTS INVENTORIES
(Run 2)

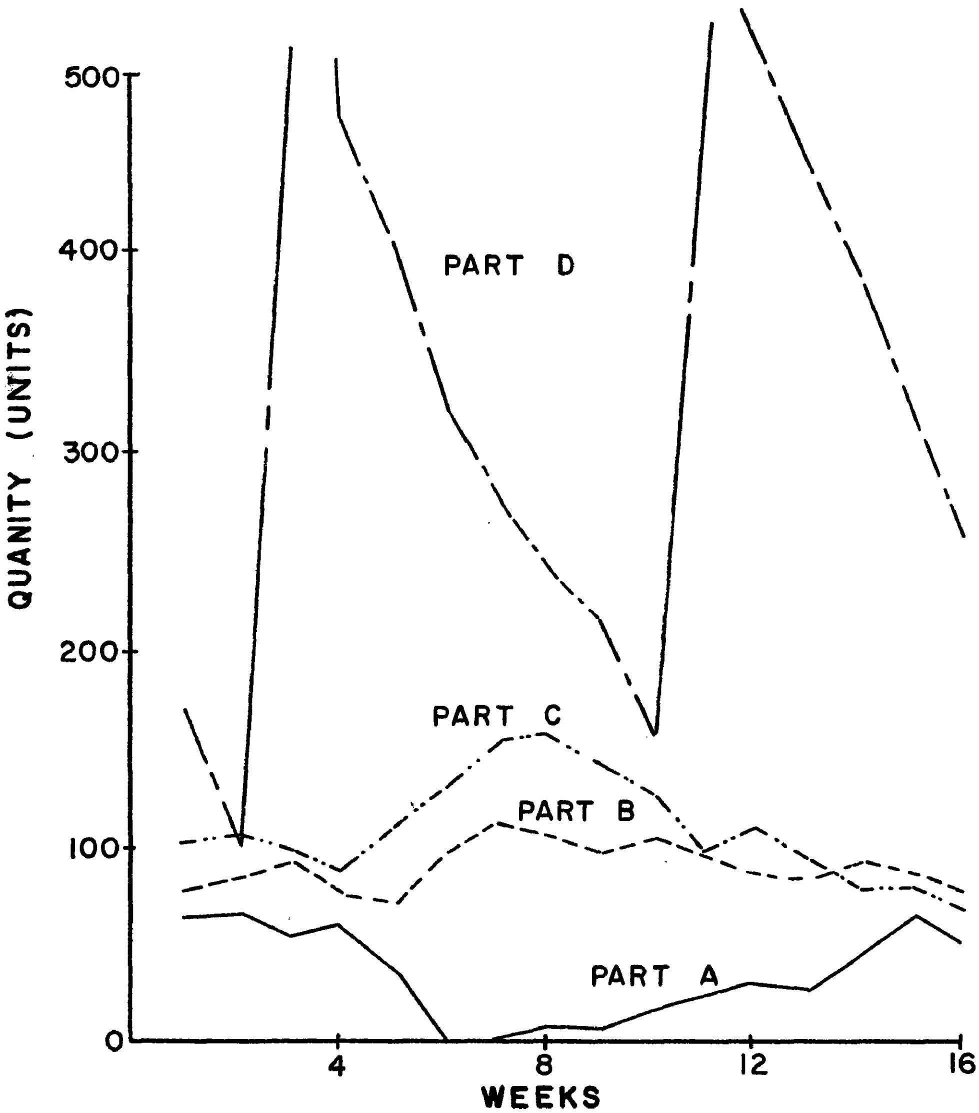


FIGURE 13

RAW MATERIAL INVENTORIES
(Run 1)

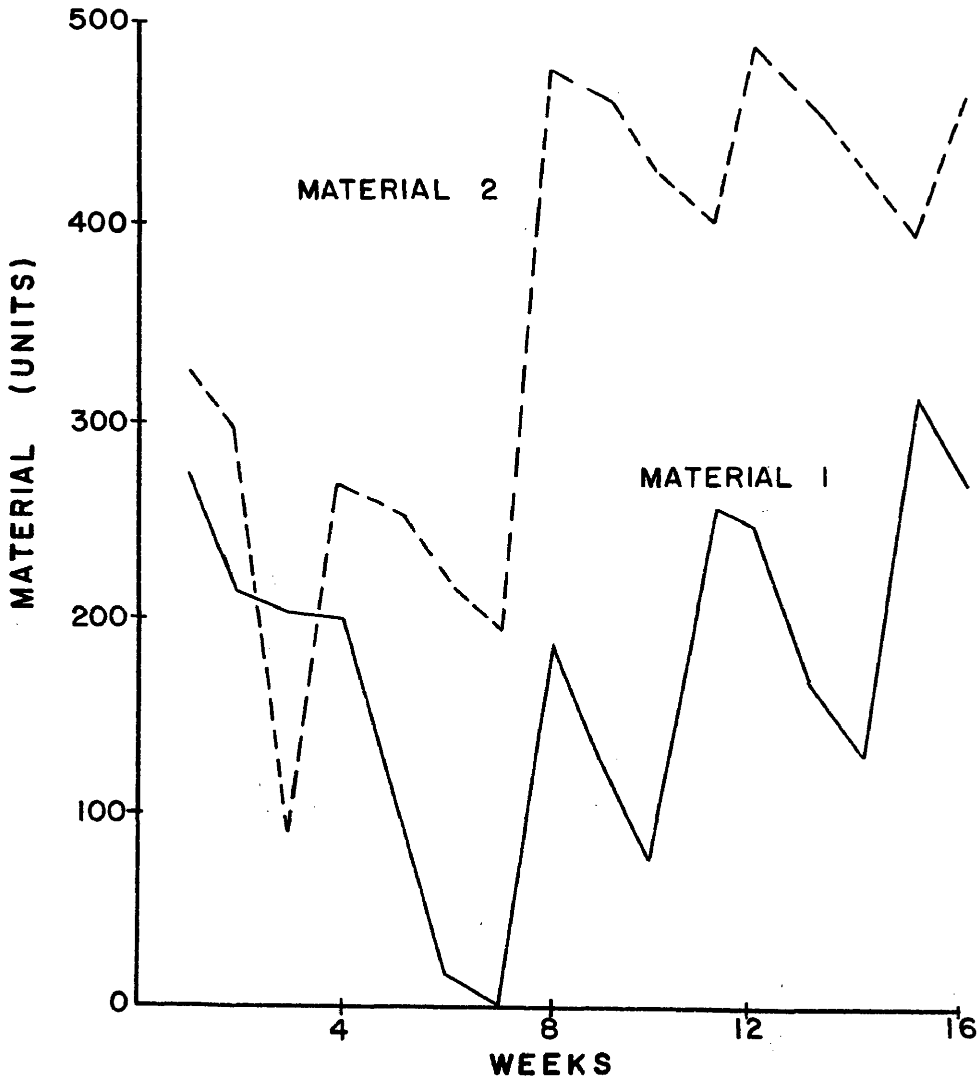
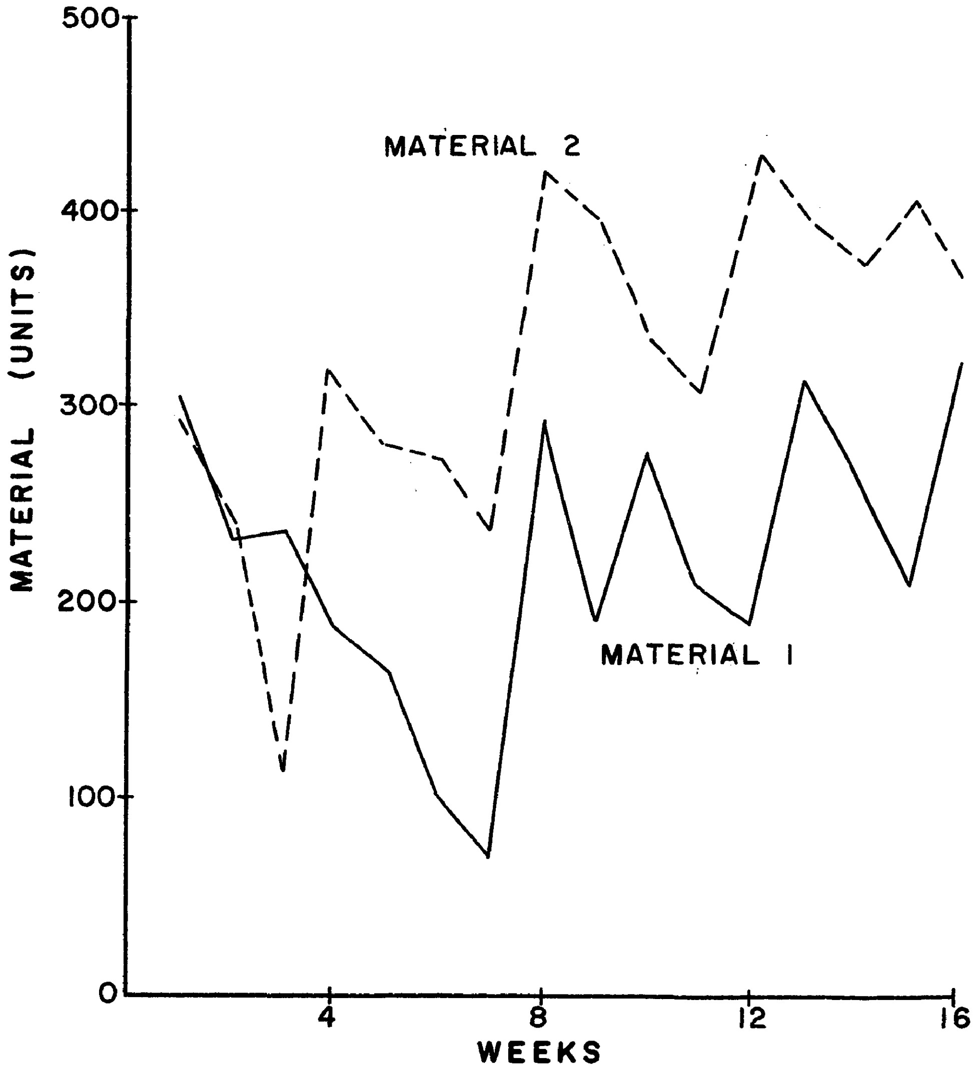


FIGURE 14

RAW MATERIAL INVENTORIES
(Run 2)



associated cost.

A second factor which hinders the shipments of Product 1 during Run 1 is the depletion of Raw Material 1 in the sixth and seventh weeks, as shown in Figure 13. The effect of exhausting the raw material inventory is to starve the facilities of work with resulting idle manpower, reduce the inventory of Part A to zero and starve the assembly area of work, and build up the backlog for Product 1 due to the inability to meet the demand. This is reflected in the very poor shipping performance for Product 1 in the eighth and ninth weeks (see Figure 5). The material outage causes substantial idleness of manpower with the result that manpower utilization for the run is 63%.

Raw Material 2 inventory builds up rapidly after the eighth week when a large shipment of material is delivered. The inventory level remains excessive thru the remainder of the run with two additional deliveries of material. The receipt of material is easily identified by the peaks in the inventory level.

During Run 2, see Figure 14, Raw Material 1 inventory dropped to its lowest level in the seventh week, but it did not reach zero as in Run 1. This provided a much better performance in terms of manpower utilization, 79% during the run, and in terms of Product 1 shipments (see Figure 6) which did not drop as severely as in Run 1. Raw

Material 2 inventory becomes excessive as in Run 1, but the level is significantly lower.

Economic Performance

The outputs from the simulation runs discussed thus far represent only selected measures of performance out of the many possible from the simulator program. These serve to illustrate the very comprehensive picture of the physical behavior of the firm which is available from the model. In addition to the weekly values, data on manpower utilization and customer order cycle time were discussed. None of these data provide a direct economic evaluation of the information system as it controls the performance of the physical system. It is necessary to refer to the accounting framework in order to provide this type of data.

Figures 15 and 16 show the profit and loss performance of the firm for the two simulation runs. During the sixteen weeks of simulation for Run 1, the firm incurred an operating loss of $29,200. Such a loss can be attributed in large to the inadequate control of inventories, both raw material and finished parts. Excessive inventories in raw material (see Raw Material 2 in Figure 13) and in finished parts (see Part C in Figure 11) greatly increased the operating costs during the run. Inadequate inventories in raw material (see Raw Material 1 in Figure 13) and finished parts (see Part A in Figure 11) curtailed

FIGURE 15

PROFIT AND LOSS
(Run 1)

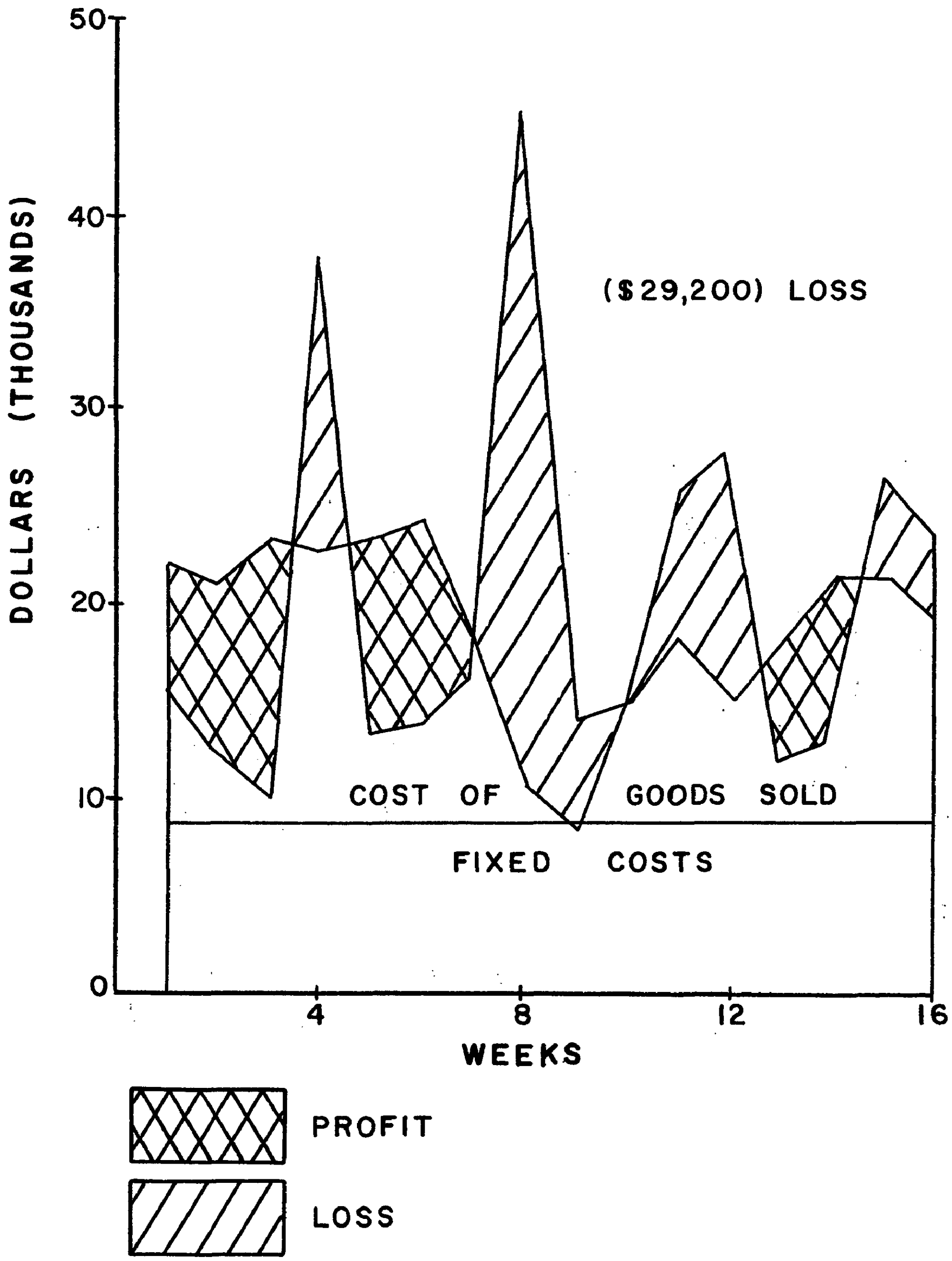
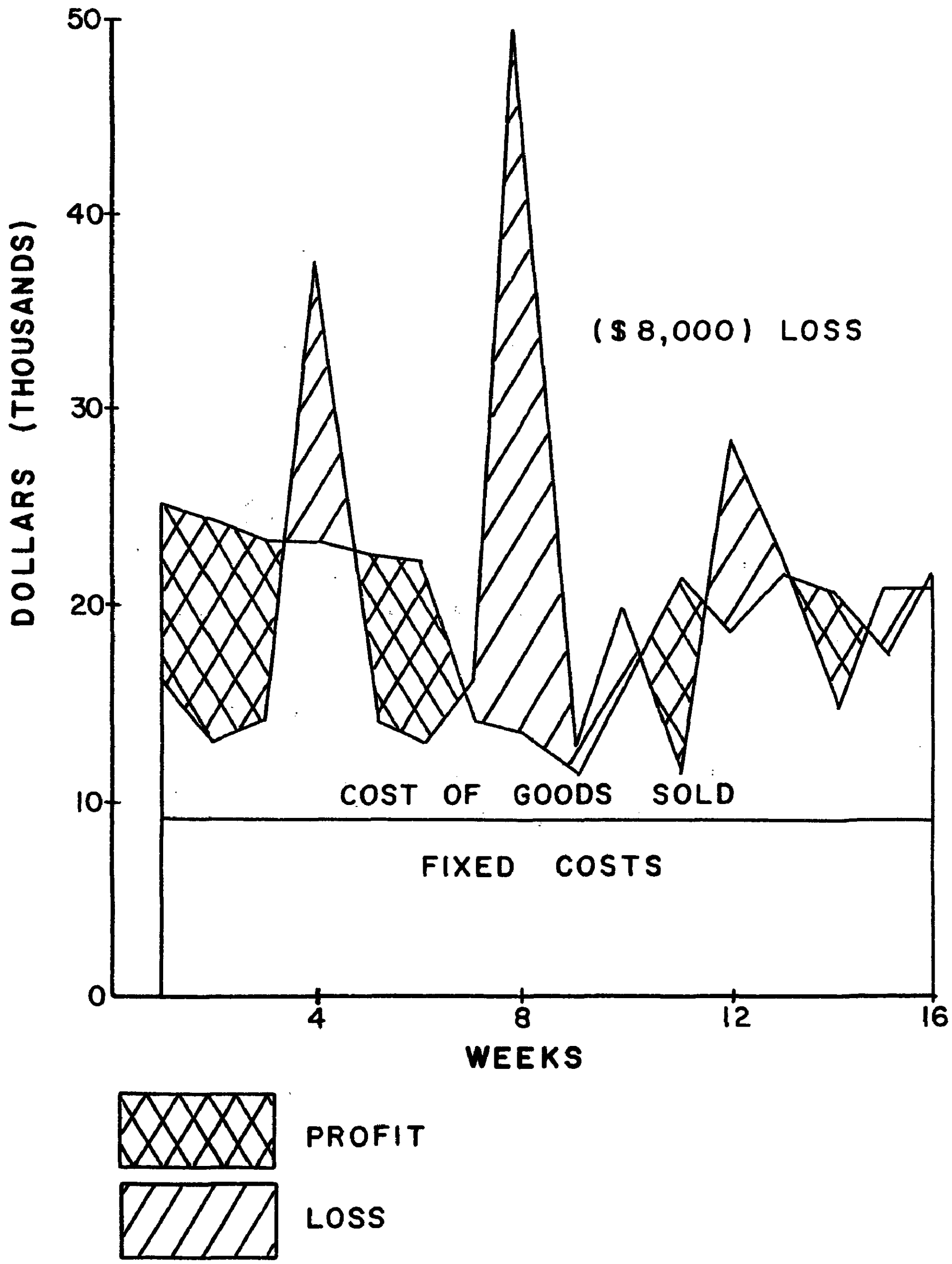


FIGURE 16

PROFIT AND LOSS
(Run 2)



product shipments and associated income as well as decreased the manpower utilization.

The financial performance realized in Run 2, as shown in Figure 16, reduced the operating loss to $8,000. Again, inadequate control of the inventories largely contributed to the loss.

## Summary of Results

The results of the simulation runs indicate very significant improvements in both the physical and economic performance of the model. Although the change in the information system parameters from Run 1 to Run 2 appeared major on the surface, simulation of the model made it possible to "actually" measure the interactions between the subsystems of the firm and predict its performance.

It should be pointed out that the only parameter change between Runs 1 and 2 was in the planning cycle with a two-week cycle being substituted for the slower four-week cycle and in the information time lags. The forecasting technique remained the same as did all the other decision rules. The demand pattern was essentially identical for both runs, and thus it presented the same hazards and opportunities. The management in Run 2 was no more "intelligent" (the decision rules were unchanged), but was simply made more effective through the improved response capability permitted by the shorter planning cycle and time lags.

As stated previously, the purpose of the simulation study is to analyze and evaluate a proposed change or improvement in the information system of the firm. For the accounting parameters employed, it is indicated that the economic value of the change from a four-week to a two-week planning cycle is of the order of $21,200 (the reduction in loss from Run 1 to Run 2). In addition, the somewhat intangible benefit of improved customer service (order cycle time) was realized. These results provide the basis for sound management evaluation of the proposed changes in the information system.

However, it must be cautioned that outputs from a simulation study cannot necessarily be accepted on "face value." Since there exists stochastic "noise" (variations) in simulation results, statistical significance must be tested by introducing different random numbers in repeat runs. The variations in performance between repeat runs establish the level of confidence that one can place in the predictive quality of the model. Statistical significance was not established in this study.

The results also indicate that further improvements in performance could be realized by changing some decision rules. The act of processing data faster has a limited effect on the performance of the firm, and further improvements must come from how the data are used.

## CHAPTER VI

## SUMMARY AND CONCLUSIONS

### Summary

Management's need for information to make effective decisions in today's dynamic market is well established. The importance of a management information system to meet this need only recently has come to be recognized.

The complex task of developing an integrated management information system poses a major problem for top management. A survey of companies with extensive computer experience has indicated that the basic requirement for achieving a successful computer-based information system is more heavily dependent on executive leadership than any other factor.[1] The conflicting interests of individual functional areas within a business make it imperative that top management provide the over-all direction (also authority) to the implementation of the information system that must necessarily cross the boundaries of all functional units.

Historically, a business enterprise has been

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[1]McKinsey & Company, Inc., Getting the Most Out of Your Computer, a brochure, p. 13.

regarded as a composite of various specialized "functions" where the whole was considered to be nothing more than the sum of these functional parts. Today, however, it is generally recognized that the corporate whole is something more than the sum of the parts. It is the corporate objectives that establish the over-all goals for all functions. The need for functional specialists is not dimished. No one person can possibly know all there is to know about any single business function much less all the functions of a business.

The basic problem confronting management today is to find some effective means of transmitting specialized functional knowledge and functional contributions into the general direction that will produce profitable over-all results. This is a problem of integration. Achieving a true integration is not an easy task, for it is necessary to develop some effective means of measuring and controlling the decision-making activities of a complex assortment of groups of variously motivated individuals that make up a modern business firm.

It is possible to integrate the functional knowledge and functional contribution of the various levels of management in accordance with their individual responsibility requirements by means of a compact body of management intelligence as the output of an integrated management information system. However, little progress has been made in the development of a compact body of management intelligence. Almost without exception, companies have focused their attention solely on cost reduction for individual applications. Data processing equipment has, generally, been used as a substitute for clerical paperwork operations. Few companies have undertaken a dynamic analysis of the entire management structure to determine the decision-making interrelationships of its various components and their information requirements.

As a result, the information flowing to the various levels of management in most companies today does not meet management's needs. The "information" made available is usually a conglomerate of usable and unusable data which complicates rather than simplifies the decision-making task. The tendency has been, and continues to be, to increase the flow of information rather than to refine it through the establishment of the necessary decision criteria. The basic question of "what real worth is information" is not answered.

Data processing has made a major impact on the organizational structure of many companies. The specialized characteristics of a cross functional service and a large dollar investment in equipment has led to the creation of new positions in the organization structure. Typically, the responsibility for the data processing function has risen in importance within the organizational structure of business firms until recently a new kind of corporate staff concerned exclusively with systems planning has emerged. This staff position is concerned with the design and operation of the management information systems of which the data processing function is an integral part. Systems Planning and Management Services are names often used to describe this new corporate position.

With the development and growth of the data processing function, it can be noted that the planning, analysis, and design of management systems have substantially broadened in scope and complexity. The successful development of a management information system in today's complex business environment requires a systems planner of the highest order. He must possess, with his knowledge of the analytical techniques available from operations research, a knowledge of business structure and management which was held by few systems specialists until only a few years ago. The development of data processing, with its subelements of data acquisition, data transmission, and computer programming; operations research, with its emphasis on advanced mathematical and analytical techniques; and other related advances have created new dimensions which many systems planners have found and will find beyond their capability.

In particular, the use of the simulation technique as a tool of systems planning presents a most powerful approach to the design, analysis, and evaluation of management information systems. The great potential of simulation lies in its use as a research tool for the study of the relationships between the variables (subsystems) of the total business system. Unlike engineering or the physical sciences, there are no convenient laboratories for testing new ideas and methods in systems planning. Experimentation directly in an actual business operation can only cause confusion and present unreliable results. The required time and cost of testing new methods is often prohibitive.

Computer simulation, on the other hand, provides an effective and rapid means for examining complex systems problems, since the computer is capable of examining a year of simulated activity in a matter of minutes. In addition, data on system performance can be obtained which are unavailable in actual situations.

It must be pointed out that the use of simulation is not an easy task. Detailed knowledge of all the aspects of the business must be gained by the systems planner in order to model the business system. The development of a model that truly reflects the real systems is a most difficult accomplishment. In addition, the actual simulation process is difficult to debug and achieve valid results.

The potential rewards from the use of simulation, however, are expected to far exceed the problems and the difficulties encountered in its use.

This study has defined a method for the analysis and evaluation of some major "intangible" aspects of an information processing system in terms of its contribution to the dynamic control of a firm as measured by the over-all performance. Application of the method has been demonstrated by the comparison of the results from two simulation runs using a specific model of a hypothetical firm. The feasibility of the method has been tested to the extent that selected parameter changes which are representative of "improved" information processing have been reflected in significant improvements in both physical and economic performance of the modeled firm.

## Conclusions

Progress has been made in the development of integrated management information system. Experience to date indicates that such progress has been and will be a slow evolution of management understanding and development of new techniques.[2]

The development of management information systems

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[2]James D. Gallagher, Management Information Systems and the Computer (New York: American Management Assn., 1961), p. 50.

should profoundly affect the content of managerial jobs, as decision-making responsibilities are redefined. It is expected that decision-making functions will be improved throughout the business organization, with the earliest and greatest progress in the lower and middle levels--the areas where computer programs can be the most effective. Ultimately, both the number and content of middle management jobs should be affected, particularly in the area of planning. If machine tools can be better loaded by a computer program than the manager, then production scheduling decisions of this nature will no longer be a normal part of the manager's job.

Another far-reaching impact of the management information system should involve the time span of executive decisions. It is indicated that there will be increased responsiveness to internal and external change. Top executives will be aware of changes more quickly and will be in a position to react far more rapidly. Also, they should be better able to look further into the future. Their ability to forecast more accurately and to explore alternatives with greater precision should permit longer term planning and decision-making.

The systems planning activity can be expected, in the future, to assume an increasingly important organizational role in most companies. The technical requirements placed on the systems planning function should create considerable demand for the talents of the systems planner. Such people will be hard to find, hard to train, and sometimes very hard to keep.

Modeling and simulation techniques should become increasingly important as tools of the systems planner. They can provide a method for bringing order and predictability out of a seeming chaos of multiple variables. Together, they offer the ability of gaining experience about real-life business systems without paying the penalities associated with real-life errors.

Simulation results such as described in this study, together with the current rapid rate of development in modeling and simulation techniques, serve to strengthen the author's belief that the analysis and evaluation of management information systems by simulation shows significant promise for eventual extension to useful evaluation of real systems.

The major effect of a management information system on management functions should be to facilitate the decision making process. This would be accomplished by giving the manager accurate and timely information with which to measure more precisely the economic and operational consequences of a decision. The manager's judgment, and the responsibility for the consequences, most likely will not be transferred to a data-processing system, at least not in the foreseeable future.

To conclude, Peter F. Drucker has summed up the expected impact of "information technology" on management as well as it might be stated:

> In dealing with their new tasks, the managers of the 1960's will, to a large extent, have to employ the same tools they are using today. But managers will also find, increasingly, that they are expected to know, understand, and handle new concepts and tools of management. Increasingly, they will find that they are expected to use systematic methods of analysis and decision making, supplemented by new tools of communication, computation and presentation.
>
> Executives can safely disregard all the faciful talk about the computer "replacing managers" and "making decisions." Manager's work, it can be said with confidence, is going to become more important and their numbers larger. But the "management sciences"--such as operations resarch or decision-making logic--and the new electronic tools and systems are going to make a difference, even to the manager in the small business.
>
> And the manager of 1970 will need all the help he can get from such concepts and tools. For his job is going to be so complex, so big, so demanding as to require all the tools of simplification and systematization that can possibly be obtained.[3]

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[3]Peter F. Drucker, "The Next Decade in Management," Dun's Review and Modern Industry, LXXIV, No. 6 (December, 1959), pp. 60-61.

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# APPENDIXES

# APPENDIX A

# THE MANUFACTURING MODEL AS DESCRIBED IN IBM GENERAL PURPOSE SYSTEMS SIMULATOR LANGUAGE

```
      JOB          ANALYSIS OF A MANUFACTURING INFORMATION SYSTEM  (RUN 1)
*
*     *****  ENVIRONMENT SYSTEM  *****
*
*
*           INCOMING SALES ORDER LOOP
*
*                  PRODUCT 1
 1    GENERATE                                    8                            GEN. PROD. 1
 2    HOLD         99                             3         *7                 ARRIVAL RATE
 3    ASSIGN       2      V1                      4                            GEN. NO. PARTS
 4    ASSIGN       8      K1                      5                            PROD. I.D.
 5    ENTER        1      P2                      6                            BACKLOG 1
 6    SAVEX        161+   P2                      7                            INFOR. DATA
 7    QUEUE        1                              350                          QUEUE UP
 8    GATE         NU99                           9
 9    ASSIGN       7      V35                     2
*                  PRODUCT 2
 11   GENERATE                                    18                           GEN. PROD. 2
 12   HOLD         199                            13        *7                 ARRIVAL RATE
 13   ASSIGN       2      V1                      14                           GEN. NO. PARTS
 14   ASSIGN       8      K2                      15                           PROD. I.D.
 15   ENTER        2      P2                      16                           BACKLOG 2
 16   SAVEX        162+   P2                      17                           INFOR. DATA
 17   QUEUE        2                              385                          QUEUE UP
 18   GATE         NU199                          19
 19   ASSIGN       7      V36                     12
*
*           MATERIAL INPUT LOOP
*
*                  RAW MATERIAL 1
 21   GENERATE                                    22                           GEN. MATL ORDR
 22   GATE         LS1                            23                           DELAY FOR REL.
 23   LOGIC        R1                             24                           SHUT GATE
 24   ASSIGN       2      X24                     25                           ORDER QUANT.
 25   SAVEX        21+    P2                      26                           ADD ON-ORDER
 26   ADVANCE                                     27        80     32          DEL. DELAY
 27   SAVEX        21-    P2                      28                           SUB ON-ORDER
 28   ASSIGN       3      V2                      29                           CALC. REJECTS
 29   ENTER        7      P3                      451                          ENTER INVENT.
*                  RAW MATERIAL 2
 31   GENERATE                                    32                           GEN. MATL ORDR
 32   GATE         LS2                            33                           DELAY FOR REL.
```

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 33   LOGIC       R2                  34                          SHUT GATE
 34   ASSIGN      2       X25         35                          ORDER QUANT.
 35   SAVEX       22+     P2          36                          ADD ON-ORDER
 36   ADVANCE                         37          80      32      DEL. DELAY
 37   SAVEX       22-     P2          38                          SUB ON-ORDER
 38   ASSIGN      3       V2          39                          CALC. REJECTS
 39   ENTER       8       P3          453                         ENTER INVENT.
*                 PURCHASED PART D LOOP
 41   GENERATE                        42                          GEN. PART ORDR
 42   GATE        LS3                 43                          DELAY FOR REL.
 43   LOGIC       R3                  44                          SHUT GATE
 44   ASSIGN      2       X26         45                          ORDER QUANT.
 45   SAVEX       23+     P2          46                          ADD ON-ORDER
 46   ADVANCE                         47          120     40      DEL. DELAY
 47   ASSIGN      3       V3          48                          CALC. REJECTS
 48   SPLIT                           49    455                   TO INFO SYSTEM
 49   ADVANCE                         50          16              MOVE TO INVEN.
 50   SAVEX       23-     P2          51                          SUB ON-ORDER
 51   ENTER       6       P3          800                         ENTER INVEN.

*     *****  PHYSICAL SYSTEM  *****
*
*
*           RAW MATERIAL RELEASE
*
*                 MATERIAL 1 FOR PART A
 101  GENERATE                        102                         GEN. ORDER, A
 102  GATE        LS4                 103                         RELEASE DELAY
 103  LOGIC       R4                  104                         SHUT GATE
 104  ASSIGN      7       K1          105                         PART A I.D.
 105  ASSIGN      6       K5          106
 106  ASSIGN      8       C1          107                         SAVE CLOCK
 107  GATE        SNE7                108                         ANY STOCK
 108  LEAVE       7       K1          109                         YES- DRAW OUT
 109  SAVEX       163+    K1          110                         INFO DATA
 110  ADVANCE                         151         8               MOVE DELAY
*           RAW MATERIAL 1 FOR PART B
 111  GENERATE                        112                         GEN. ORDER, B
 112  GATE        LS5                 113                         RELEASE DELAY
 113  LOGIC       R5                  114                         SHUT GATE
 114  ASSIGN      7       K2          115                         PART B I.D.
 115  ASSIGN      6       K4          106
            RAW MATERIAL 2 FOR PART C
```

```
 121  GENERATE                                    122                        GEN. ORDER, C
 122  GATE        LS6                             123                        RELEASE DEALY
 123  LOGIC       R6                              124                        SHUT GATE
 124  ASSIGN      7      K3                       125                        PART C I.D.
 125  ASSIGN      8      C1                       126                        SAVE CLOCK
 126  GATE        SNE8                            127                        ANY STOCK
 127  LEAVE       8      K1                       128                        YES- DRAW
 128  SAVEX       164+   K1                       129                        INFO. DATA
 129  ADVANCE                                     250          8             MOVE DELAY
*
*           PROCESS
*
*                 FACILITY 1
 151  QUEUE       3                               152                        FAC. 1 QUEUE
 152  GATE        LR110                           153                        DELAY GATE
 153  ASSIGN      1      K9                       154                        LOC.- MANPOWER
 154  ASSIGN      2      K108                     155                              UNITS
 155  ASSIGN      2+     K1               BOTH    156    170
 156  GATE        LR*1                    BOTH    157    170                 ANY MEN
 157  GATE        NU*1                    BOTH    158    177                 UNIT IN USE
 158  GATE        LR108                   BOTH    159    176                 NEW SETUP
 159  COMPARE     P7     E      X*2               160                        SAME PART
 160  HOLD        *1                              161          *6     1      USE UNIT
 161  LOGIC       R108                            162                        RESET GATES
 162  LOGIC       R110                            163
 163  ASSIGN      3      FN5              BOTH    164    182                 ANY REJECTS
 164  COMPARE     P3     E      K0        BOTH    165    201                 WHICH PART
 165  COMPARE     P7     E      K2                166
 166  ASSIGN      6      K2                       301                        PART B
 170  INDEX       1      1                BOTH    171    155                 STEP LOCATOR
 171  COMPARE     P1     GE     K21       BOTH    172    175                 LAST UNIT
 172  GATE        LS109                           173                        SETUP GATE
 173  LOGIC       S108                            174                        RESET GATES
 174  LOGIC       R109                            153
 175  LOGIC       S110                            152                        SETUP REQUIRED
 176  LOGIC       S109                            170
 177  HOLD        *1                              178          1      FN9    MAKE SETUP
 178  SAVEX       *2     P7                       160                         SET PART TYPE
 182  ADVANCE                             BOTH    183    186                 DETERMINE
 183  COMPARE     P7     E      K1                184                           REJECT
 184  SAVEX       77-    K1                       800                           TYPE
 186  ADVANCE                             BOTH    187    190                    AND
 187  COMPARE     P7     E      K2                188                           REMOVE.
```

```
 188  SAVEX       78-   K1                 800
 190  SAVEX       79-   K1                 800
*             FACILITY 2
 201  QUEUE       4                        202                       FAC. 2 QUEUE
 202  GATE        LR30                     203                       DELAY GATE
 203  ASSIGN      1     K21                204                       LOC.- MANPOWER
 204  ASSIGN      2     K120               205                             UNITS
 205  ASSIGN      2+    K1           BOTH  206    220
 206  GATE        LR*1               BOTH  207    220                MAN ASSIGNED
 207  GATE        NU*1                     208                       UNIT AVAILABLE
 208  HOLD        *1                       209          10     1     USE UNIT
 209  LOGIC       R30                      210                       RESET GATE
 210  ASSIGN      3     FN6          BOTH  211    182                ANY REJE3TS
 211  COMPARE     P3    E     K0           212                       ANY REJECTS
 212  ADVANCE                              214                       MOVE TO INVEN.
 214  ENTER       3     K1                 215                       ENTER INVEN.
 215  SAVEX       13+   C1                 216                       ACCUM. LEAD
 216  SAVEX       13-   P8                 217                         TIME
 217  SAVEX       14+   K1                 218                         DATA
 218  SAVEX       77-   K1                 219
 219  SAVEX       165+  K1                 800                       INFO. DATA
 220  INDEX       1     1            BOTH  221    205                STEP LOCATOR
 221  COMPARE     P1    GE    K26          222                       LAST UNIT
 222  LOGIC       S30                      202                       RESET GATE
*             FACILITY 3
 250  QUEUE       5                        251                       FAC. 3 QUEUE
 251  GATE        LR40                     252                       DELAY GATE
 252  ASSIGN      1     K31                253                       LOC.-MANPOWER
 253  ASSIGN      2     K130               254                            UNITS
 254  ASSIGN      2+    K1           BOTH  255    270
 255  GATE        LR*1               BOTH  256    270                ANY MEN
 256  GATE        NU*1                     257                       UNIT AVAILABLE
 257  HOLD        *1                       258          1            USE UNIT
 258  LOGIC       R40                      259                       SHUT GATE
 259  ASSIGN      3     FN7          BOTH  260    182                CALC. REJECTS
 260  COMPARE     P3    E     K0           261                       ANY REJECTS
 261  ASSIGN      6     K3                 301
 270  INDEX       1     1            BOTH  271    254                STEP LOCATOR
 271  COMPARE     P1    GE    K36          272                       LAST UNIT
 272  LOGIC       S40                      251                       RESET GATE
*          FACILITY 4
 301  QUEUE       6                        302                       FAC. 4 QUEUE
 302  GATE        LR154                    303                       DELAY GATE
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 303   ASSIGN       1      K39                    304                          LOC.- MANPOWER
 304   ASSIGN       2      K138                   305                                UNITS
 305   ASSIGN       2+     K1             BOTH    306    330
 306   GATE         LR*1                  BOTH    307    330                   ANY MEN
 307   GATE         NU*1                  BOTH    308    337                   UNIT AVAILABLE
 308   GATE         LR152                 BOTH    309    336                   SETUP REQUIRED
 309   COMPARE      P7     E      X*2             310                          SAME PART
 310   HOLD         *1                            311           *6     1
 311   LOGIC        R154                          312                          RESET GATE
 312   LOGIC        R152                          313
 313   ASSIGN       3      FN8            BOTH    314    182                   GEN. REJECTS
 314   COMPARE      P3     E      K0              315                          ANY REJECTS
 315   ADVANCE                            BOTH    316    325                   MOVE TO INVEN.
 316   COMPARE      P7     E      K2              318                          WHICH PART
 318   ENTER        4      K1                     319                          ENTER B INVEN.
 319   SAVEX        15+    C1                     320                          ACCUM. LEAD
 320   SAVEX        15-    P8                     321                             TIME
 321   SAVEX        16+    K1                     322                             DATA.
 322   SAVEX        78-    K1                     323
 323   SAVEX        166+   K1                     800                          INFO. DATA
 324   SAVEX        167+   K1                     800                          INFO. DATA
 325   ENTER        5      K1                     326                          ENTER C INVEN.
 326   SAVEX        17+    C1                     327                          ACCUM. LEAD
 327   SAVEX        17-    P8                     328                             TIME
 328   SAVEX        18+    K1                     329                             DATA.
 329   SAVEX        79-    K1                     324
 330   INDEX        1      1              BOTH    331    305                   STEP LOCATOR
 331   COMPARE      P1     GE     K51     BOTH    332    335                   LAST UNIT
 332   GATE         LS151                         333                          MACH. AVAILABL
 333   LOGIC        S152                          334                          YES- NEW SETUP
 334   LOGIC        R151                          303
 335   LOGIC        S154                          302                          NO- WAIT
 336   LOGIC        S151                          330
 337   HOLD         *1                            338           1              SETUP DELAY
 338   SAVEX        *2     P7                     310
*
*            INVENTORY CONTROL
*
*                   PRODUCT 1
 350   QUEUE        11                            351
 351   COMPARE      P2     LE     S3              376                          ANY A PARTS
 352   SAVEX        168+   P2                     353                          INFO. DATA
 353   LEAVE        3      P2             BOTH    354    360                   YES- PULL PART
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 354   COMPARE     V31    L      X33             355                         REORDER
 355   ASSIGN      1      X37                    356                         YES- ISSUE
 356   SAVEX       77+    P1                     357
 357   LOGIC       S4                            358                           ORDER TO
 358   GATE        LR4                           359                           MATL 1 REL.
 359   LOOP        1                             357     360
 360   QUEUE       12                            361
 361   COMPARE     P2     LE     S4              362                         ANY B PARTS
 362   SAVEX       169+   P2                     363                         INFO. DATA
 363   LEAVE       4      P2           BOTH      364     372
 364   COMPARE     V32    L      X34             365                         REORDER
 365   ASSIGN      1      X38                    366                         YES- ISSUE
 366   SAVEX       78+    P1                     367
 367   LOGIC       S5                            368                           ORDER TO
 368   GATE        LR5                           369                           MATL 1 REL.
 369   LOOP        1                             367     372
 372   QUEUE       14                            373
 373   COMPARE     P2     LE     S6              374                         ANY D PARTS
 374   SAVEX       171+   P2                     375                         INFO. DATA
 375   LEAVE       6      P2                     398
 377   ASSIGN      6      K6                     386
 376   ASSIGN      6      K4                     352
*                 PRODUCT 2
 384   QUEUE       13                            387
 385   ASSIGN      3      P2                     377                         CALC. REQUIRE
 386   ASSIGN      3+     P2                     384                            PART C
 387   COMPARE     P3     LE     S5              388                         ANY C PARTS
 388   SAVEX       170+   P3                     389                         INFO. DATA
 389   LEAVE       5      P3           BOTH      390     360                 YES- PULL PART
 390   COMPARE     V33    L      X35             391                         REORDER
 391   ASSIGN      1      X39                    392                         YES- ISSURE
 392   SAVEX       79+    P1                     393                            ORDER TO
 393   LOGIC       S6                            394                            MATL 2 REL.
 394   GATE        LR6                           395
 395   LOOP        1                             393     360
*
*           ASSEMBLY LOOP
*
 398   ASSIGN      5      V38                    399                         CALC. T9M5
 399   ADVANCE                                   400           24     8      DELAY - MOVE
 400   QUEUE       7                             401                         QUEUE UP
 401   GATE        LR53                          402                         DELAY GATE
 402   ASSIGN      1      K150                   403                         SET LOCATOR
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 403   INDEX        1     1           BOTH  404    430                       
 404   GATE         NU*1                    405                    MAN AVAILABLE
 405   HOLD         *1                      406          *5    2   USE HIM
 406   LOGIC        R53               BOTH  407    421             RESET GATE
 407   COMPARE      P8    E     K1          408                    WHICH PART
 408   LEAVE        1     P2                409                    PROD. 1
 409   SPLIT                                410    496             TO INFO SYSTEM
 410   TABULATE     1                       411
 411   TABULATE     3                       800
 421   LEAVE        2     P2                422                    PROD. 2
 422   SPLIT                                423    499             TO INFO SYSTEM
 423   TABULATE     2                       424
 424   TABULATE     4                       800
 430   ADVANCE                        BOTH  431    403             MAN BUSY- NEXT
 431   COMPARE      P1    GE    K159        432                    LAST MAN
 432   LOGIC        S53                     401                       YES- WAIT
*
*      *****  INFORMATION SYSTEM  *****
*
*           INFORMATION DELAY LOOPS
*
*                   INCOMING ORDERS DELAY LOOP
 439   ORIGINATE                            440          8         PROD. 1, 2
 440   ASSIGN       1     X161              441                    BATCH ORDERS
 441   ASSIGN       2     X162              442                       DAILY
 442   SPLIT                                443    457
 443   ADVANCE                              444          40        DELAY (5 DAYS)
 444   SAVEX        1+    P1                445                    ACCUM. ORDERS
 445   SAVEX        2+    P2          BOTH  446    448                FOR MONTH
 446   COMPARE      P1    E     K0    BOTH  447    449
 447   COMPARE      P2    E     K0          800
 448   ENTER        13    P1          BOTH  447    449             ADD ORDERS TO
 449   ENTER        14    P2                800                       BACKLOG
*                   MATERIAL RECEIPTS DELAY
 451   ADVANCE                              452          24        5 DAY DELAY
 452   ENTER        15    P3                800                    MATL 1 INVEN.
 453   ADVANCE                              454          24        3 DAY DELAY
 454   ENTER        16    P3                800                    MATL 2 INVEN.
 455   ADVANCE                              456          32        4 DAY DELAY
 456   ENTER        21    P3                800                    PART D INVEN.
*                   MATERIAL MOVE INTO PROCESS DELAY
 457   ASSIGN       1     X163              458                    BATCH MATL
 458   ASSIGN       2     X164              459                        MOVE DAILY
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 459  SPLIT                                  460   466
 460  ADVANCE                          BOTH  461   506   16            2 DAY DELAY
 461  COMPARE    P1    E     K0              462
 462  ADVANCE                          BOTH  463   507
 463  COMPARE    P2    E     K0              800
 464  LEAVE      15    P1                    462                       DECREASE
 465  LEAVE      16    P2                    800                        MATL INVEN.
*                FINISHED PARTS MOVE INTO INVENTORY DELAY
 466  ASSIGN     1     X165                  467                       BATCH PARTS
 467  ASSIGN     2     X166                  468                          DAILY
 468  ASSIGN     3     X167                  469
 469  SPLIT                                  470   481
 470  ADVANCE                                471         16            2 DAY DELAY
 471  SAVEX      30+   P1                    472                       ACCUM.
 472  SAVEX      31+   P2                    473                          COMPLETED
 473  SAVEX      32+   P3              BOTH  474   477                    PARTS
 474  COMPARE    P1    E     K0        BOTH  475   478
 475  COMPARE    P2    E     K0        BOTH  476   479
 476  COMPARE    P3    E     K0              800
 477  ENTER      18    P1              BOTH  475   478                 ENTER PARTS
 478  ENTER      19    P2              BOTH  476   479                    INVENTORY
 479  ENTER      20    P3                    800
*                FINISHED PARTS MOVE TO ASSEMBLY DELAY
 481  ASSIGN     1     X168                  482                       BATCH PARTS
 482  ASSIGN     2     X169                  483                          DAILY
 483  ASSIGN     3     X170                  484
 484  ASSIGN     4     X171                  485
 485  SPLIT                                  486   491
 486  ADVANCE                          BOTH  502   487   24            3 DAY DELAY
 487  LEAVE      18    P1              BOTH  503   488                 WITHDRAW
 488  LEAVE      19    P2              BOTH  504   489                    PARTS
 489  LEAVE      20    P3              BOTH  505   490                    FROM
 490  LEAVE      21    P4                    800                          INVENTORY
 502  COMPARE    P1    E     K0        BOTH  503   488
 503  COMPARE    P2    E     K0        BOTH  504   489
 504  COMPARE    P3    E     K0        BOTH  505   490
 505  COMPARE    P4    E     K0              800
 506  COMPARE    P1    LE    S15             464
 507  COMPARE    P2    LE    S16             465
*
 491  ASSIGN     1     K161                  492
 492  ASSIGN     2     K11                   493
 493  SAVEX      *1    K0                    494
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 494   INDEX        1      1                  495
 495   LOOP         2                         493    800
*                   PRODUCT SHIPMENT DELAY
 496   ADVANCE                                497           24          3 DAY DELAY
 497   COMPARE      S13    GE     P2          498
 498   LEAVE        13     P2                 800                       PROD. 1 SHIP.
 499   ADVANCE                                500           24          3 DAY DELAY
 500   COMPARE      S14    GE     P2          501
 501   LEAVE        14     P2                 800                       PROD. 2 SHIP.
*
*            FORECASTING LOOP
*
 511   ORIGINATE                              512           160         CYCLE- 4 WEEKS
 512   ASSIGN       8      S13                513                       SAVE ORDER
 513   SAVEX        3      P8                 514                         BACKLOG
 514   ASSIGN       7      S14                515                         LEVELS
 515   SAVEX        4      P7                 520
 520   ASSIGN       6      K1                 521                       SET LOCATOR
 521   ASSIGN       1      K5                 522
 522   ASSIGN       3      X*6                523                       ACTUAL ORDERS
 523   SAVEX        *6     K0          BOTH   524    528                ZERO COUNT
 524   COMPARE      P3     G      X*1         525                       COMP TO FORECT
 525   ASSIGN       4      V4                 526                       INCREASE
 526   ASSIGN       5      V5                 531
 528   ASSIGN       4      V6                 529                       DECREASE
 529   ASSIGN       5      V7                 531
*                   PARTS  EXPLOSION
 531   SAVEX        *1     P5                 532                       NEW FORECAST
 532   ASSIGN       1      K6          BOTH   533    544
 533   COMPARE      P6     E      K1          534                       WHICH PART
 534   SAVEX        7      P5                 535                       FORECST- A
 535   SAVEX        9      P5                 536                                B
 536   SAVEX        19     P5                 537                                D
 537   SAVEX        8      P8                 538                       BACKLOG- A
 538   SAVEX        10     P8                 539                                B
 539   SAVEX        20     P8                 540                                D
 540   ASSIGN       6      K2                 522
 544   SAVEX        9+     P5                 545                       FORECST- B
 545   SAVEX        11     P5                 546                                C
 546   SAVEX        11+    P5                 547                                C
 547   SAVEX        19+    P5                 548                                D
 548   SAVEX        10+    P7                 549                       BACKLOG- B
 549   SAVEX        12     P7                 550                                C
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 550  SAVEX       12+   P7                    551                          C
 551  SAVEX       20+   P7           BOTH     552   562
 552  COMPARE     C1    G     K2              561
*                 IMPLEMENTATION DELAY
 561  ADVANCE                                 562         40         5 DAY DELAY
 562  ASSIGN      8     X8                    563
 563  ASSIGN      7     X7                    564
 564  ASSIGN      6     V8                    565
 565  SAVEX       41    K42                   566
 566  SAVEX       42    V9                    567
 567  SAVEX       43    V10                   568
 568  SAVEX       44    V11                   569
 569  SAVEX       45    V12                   570
 570  SAVEX       46    P6                    571
 571  SAVEX       47    P6                    575
 575  ASSIGN      8     X10                   576
 576  ASSIGN      7     X9                    577
 577  ASSIGN      6     V8                    578
 578  SAVEX       48    K49                   579
 579  SAVEX       49    V9                    580
 580  SAVEX       50    V10                   581
 581  SAVEX       51    V11                   582
 582  SAVEX       52    V12                   583
 583  SAVEX       53    P6                    584
 584  SAVEX       54    P6                    585
 585  ASSIGN      8     X12                   586
 586  ASSIGN      7     X11                   587
 587  ASSIGN      6     V8                    588
 588  SAVEX       55    K56                   589
 589  SAVEX       56    V9                    590
 590  SAVEX       57    V10                   591
 591  SAVEX       58    V11                   592
 592  SAVEX       59    V12                   593
 593  SAVEX       60    P6                    594
 594  SAVEX       61    P6                    610
*
*           MATERIAL PLANNING
*
 610  ASSIGN      2     V13                   611                   MATL 1
 611  ASSIGN      5     X21                   612                    CALC.
 612  ASSIGN      4     V14          BOTH     613   620              REQ.
 613  COMPARE     P4    G     P5              614                    MATL
 614  ASSIGN      3     V18          BOTH     627   620
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 627  COMPARE     P3    GE    S15         628          TEST INVEN.
 628  ASSIGN      4     V15               629          CALC. ORDER
 629  ASSIGN      5     V16               630          SCRAP ALLOW.
 630  SAVEX       24    P5                631
 631  LOGIC       S1                      632          RELEASE
 632  GATE        LR1                     620            ORDER
 620  ASSIGN      2     V17               621          MATL 2
 621  ASSIGN      5     X22               622             CALC.
 622  ASSIGN      4     V14         BOTH  623   645       REQ.
 623  COMPARE     P4    G     P5          624             MATL
 624  ASSIGN      3     V18         BOTH  637   645
 637  COMPARE     P3    GE    S16         638          TEST INVEN.
 638  ASSIGN      4     V19               639          CALC. ORDER
 639  ASSIGN      5     V16               640          SCRAP ALLOW.
 640  SAVEX       25    P5                641
 641  LOGIC       S2                      642          RELEASE
 642  GATE        LR2                     645            ORDER
 645  ASSIGN      2     V20         BOTH  646   661    PART D
 646  COMPARE     P2    G     S21         647
 647  ASSIGN      3     V39         BOTH  648   661
 648  COMPARE     P3    L     K500        649
 649  SAVEX       26    K500              650
 650  LOGIC       S3                      651
 651  GATE        LR3                     661
*                 INVENTORY PLANNING
 661  ASSIGN      2     V21               662          PART A
 662  SAVEX       33    P2                663
 663  ASSIGN      3     V44               664
 664  SAVEX       37    P3                665
 665  SAVEX       13    K0                666
 666  SAVEX       14    K0                671
 671  ASSIGN      2     V22               672          PART B
 672  ASSIGN      3     V45               673
 673  SAVEX       34    P2                674
 674  SAVEX       38    P3                675
 675  SAVEX       15    K0                676
 676  SAVEX       16    K0                681
 681  ASSIGN      2     V23               682          PART C
 682  ASSIGN      3     V46               683
 683  SAVEX       35    P2                684
 684  SAVEX       39    P3                685
 685  SAVEX       17    K0                686
 686  SAVEX       18    K0                800
```

```
*
*          SCHEDULING LOOP
*
*                    PROCESS
 701  ORIGINATE                                          702          40
 702  ASSIGN        1       X41                          703
 703  ASSIGN        2       X48                          704
 704  ASSIGN        3       X55                          705
 705  ASSIGN        7       V24                          706
 706  ASSIGN        8       P7                           707
 707  SAVEX         62      P7                           708
 708  ASSIGN        7       V25                          709
 709  ASSIGN        8+      P7                           710
 710  SAVEX         63      P7                           711
 711  ASSIGN        7       X*3                          712
 712  ASSIGN        8+      P7                           713
 713  SAVEX         64      P7                           714
 714  ASSIGN        7       V26                          715
 715  ASSIGN        8+      P7                           716
 716  SAVEX         65      P7                           717
 717  SAVEX         66      P8                           721
 721  ASSIGN        2       X62                          722
 722  ASSIGN        3       V27                          723
 723  ASSIGN        4       V28                          724
 724  SAVEX         67      P4                           725
 725  ASSIGN        2       X63                          726
 726  ASSIGN        3       V27                          727
 727  ASSIGN        4       V28                          728
 728  SAVEX         68      P4                           729
 729  ASSIGN        2       X64                          730
 730  ASSIGN        3       V27                          731
 731  ASSIGN        4       V28                          732
 732  SAVEX         69      P4                           733
 733  ASSIGN        2       X65                          734
 734  ASSIGN        3       V27                          735
 735  ASSIGN        4       V28                          736
 736  SAVEX         70      P4                           740
 740  ASSIGN        1       K9                           741
 741  ASSIGN        2       V40                          742
 742  LOGIC         R*1                                  743
 743  INDEX         1       1                BOTH        744    750
 744  COMPARE       P1      L       K21                  745
 745  LOOP          2                                    742    746
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```
 746   LOGIC          S*1                                   747
 747   INDEX          1       1              BOTH    748    746
 748   COMPARE        P1      GE      K21            750
 750   ASSIGN         1       K21                    751
 751   ASSIGN         2       V41                    752
 752   LOGIC          R*1                            753
 753   INDEX          1       1              BOTH    754    760
 754   COMPARE        P1      L       K26            755
 755   LOOP           2                              752    756
 756   LOGIC          S*1                            757
 757   INDEX          1       1              BOTH    758    756
 758   COMPARE        P1      GE      K26            760
 760   ASSIGN         1       K31                    761
 761   ASSIGN         2       V42                    762
 762   LOGIC          R*1                            763
 763   INDEX          1       1              BOTH    764    770
 764   COMPARE        P1      L       K36            765
 765   LOOP           2                              762    766
 766   LOGIC          S*1                            767
 767   INDEX          1       1              BOTH    768    766
 768   COMPARE        P1      GE      K36            770
 770   ASSIGN         1       K39                    771
 771   ASSIGN         2       V43                    772
 772   LOGIC          R*1                            773
 773   INDEX          1       1              BOTH    774    780
 774   COMPARE        P1      L       K51            775
 775   LOOP           2                              772    776
 776   LOGIC          S*1                            777
 777   INDEX          1       1              BOTH    778    776
 778   COMPARE        P1      GE      K51            780
*                     ASSEMBLY
 780   ASSIGN         2       V29                    781
 781   ASSIGN         3       V30                    782
 782   SAVEX          71      P2                     783
 783   SAVEX          72      P3                     784
 784   SAVEX          41+     K1                     785
 785   SAVEX          48+     K1                     779
 779   SAVEX          55+     K1                     800
*
*            INITIALIZE LOOP
*
 786   GENERATE               1                      787
 787   ENTER          3       K40                    788
```

```
 788   ENTER         4      K200              789
 789   ENTER         5      K200              790
 790   ENTER         6      K450              791
 791   SAVEX         5      K60               792
 792   SAVEX         6      K250              793
 793   ENTER         7      K500              794
 794   ENTER         8      K500              795
 795   ENTER         15     K500              796
 796   ENTER         16     K500              797
 797   ENTER         18     K40               798
 798   ENTER         19     K200              799
 799   ENTER         20     K200              690
 690   ENTER         21     K450              691
 691   SAVEX         75     K1                692
 692   SAVEX         1      K60               693
 693   SAVEX         2      K250              694
 694   SPLIT                                  512    696
 696   ADVANCE                                702          1
 75    ORIGINATE                              76           40
 76    SAVEX         75+    K1                800
 800   TERMINATE
*
*          VARIABLES
*
 1     VARIABLE      FN10
 2     VARIABLE      P2-P2/FN3
 3     VARIABLE      P2-P2/FN4
 4     VARIABLE      P3-X*1
 5     VARIABLE      X*1+P4/K2
 6     VARIABLE      X*1-P3
 7     VARIABLE      X*1-P4/K2
 8     VARIABLE      P7/K4
 9     VARIABLE      P8/K3+P8/K3+P6
 10    VARIABLE      P8/K8+P6
 11    VARIABLE      P8/K14+P6
 12    VARIABLE      P8/K25+P6
 13    VARIABLE      X7+X8+X9+X10
 14    VARIABLE      P2/K2+P2
 15    VARIABLE      P3-S15
 16    VARIABLE      P4+P4/K10
 17    VARIABLE      X11+X12
 18    VARIABLE      P4-P5
 19    VARIABLE      P3-S16
```

```
 20    VARIABLE     X19+X20+X23
 21    VARIABLE     X47*K3
 22    VARIABLE     X54*K3
 23    VARIABLE     X61*K3
 24    VARIABLE     X*1*K5+X*2*K4
 25    VARIABLE     X*1*K10
 26    VARIABLE     X*2*K2+X*3*K2
 27    VARIABLE     P2*K1000/P8
 28    VARIABLE     K1088*P3/K100/K40+K5
 29    VARIABLE     X1*K4+X3*K4
 30    VARIABLE     X2*K6+X4*K6
 31    VARIABLE     S3+X77
 32    VARIABLE     S4+X78
 33    VARIABLE     S5+X79
 35    VARIABLE     FN1/FN11
 36    VARIABLE     FN2*FN11
 37    VARIABLE     X75
 38    VARIABLE     P2*P6
 39    VARIABLE     P2-S21
 40    VARIABLE     X67/K10
 41    VARIABLE     X68/K10
 42    VARIABLE     X69/K10
 43    VARIABLE     X70/K10
 44    VARIABLE     X42+X47
 45    VARIABLE     X49+X54
 46    VARIABLE     X56+X61
*
*           STORAGE CAPACITY
*
 1     CAPACITY     2000
 2     CAPACITY     2000
 3     CAPACITY     2000
 4     CAPACITY     2000
 5     CAPACITY     2000
 6     CAPACITY     2000
 7     CAPACITY     2000
 8     CAPACITY     2000
 9     CAPACITY     2000
 10    CAPACITY     2000
 11    CAPACITY     2000
 12    CAPACITY     2000
 13    CAPACITY     2000
 14    CAPACITY     2000
```

```
 15     CAPACITY     2000
 16     CAPACITY     2000
 17     CAPACITY     2000
 18     CAPACITY     2000
 19     CAPACITY     2000
 20     CAPACITY     2000
 21     CAPACITY     2000
*
*            DISTRIBUTIONS
*
 1      FUNCTION     RN1    D4
.25     3      .5    4      .75    5      1.     6
 2      FUNCTION     RN1    D3
.80     1      .95   2      1.     3
 3      FUNCTION     RN1    C2
0       10     1.    100
 4      FUNCTION     RN1    C2
0       8      1.    100
 5      FUNCTION     RN1    D2
.95     0      1.    1
 6      FUNCTION     RN1    D2
.92     0      1.    1
 7      FUNCTION     RN1    D2
.94     0      1.    1
 8      FUNCTION     RN1    D2
.97     0      1.    1
 9      FUNCTION     RN1    D2
.9      1.     1.    2
 10     FUNCTION     RN1    D4
.5      1.     .75   2.     .95    3.     1.     4.
 11     FUNCTION     V37    D2
8       1      30    3.
 99     FUNCTION     RN1    D12
.20     .22    .34   .42    .46    .63    .56    .82    .63    1.0    .70    1.2
.75     1.4    .82   1.7    .87    2.1    .94    2.8    .97    3.5    1.0    7.0
*
*            TABLES
*
 1      TABLE        M1     8      8      30
 2      TABLE        M1     8      8      30
 3      TABLE        P2     1      1      10
 4      TABLE        P2     1      1      10
        START                      160
```