SIMULATION OF A MANAGEMENT DECISION PROCESS UTILIZING A COMPUTER MODEL OF THE AEROSPACE INDUSTRY

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By

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PREFACE

ABSTRACT

To date the use of electronic data processing equipment in business management has been largely confined to accounting applications. Relatively few systems are designed to assist management in the guidance, planning, and control of a business enterprise. This dissertation reports an investigation of the potential utilization of the computer for such a purpose. An environmental model, the Aerospace Business Environment Simulator (ABES), was programmed and tested with more than 300 manager participants who operated fictional companies within this environment. Based on observation of the decision-making patterns of these management teams, a theory of business decision-making was formulated and programmed. This model, the Heuristic Decision-Maker (HDM), operates one (or more) of the companies in the ABES environment using a stipulated set of policies and objectives. A one-half replicate of a 2^5 factorial experiment was designed and conducted to evaluate the methodology employed by HDM. The results indicated that a decision-making algorithm, such as that embodied in HDM, can make decisions which produce reasonable, consistent, adequate, and stable results as compared with those obtained by human decision-makers operating in a similar environment.

ACKNOWLEDGMENTS

The author is particularly indebted to the 300 Lockheed managers for their reactions and critical comments which guided the evolution of the business environmental model and which provided the basis for the theory of business decision-making.

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Appreciation is also due to the many others at Stanford and Lockheed who have contributed their time and ideas. E. K. Fisher supported and encouraged the early phases of this work, as did C. E. Duncan the latter part. Professor Charles Bonini assisted in the experimental design. G. K. Hutchinson developed the factorial analysis program used to analyze the results of the experimental design. I am also grateful to Jarvis Todd for his helpful editorial assistance.

The computation for the business environment model was conducted at the Lockheed computation center. Computation for the seemingly endless checkout of the Heuristic Decision-Making Model was conducted at the Stanford Computation Center and supported by the National Science Foundation grant, NSF GP948. Special thanks are due the personnel of these organizations for their assistance and cooperation.

Finally, I wish to acknowledge the patient help of my wife, Ginger, who regressed from mother to secretary during the production of this manuscript.

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Chapter I

INTRODUCTION

There are many physical processes which man observes but which he is unable to describe in complete and explicit fashion. One such process is decision-making. Although there are several theories of decision-making, none provides a complete framework from which to investigate and experiment with the decision process in any but the most elementary manner. The advent of the high-speed electronic computer has made possible a new method for examining decision processes. The logical capability of the computer enables one to represent complex processes in terms of symbolic models. Because the model is completely known and defined, it is possible to change model parameters and to study the effects of such changes on the behavior of the model. Such experimentation can suggest changes to be made in real-world parameters, can aid in understanding the interaction among the real variables, and can predict qualitative variations which can be expected from changes in parameter values. Forrester[1] summarizes these notions by saying that definition and use of a model implies (1) that we have some knowledge about the detailed characteristics of the system, (2) that the known and assumed facts interact to influence the way in which the simulated process will evolve with time, (3) that our intuitive ability to visualize the interaction of the parts is less reliable than our knowledge of the parts individually, and (4) that by constructing the model and watching the interplay of the factors within it, we will come to a better understanding of the system with which we are dealing.

Although man has used models, both physical and abstract, to aid him in a variety of tasks ranging from construction to automatic control, considerably less work has been done in decision simulation pertaining to the business enterprise. This dissertation describes the development of an abstract model of the

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[1]Forrester, J. W., "Models of Dynamic Behavior of Industrial and Economic Systems," Unpublished notes from Industrial Dynamics Class, Massachusetts Institute of Technology, Cambridge, Mass., August 1959, p. 12.

aerospace industry and its use with aerospace executives, discusses the design of a decision model to operate companies in the aerospace industry, and presents the results of a factorial experiment carried out to examine the effects of several specific policies assigned to the decision model.

Relevant aspects of the use of various models in the behavioral sciences are summarized to provide perspective for the investigation discussed in succeeding chapters.

Physical vs. Abstract Models. A primary distinction can be drawn between physical models and abstract or conceptual models. Physical models are material constructs of physical or non-physical mechanisms. The physical model is made to represent certain aspects of the mechanism it represents to aid in design, construction, or understanding of the mechanism. Examples of physical models include wind-tunnel models of aircraft, bridge models, automobile mock-ups and the like. Abstract or conceptual models may be thought of as symbolic expression of theoretical concepts. Abstract models may use language, symbols, mathematics, or computer programs for their expression. Examples of abstract models include most natural science laws and theories. Forrester[2] provides an extensive classification of models (Fig. 1).

Physical models preceded abstract models. There is some indication that the ancient paintings found on the walls of Cro-Magnon caves (15,000 B.C.) were used in coordinating and planning the group effort required by the hunt. Physical models were used by Egyptian engineers in the design and construction of the pyramids as early at 2700 B.C. An instance of an early transition to a symbolic model of a mathematical nature was in astronomy in the second century B.C. The computer in recent times, with its symbol manipulative power, is widely used for computing mathematical and symbolic models.

Mathematical models symbolically describe the systems they represent. Somewhat more abstract than physical models, they are nonetheless in common usage.

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[2] Forrester, J. W., Industrial Dynamics, M.I.T. Press and John Wiley & Sons, Cambridge, Mass., 1961, p. 49.

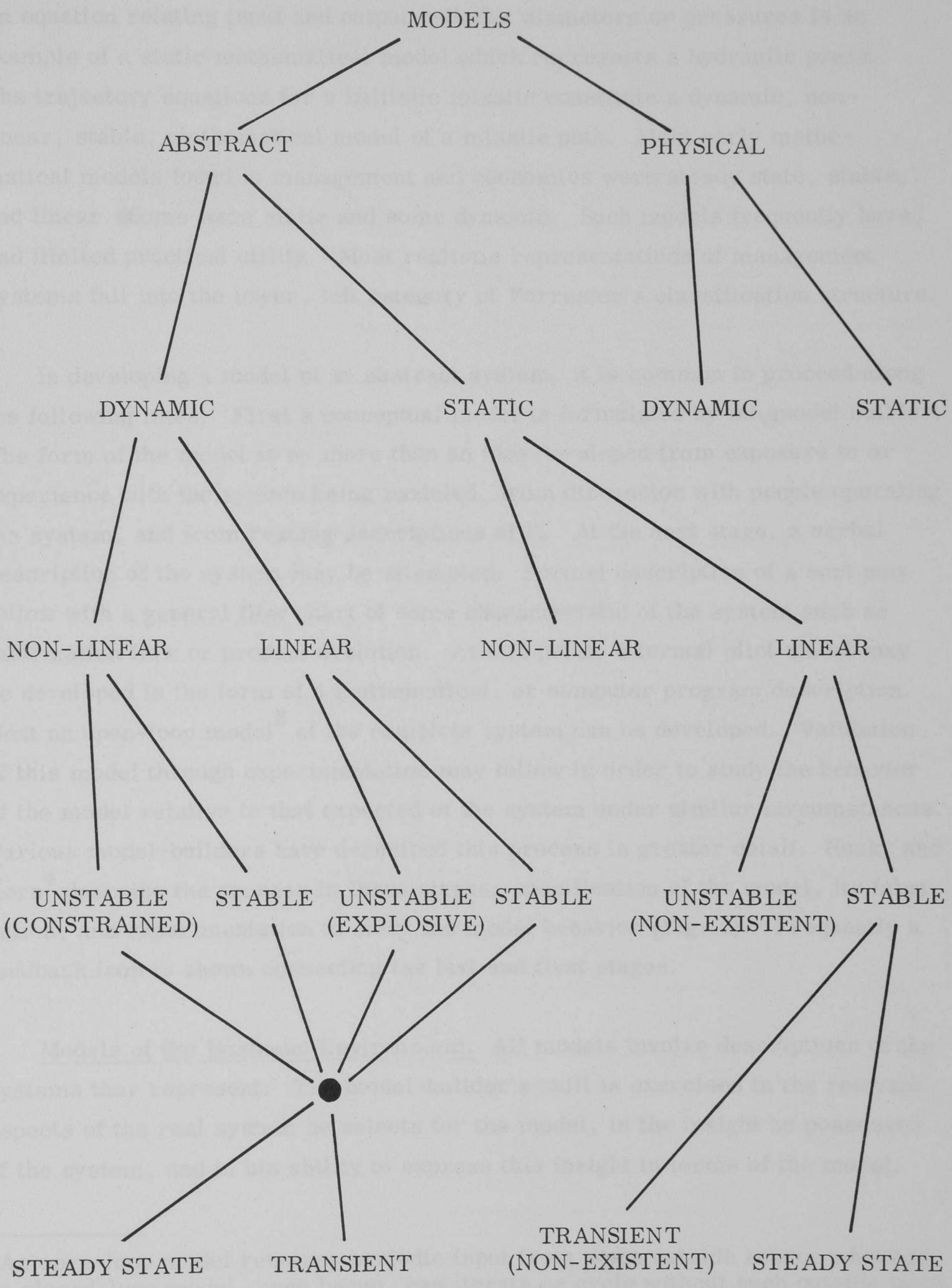

Fig. 1 Classification of Models

An equation relating input and output cylinder diameters or pressures is an example of a static mathematical model which represents a hydraulic press. The trajectory equations for a ballistic missile constitute a dynamic, non-linear, stable, mathematical model of a missile path. Most early mathematical models found in management and economics were steady state, stable, and linear. Some were static and some dynamic. Such models frequently have had limited practical utility. Most realistic representations of management systems fall into the lower, left category of Forrester's classification structure.

In developing a model of an abstract system, it is common to proceed along the following lines. First a conceptual model is formulated by the model builder. The form of the model is no more than an idea developed from exposure to or experience with the system being modeled, from discussion with people operating the system, and from reading descriptions of it. At the next stage, a verbal description of the system may be attempted. Formal description of a sort may follow with a general flow chart of some characteristic of the system such as information flow or product evolution. At this point, a formal pilot model may be developed in the form of a mathematical, or computer program description. Next an open-loop model[3] of the complete system can be developed. Validation of this model through experimentation may follow in order to study the behavior of the model relative to that expected of the system under similar circumstances. Various model-builders have described this process in greater detail. Husky and Korn[4] describe the process in three stages: specification of the model, its fabrication, and experimentation to study the model behavior (Fig. 2). Frequently a feedback loop is shown connecting the last and first stages.

Models of the Business Environment. All models involve descriptions of the systems they represent. The model-builder's skill is exercised in the relevant aspects of the real system he selects for the model, in the insight he possesses of the system, and in his ability to express this insight in terms of the model.

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[3] An open-loop model requires periodic input from some outside source whereas a closed-loop model, once begun, can iterate or cycle without such outside input.

[4] Husky, H. D. and Korn, G. A., ed., Computer Handbook, McGraw-Hill Book Co., New York, 1962, p. 21–43.

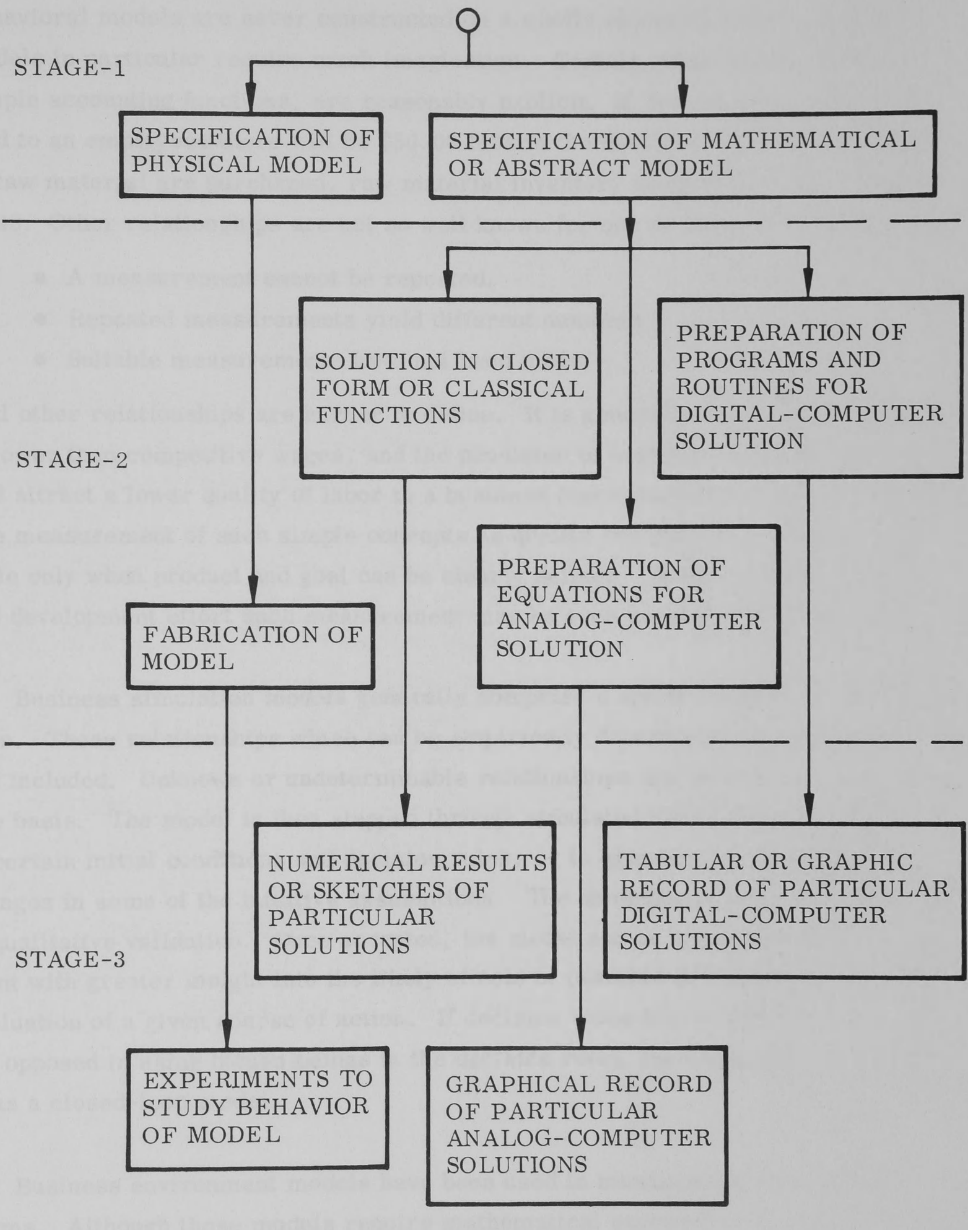

Fig. 2 Three Stages in Simulation

Behavioral models are never constructed on a wholly objective basis. Business models in particular require much imagination. Certain relationships, namely simple accounting functions, are reasonably explicit. If, for example, $50.00 is paid to an employee, there will be $50.00 less in the cash account. If 40 pieces of raw material are purchased, raw material inventory quantity will be increased by 40. Other relationships are not so well known for one or more of these reasons:[4]

- A measurement cannot be repeated.
- Repeated measurements yield different numbers.
- Suitable measurements have not been made.

Still other relationships are harder to define. It is generally felt that the payment of lower than competitive wages, and the provision of less than adequate facilities will attract a lower quality of labor to a business (union regulations notwithstanding). The measurement of such simple concepts as quality and efficiency of labor is possible only when product and goal can be clearly defined. In the case of research and development effort such measurement may be even conceptually inadequate.

Business simulation models generally comprise a specific aspect of the business. Those relationships which can be empirically determined are measured and included. Unknown or undeterminable relationships are included on an intuitive basis. The model is then stepped through simulated time to test the effect of certain initial conditions and decision rules, or to examine its sensitivity to changes in some of the intuitive assumptions. The objective of such manupulation is qualitative validation. Once accepted, the model can be used to provide management with greater insight into the likely effects of possible decisions, or to allow evaluation of a given course of action. If decision rules are included in the model (as opposed to using human beings in the decision role), the simulation is referred to as a closed-loop model.

Business environment models have been used in management training programs. Although these models require mathematical expression of a set of assumptions concerning relationships in the business environment, they are

[4]Forrester, I. W., ibid, p. 70.

usually not closed-loop systems; i.e., they include humans as decision-makers. The business model requires as input a set of decisions with which it interracts to produce a set of hypothetical results. This process is known as management gaming and may be considered an interactive man-machine system. The computer contains a model simulating the relationships of some physical environment. The man exercises purposeful behavior by making decisions which to some degree direct and control the simulated environment. The computer model reacts with these decisions, and provides the man with evidence of this reaction in the form of financial and operating reports. These reports provide clues to the environmental relationships, and enable the man to evaluate the effectiveness of his decisions and to assess the thoroughness of his understanding of the environment.

Usually business models have been used to train managers and to provide them practice in decision-making. It occasionally is of interest to study the reaction of the human manager to the simulated environment. This was one objective of the RAND Corporation in testing a series of logistics policies in a detailed man-machine simulation of the Air Force logistics system.[5]

Whether or not a particular model effectively represents reality depends not so much on the amount of detail included, but more on its use, on the basic assumptions represented in the model, and on the degree of acceptance of the model by those who must use it in reality. There are business models that closely approximate reality; there are other simulation models which have little basis in reality. Bross[6] summarizes the case for simulation models as follows:

> "...the proof of the pudding is not brilliant verbal argument, high-sounding abstract principles, or even precise logic or mathematics — it is results in the real world. Not all cases have to be carried all the way to the final court, but in the event of disagreement, the real world has the last word."

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[5]Geisler, Murray A., "The Simulation of a Large-Scale Military Activity," Management Science, 5, No. 4, July 1959, pp. 359–368.

[6]Bross, I. D. J., Design for Decision, Macmillan Company, New York, 1953, p. 29.

The particular business environment model, with which the first phase of the investigation discussed in this dissertation is concerned, is the Aerospace Business Environment Simulator (ABES). This model is an open-loop, abstract, dynamic, non-linear, constrained system which requires submission of a set of decisions by each of several companies which constitute the simulated industry. The ABES model interacts with the decisions and prints out results for each company in the form of financial and operating reports. It has been used for four years as an adjunct to a management development course which has been attended by over 300 management personnel of a major aerospace company.[7] A detailed consideration of the ABES model and its use in business management training is given in Chapter II.

Decision-making Models. Although many investigations have been made of the decision rules to be followed in specific situations and an abundance of theoretical material written about many elements of the decision problem, the development of a generalized business decision-making model has been largely neglected. Inventory management contains a wealth of theory regarding reorder point and reorder quantity. There are various scheduling algorithms for the optimum sequencing on n jobs through m machines. Some consideration has been given to theoretical problems of measurement, utility, and optimization associated with business processes. There exist a variety of algorithms and even computer programs for maximizing or minimizing the response surface of a set of decisions. An extensive literature search however provided only a few reports of the decision-making systems, and these were usually limited to single areas in business or to a simulation of decision-making in game playing.

An example of a model dealing with the cost trade-offs of alternative production decisions is one devised by Holt, Modigliani, Muth, and Simon. In this model both a production quantity and an employment level were chosen so as to minimize a set of quadratic cost functions.[8] The model was structured for solution by analytical techniques as opposed to iterative solution through simulation. The input

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[7] "Executive Decision Making," Lockheed Missiles & Space Company, Sunnyvale, Calif.

[8] Holt, C. C. et al., Planning, Production, Inventories, and Work Force, Prentice Hall, Edgewood Cliffs, N.J., 1960.

consisted of a set of quadratic cost functions and a 12-month sales forecast. The output provided an optimum (under the assumptions of the model) production quantity and employment level.

Another decision-making model, General Problem Solver (GPS), is described by Herbert A. Simon.[9] It is called GPS not because it can solve any kind of problem – it cannot – but because the program itself makes no specific reference to the subject matter of the problem.[10] The computer program based on the model can reason in terms of means and ends about any problem that is stated in a general form which can be understood by the program. The program analyzes differences between objectives (ends) and present status in terms of available alternatives (means) of reducing these differences. In particular the GPS has programs which enable it to formulate and attack three kinds of goals:

- Transform goals – Change A to B
- Reduce difference goals – Eliminate or reduce the difference between A and B
- Apply operator goals – Apply the program (operator or method) Q to Situation A

Programs or models like the GPS which carry out complex information processes by using some selectivity in exploration similar to rules of thumb as used by humans are coming to be called heuristic programs. Such programs are not so strictly defined and structured as algorithms, but tend to selectively adapt to the problem at hand by using currently developed results to alter the pathway of computation. Other non-business heuristic programs have been developed to prove geometry theorems,[11] to play checkers,[12] to prove theorems in logic,[13] and to

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[9] Simon, Herbert A., The New Science of Management Decision, Harper Brothers, New York, 1960

[10] Newell, A., J. C. Shaw, and H. A. Simon, "The Elements of a Theory of Human Problem Solving," Psychological Review, 65 10–17, March 1958

[11] Gelernter, H. L., and Rochester, N., "Intelligent Behavior in Problem-Solving Machines," IBM Journal of Research and Development 2, No. 4 336-345, (1958)

[12] Samuel, A. L., "Some Studies in Machine Learning, Using the Game of Checkers," IBM Journal of Research and Development, 3, No. 3, 210-229, (1959)

[13] Newell, Shaw, and Simon, "Emperical Explorations of the Logic Theory Machine: a Case Study in Heuristic." Proceedings of the Western Joint Computer Conference, February 1957, San Francisco: Institute of Radio Engineers, 1957, pp. 218-230

play chess.[14] Perhaps the most interesting of these programs is the last, at least in terms of a business decision-maker. Simon[9] distinguishes three phases of decision-making: (1) intelligence, (2) design, and (3) choice – processes for scanning the environment to see what matters require decisions, processes for developing and examining possible courses of action, and processes for choosing among the courses of action. The chess program as developed by Carnegie Institute of Technology and the RAND Corporation follows a somewhat similar pattern. In the first or intelligence stage, the chess position is examined to see what features call for attention in terms of a set of pre-defined goals (such as winning pieces or securing control of the center of the board). The next phase generates possible moves from features discovered in the intelligence phase. This is analogous to the design phase previously outlined. The choice phase consists of an evaluation of the consequences of the possible moves and selection of the move that is best from among those that have been examined.

To the best of our knowledge there are no similar programs which deal with business decision-making.[15] One explanation seems to be that the processes involved in managing a business are not so well understood as are the rules and strategy for a game of chess. Because the problem solving heuristic described is similar to that used in a variety of applications, however, it is possible that some insight gained from such a program would provide a basis for understanding, and even solving ill-structured, ill-defined processes such as business management

Simon[9] divides decisions into two types: programmed and non-programmed. Programmed decisions include routine, repetitive decisions for which the organization develops specific handling processes. Non-programmed decisions include one-shot, ill-structured, novel, policy decisions which are handled by general problem-solving processes. He argues that within twenty years, machines will be capable of doing any work that a man can do (economics may be another question). He concludes that many programmed decisions presently performed by middle management will be performed in the future by the computer. Furthermore,

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[14] Newell, A., J. C. Shaw, and H. A. Simon, "Chess Playing Programs and the Problem of Complexity," IBM Journal of Research and Development, 2, No. 4, 320–335 (1958).

[15] A program, the abstract of which relates to business decision making, was described at the 28th National Meeting of ORSA in Houston, Texas, November 1965, entitled "An Investigation of Decision Systems for a Complex Management Game," by Robert B. DesJardins.

he states that the processes of non-programmed decision-making will soon undergo as fundamental a revolution as the one currently transforming programmed decision-making in business organizations.

It is of interest to ponder the means by which the revolution in non-programmed decision-making will take place. Will it be through a merging of the many specific functional models which now exist? Is it possible to attack the problem of the total business system without first addressing the parts? Will revolutionary new computer languages and algorithms be developed which will allow more explicit description of business interactions? Still another possibility is that through the use of relatively simple, well-structured business environments, decision-making models can be developed which then will be capable of generalization to more complex business systems.

The decision-making model with which this dissertation is concerned is the Heuristic Division Maker (HDM). To test the theory of decision-making presented in Chapter III, the HDM model was developed to operate one or more of the companies in the ABES environment which was originally designed as an open-loop system. This model was formulated on the basis of observation of the decision-making characteristics of the managers participating in the Executive Decision-Making course. The structure of the HDM model is discussed in detail in Chapter IV.

To evaluate the operation of the HDM model, a one-half replicate of a 2^5 factorial experiment was performed, the design of which is discussed in Chapter V. The factorial experiment is a formal method of experimentation which allows one to associate changes in results with changes to input factors and to express the statistical significance of the effects with analysis of variance techniques. The experimental findings are discussed in detail in Chapter VI. An appendix provides some of the technical details of the computer programs underlying this investigation together with examples of the input they require and the output they produce.

Chapter II

THE AEROSPACE BUSINESS ENVIRONMENT SIMULATOR

Traditionally, management is charged with planning, organizing, directing, and controlling the operations of a business. Such planning must be accomplished in an uncertain environment; effort must be organized with a full knowledge of the capability of that effort; action must be directed although the full impact of that action is unknown; and operations must be controlled with incomplete and often inaccurate information concerning the status of those operations. It is surprising that management can function effectively under these complex circumstances. One explanation seems to be that through experience managers develop an intuitive process which enables them to evaluate a wide range of possible courses of action without overt consideration of the many variables involved.

The Aerospace Business Environment Simulator has been used to provide practice in performing these management functions somewhat as a Link trainer is used to provide simulated flying experience. The simulated environment is supplied by a computer program which contains mathematical descriptions of many important relationships found in the aerospace industry. Teams of management personnel gain experience by operating competing companies within this simulated environment. Appendix B is a copy of the ABES participants' manual.

Participation in the simulation exercise does not teach a series of rules for success, but rather provides opportunities for team members to use available information to formulate policies, define objectives, and to gain experience in decision-making without the attendant hazard of placing the actual firm in an undesirable position. Furthermore the experience can be gained in a relatively short period.

<u>Operating Procedure.</u> Each period (a simulated quarter year), the participating teams submit sets of decisions on a decision form (Fig. A-1) to the computer (an IBM 7094). The effects of the decisions on the environmental model are computed. The results of this interaction are then printed as operating reports which are distributed to the teams. The operating cycle is indicated in Fig. 3.

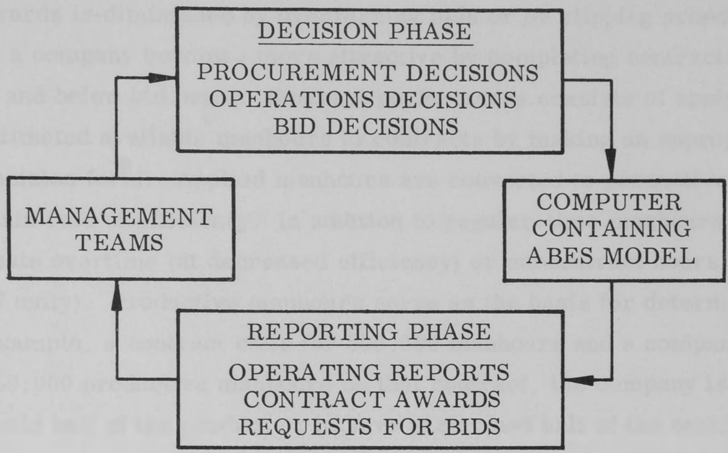

Fig. 3 ABES – Cycle of Operation

There are two independent functional areas of effort with which the teams are concerned:

- Research and development
- Production

Within each of these areas, there are two products: space systems and missile systems. There are three types of decisions to be made each period for each functional area:

- Resource management (acquisition and utilization of resources)
- Contract performance (application of manhours to contracts)
- Contract bidding (decisions involved in obtaining new business)

Resources provide the basis for the performance capability of a company. In the simulation exercise resources consist of men (manhours), facilities, and cash. Men and facilities are either of a research-and-development type or production type. These functional areas are essentially independent; i. e. , production men and facilities cannot be used for effort on research and development contracts and vice versa. Cash, of course, can be used for either function. The resources can be increased or decreased for any period by an appropriate entry on the decision form. Just as in reality there are no absolute constraints imposed on the values decisions can be assigned. An extreme decision may, however, cause an extreme result.

The objective of contract performance is to complete a contract manhour requirement by the end of the contract period. A company's attractiveness on future awards is diminished by overrunning bids or by slipping schedules. Conversely, a company becomes more attractive by completing contracts ahead of deadline and below bid price. Contract performance consists of applying (scheduling) estimated available manhours to contracts by making an appropriate entry on the decision form. Applied manhours are converted to productive manhours at a certain rate of efficiency. In addition to regular-time manhours, a company can allocate overtime (at decreased efficiency) or subcontract hours (at an efficiency of unity). Productive manhours serve as the basis for determining sales. If, for example, a contract calls for 500,000 manhours and a company has completed 250,000 productive manhours on that contract, the company is considered to have sold half of the product or to have performed half of the contracted service. This does not mean that the company has been paid. The asset reflection of sales prior to cash payment is in receivables. Accounts receivable are converted to cash with a constant delay.

Each period the Government solicits bids. Such requests specify the desired function and product, the total productive manhour requirement, the contract period, and the maximum bid which will be entertained. For every bid request, each management team must decide whether or not to bid and how much to spend in presenting the bid. The amount of the bid together with the amount to be spent in presenting it are to be entered on the decision form. All research and development contracts are assumed to be cost plus fixed fee (CPFF), whereas all production contracts are fixed price.[1]

Exogenous variables include wage rates, subcontract rates, and interest rate. These variables change during the course of an exercise according to supply of and demand for the commodity they represent.

The results of the interaction of the decisions with the environmental model in the computer are operating reports (see Appendix A for examples) which are distributed to each simulated company. These include financial reports, depicting

[1]All costs incurred by a contractor are reimbursed by the Government in CPFF contracts, but the fee is a fixed percentage (approximately 7%) of the initial bid price. Only the amount of the bid is paid on a fixed price contract, irrespective of the final cost.

the operations of the preceding period; requests for bid, describing work desired by the Government; and contract awards, indicating companies to whom awards have been made. This information serves as a basis for the teams to evaluate their past performance, and to formulate future plans. The receipt of the reports signals the end of one period and sets the stage for the next. This cycle continues from period to period for the duration of the simulation exercise.

A final critique which is designed to breach the proprietary barrier of competition present during the exercise is held at its conclusion. The setting is that of a stockholders' meeting wherein a board of directors defends its actions throughout the simulation exercise, discusses the applicability of lessons learned to real-life problems, and indicates the usefulness of objectives, policies, and analytical techniques in the process of decision-making.

The Use of Business Models in Training. The well-designed business model provides the manager (or student) with a laboratory environment containing important aspects similar to those of actual business life. He must learn to understand this environment through critical observation and to develop tools for analyzing it. From such understanding comes his ability to forecast the likely results of alternative actions. This ability is paramount in determining the objectives and policies by which a decision-maker directs and controls an enterprise.

Business simulation models encourage integrated application of the multitude of functional specialties a participant may possess, indicate areas which need additional emphasis, facilitate the consideration of a problem in its entirety, and provide a structure similar to an actual business environment in which one can practice decision-making and experiment with control techniques. The participant in a training program that uses business simulation models literally "plays a business-management game."

Traditionally business education, whether obtained through formal instruction or through on-the-job apprenticeship, tends to consider each functional area as a separate entity. Accounting, economics, and statistics are learned from men prominent in their own specialty. Company training programs frequently are designed to serve the needs of only one organization in the company, or at best to present the requirements of a variety of organizations successively. It is left for the participant to integrate and relate the variety of special knowledge he has acquired into an effective whole. As a result of such unintegrated training, the new manager (or even the experienced manager) may be indecisive when exposed to the broad demands of decision-making in an actual business situation where he must bear the burden or responsibility for the outcome of his decisions.

Conventional apprenticeship training tends to emphasize functional specialties without necessarily interrelating them, is less inclusive than is desirable, and this leaves the manager ill-equipped to evaluate all relevant aspects of a problem when he is called on to do so. What is needed is training and practice in decision-making detached from the pressure and risk associated with the actual operation of a business. The manager needs guidance in integrating the variety of functional tools at his disposal. He needs an awareness of the total spectrum of effects associated with any decision, as opposed to the short-term, obvious effects which are frequently the only ones considered. He should develop a conceptual structure of the business as a dynamic, interrelated system.

The effectiveness of a management gaming program is best described by its participants. The following are comments from participants in the Executive Decision-Making course in which the ABES model was used:

"A better appreciation of the costs of running a business and the factors that influence the overall success of the endeavor, together with the need to integrate all functional areas to insure the success of the endeavor."

"Helps me to better understand the reaction of people with varying functional backgrounds when involved in working as a group in problem-solving."

"Good review of analytical training which I had not used for some time. I feel I also gained a great deal of insight into many aspects of 'real world' business as it affects this company. I can better discuss the company's day to day changes to employees who are concerned and confused."

"I tend to push strongly for what I believe and by so doing, tend to overwhelm those opposed to my views. I found much value in the views of others on the team. It was brought home to me that their decisions were equal to, or better than mine and that I should listen to contrary views."

"Provides information on effects of direct costs versus indirect costs; provides background on why some decisions, seemingly arbitrary on the surface, are made by top management and why."

"Objective and comprehensive review of the financial problems of a company will further my understanding in negotiation with contracts, price, budget and estimating departments."

"Gave insight into factors entering basic management decisions and the sketchy information that often must be used. Gets one out of the rut of thinking only of his own job."

"Pinpointed the need for advanced planning within the framework of established policies. If you do not believe in the policies, rewrite them – do not ignore them."

"The degree of value is specific to each participant, in terms of his need to gain an appreciation of factors to be considered, segregation of those factors by degree of significance, and the resulting interplay of the signficant factors. The course increased my knowledge of computers and tends to increase my confidence and unterstanding of computer potential."

Psychological studies of memory indicate recall is a considerably more difficult task than recognition.[2] This fact was exploited in the evolution of the ABES model by soliciting extensive critical evaluation of the model from the participants. The same managers who were hard-pressed to describe, say, the marketing function at Lockheed (the process of recall), became quite articulate in evaluating contract awards function when their simulated company lost a badly needed contract (the process of recognition). As a consequence of such evaluation, the ABES model was modified both logically and parametrically during its early use to correspond more exactly with the intuitive image of the aerospace environment held by men who operate within it.

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[2]Hebb, D., A Textbook of Psychology, W. B. Saunders Company, Philadelphia and London, 1958, p. 246.

Chapter III

PATTERNS OF DECISION-MAKING

This chapter describes the decision process used by Lockheed managers in the Executive Decision-Making course which uses the ABES model as a laboratory tool. Observed patterns of decision-making are examined, and a case history of one participating team is presented. These observations establish the framework for a theory of business decision making described at the end of this chapter and the HDM model presented in the following chapter.

Performance Patterns. The pattern of success and failure of management teams participating in the simulation exercise has characteristically paralleled a pattern that can be observed in actual companies. The profit of simulated companies has varied from a high of approximately 10% return on investment, to near bankruptcy. Successful companies have usually been selective in choosing the proposals on which they bid, and their bids generally have been sufficiently high to recover all direct costs, an approximate portion of indirect costs, and a reasonable profit. In addition, they have tended to develop plans and policies rather than meet each situation as a new problem.

Less successful management teams, on the other hand, tended to be too competitive in bidding, and frequently ignored indirect costs and profit. An initial influx of new contracts would require them to expand facilities, manpower, and debt rapidly. Costs would frequently increase more than anticipated, causing closely bid contracts to be overrun. Successive quarters of unprofitable or marginally profitable operation placed further burdens on their financial structures and made them less attractive contenders for future contract awards. At some point, the spiral of increasing operating costs and decreasing competitive attractiveness became inescapable, and bankruptcy would follow. One or more of the following characteristics is usually observed in the unsuccessful team:

- Lack of planning – no attempt is made to establish explicit objectives, or if established, they tend to be vague and unmeasurable.
- Lack of post-mortems – "Why did we fail?" is a question never asked in considering the results of a previous period of operation.

- Lack of organization – Specific functions and responsibilities are not assigned. Teams act in anarchy with each member doing a cursory job of analysis on the total span of decision-making.
- Lack of leader initiative – No single strong individual guides company progress, assigns tasks and responsibilities, and monitors progress.
- Dogmatism – Participants conclude on the basis of insufficient information and even defend these hasty conclusions against contradictory evidence.
- Vacillation – Perhaps because of lack of objectives, there is no consistent direction to operations.
- Over-reaction – When a problem is identified, the full energies of the company are brought to bear on it, perhaps creating other problems in the wake of solving the first.

The image presented by unsuccessful companies is one of erratic management – vast changes in direction from one period to the next with high attendent administrative costs and great dissipation of energy.

DECISION-MAKING: A CASE HISTORY

In addition to the Executive Decision Making course, several exercises using the ABES model have been conducted with other companies engaged in government contracting. As a result of one such exercise, the Federal Systems Division of International Business Machines Corporation reported their approach to decision-making in the ABES environment.[1] This approach is typical of that employed by the more successful companies and provides a basis for formulation of the conceptual model of the decision process described in the next section of this chapter.

The Federal Systems Division (FSD) team began initially by considering the following major operating elements:

- Establishing company objectives
- Planning a course of action to meet objectives

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[1]Brounstein, S. H., "Managerial Decision-Making in a Simulated Aerospace Business Environment," International Business Machines, Bethesda, Md., 15 January 1963

- Determining an effective organization; assigning functions and responsibilities to individual team members
- Reviewing progress toward objectives through evaluation of information reported as operating results

Company objectives were stated in terms of time-phased goal points for sales, profit, and manpower levels. Goal points were stated in a variety of forms including annual rates of growth and desired ratios (e.g., profit to sales). Concomitant policies were developed which related to the decision factors such as hiring rates, wage rates, bidding, and plant investment. Some examples of objective-formulated policies used by the team were as follows:

- Increase manpower by hiring no more than a certain percentage.
- Maintain a plant investment per man of so many dollars.
- Complete contracts one period early whenever possible.
- When the anticipated annual rate of return on investment is greater than the incremental cost of the interest rate, finance expansion by borrowing additional capital.

Although the initial set of policies and objectives were modified, they tended to provide guidelines both for decision-making and for the evaluation of performance, as well as to measure the degree of understanding of the operating environment. Although the process for selecting individual decisions appeared to be largely intuitive, the following elements were usually present:

- Identification of alternative actions as constrained by policies
- Determination of the possible outcomes for each action
- Estimation of the probability of each outcome
- Selection of the most desirable action based on the above evaluation

The FSD team found it useful to organize so that different members of the team represented distinct functions of the business. They felt that the best decisions resulted from a balanced appraisal of all points of view bearing on the particular question, as represented by the following functions and responsibilities:

- Marketing – sales forecasts and bidding policies to assure an adequate flow of incoming business (contracts)
- Controller – financial plans, cost analyses, and pricing policies to assure a profitable operation

- Systems management – planning and monitoring in-house contracts to assure that time, cost, and performance objectives are met
- Personnel – planning and evaluation of hiring and firing rates, wage rates, education and training, and internal research expenditures to assure an adequate level of employee satisfaction and capability development
- President – general management to assure the development of coordinated plans and decisions to meet a balanced set of objectives

Measurement of success was a matter of evaluating the results of a previous period of operations against established, time-phased objectives. Examples of generally measurable success indicators used by the FSD team included contract awards, reduced turnover, higher efficiency, higher earnings, higher profit margins, and return on investment. Continual monitoring of such a set of indicators or objectives emphasized the need for changing ineffective policies, and also exposed misunderstandings of environmental relationships.

Besides performing the planning and decision-making operations just described, the FSD team systematically varied certain factors to roughly estimate the sensitivity of the model environment to such changes. For example, it was found that 10% increase in the level of education and training expenditure had relatively little effect on employee turnover, but seemed to increase efficiency sufficiently to be justified.

A THEORY OF BUSINESS DECISION-MAKING

The theory to be described draws on concepts which have been discussed by Simon, Emery, Shubik, and Cyert and March, among others. The theory does not attempt to synthesize these concepts but rather attempts to use them where applicable, to formulate a generalized scheme of business decision-making whose structure not only will encompass observed corporate organizational behavior but also will provide methodology sufficiently well defined that it can serve as the basis for a computer model of the decision process to be discussed in the next chapter.

The theory distinguishes three levels in the decision-making process: strategic, tactical, and operating. It further distinguishes between objectives and policies and procedures. Figure 4 depicts the flow in the decision-making process insofar as a two dimensional figure can depict a multidimensional process.

The Structure of Business Decision-Making. The strategic planning process is represented at the highest corporate level of management. This level interacts with the external environment of the company to establish strategic policies and objectives which are interpreted or factored into tactical policies and objectives at the tactical level of planning. At this point operating managment begins the decision selection iteration. A complete but tentative set of decisions is generated within the constraints provided by the tactical policies and in accordance with the dictates of procedures. Such a set of decisions constitutes an operating plan which is submitted to a forecasting process for determing operating results. Operating results are evaluated against tactical objectives. This evaluation is compared with that of the best previous tentative operating plan; if better, the present tentative operating plan replaces the best previous one. This iteration is performed an arbitrary number of times, and the best tentative plan is selected for implementation. Interaction with the environment produces operating results which may be used to adjust the forecasting model on the basis of comparison with forecast results, which feed back to operating management and the tactical planning function on the basis of comparison with tactical objectives, and which finally feed back to strategic planning on the basis of a comparison with strategic objectives.

Within this theory we have defined only relative or local optimum points (as opposed to an global optimum). The objective of the operating manager is that of selecting a plan which will produce a relative optimum with respect to the measure of effectiveness defined by tactical objectives. Increasing the number of tentative plans developed will usually increase the relative optimum achieved. The multiciplicity and complexity of interacting goals in the business enterprise precludes definition of a global optimum at present.

Strategic planning is distinguished from tactical planning by its longer time horizon and its more general formulation. The strategic planner in developing policies and objectives must consider both the external and the internal environment of his company. The former involves the interaction with stockholders,

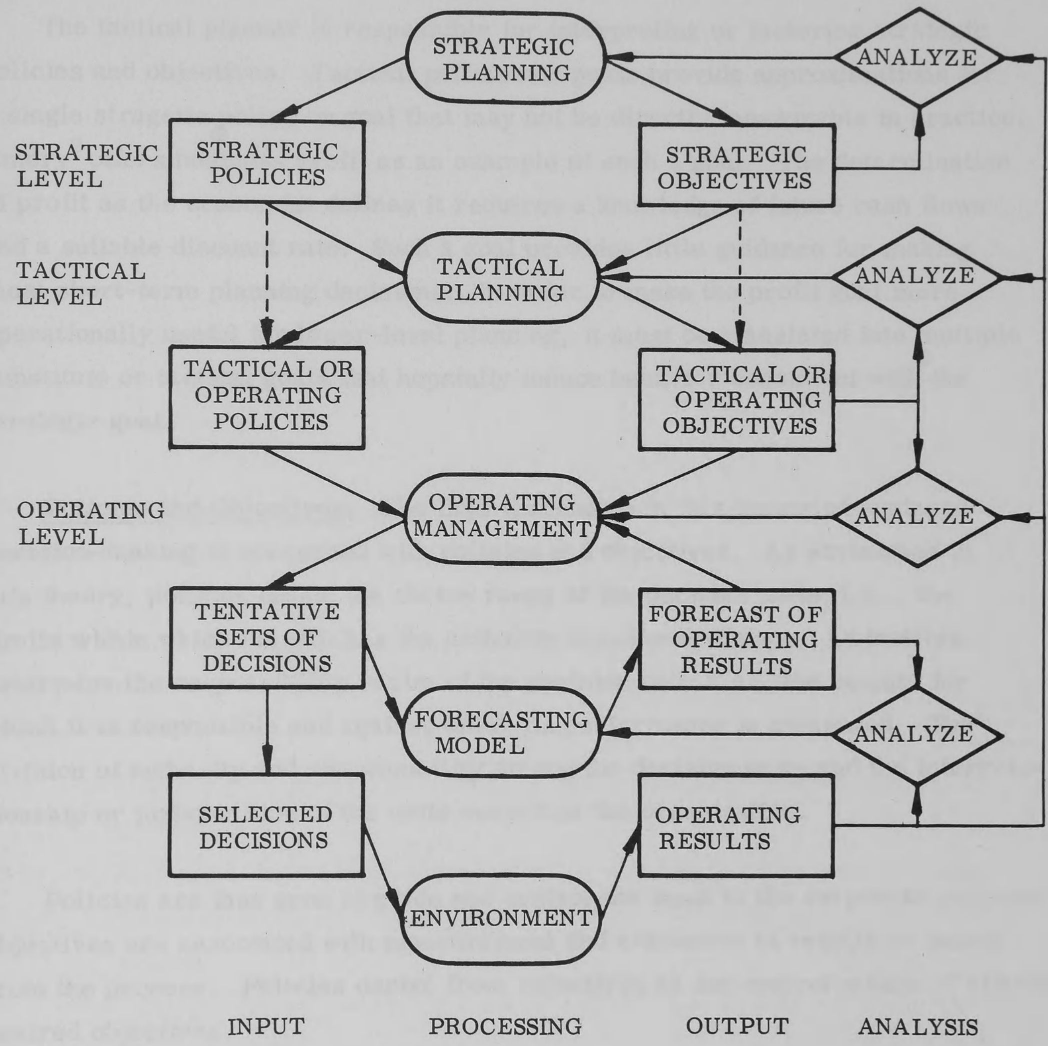

Fig. 4 Business Decision-Making Process

unions, directors, and government agencies. The policies and objectives so derived are directed at assuming the long-term continuance of a satisfactory corporate existence.

The tactical planner is responsible for interpreting or factoring strategic policies and objectives. Tactical policies or goals provide approximations for a single stragetic policy or goal that may not be directly measurable in practice. Emery[2] offers business profit as an example of such a goal. The determination of profit as the economist defines it requires a knowledge of future cash flows and a suitable discount rate. Such a goal provides little guidance for making most short-term planning decisions. In order to make the profit goal more operationally useful for lower-level planning, it must be translated into multiple substitute or tactical goals that hopefully induce behavior consistent with the strategic goal.

Policies and Objectives. The final discussion in this theory of business decision-making is concerned with policies and objectives. As envisioned in this theory, policies define the choice range of the decision units; i.e., the limits within which the unit has the authority to make decisions. Objectives determine the responsibility realm of the decision unit; i.e., the results for which it is responsible and against which its performance is measured. The division of authority and responsibility among the decision units and the interrelationship or juxtaposition of the units constitute the organization.

Policies are thus seen to guide and control the input to the corporate process; objectives are associated with measurement and evaluation of results or output from the process. Policies derive from objectives as the control means of effecting desired objectives.

A procedure or decision rule is a special case of a policy. A procedure is a policy without a choice range and consequently requires no judgment or discretion on the part of the decision-maker.

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[2] Emery, James C., "The Planning Process and Its Formalization in Computer Models," MIT Report 108-65, January 1965, p. 22

The operating manager generates tentative operating plans within the constraints of tactical policies, forecasts results, evaluates results against tactical objectives, and selects the best tentative plan for implementation.

This heirarchy from strategic to operating levels parallels the organizational heirarchy found in many businesses. The president and senior or executive vice-presidents operate at the strategic level. Vice presidents or directors act at the tactical level. Managers have responsibility at the operating level. The channels for communication between strategic, tactical, and operating levels are policies and objectives. These channels can also serve to coordinate the diverse motivations of the individual decision units into an effective working force, thereby reducing the problem of sub-optimality often associated with decentralized decision-making.

Simon[3] discusses policy-based from procedure-based decisions as non-programmable and programmable decisions.

To be effective, policies must be clearly stated in their role as decision-controllers. Consequently, a policy statment has the following minimum requirements:

- The decision domain of a policy must be defined – what decisions does it control?
- Each decision within the domain of a policy must have clearly stated boundary conditions which define a range of discretion for the decision maker.
- A procedure or decision-rule is a special type of policy having a zero range of discretion.
- No two policies should exist such that a particular decision is permissible under one policy and not permissible under the other.

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[3] Simon, Herbert A., The New Science of Management Decision, Harper Brothers, New York, 1960

Likewise, an objective has a set of requirements:

- The definition of an objective must include a statement as to the time realm of the objective and must specify the units for measurement of performance against the objective.
- An objective must be sufficiently quantified that any result falling within its realm can be measured relative to the objective.

Chapter IV

THE HEURISTIC DECISION-MAKER

The HDM model is a decision-making procedure programmed to allow the computer to manage one or more of the companies in the ABES environment. This model can compete against itself or against companies operated by human decision-makers. In either case, it has access to no more information than its human counterparts, and makes no use of the ABES model itself. It performs many of the same functions displayed by human decision-makers such as decision formulation, forecasting results, and evaluation of results. Because its policies and objectives are assignable as parameters, it is possible to observe the long-range effects of these policies and to compare the performance of a totally formalized decision process with that embodied in the human decision-maker.

In what follows, a general description of the HDM model precedes a detailed examination of each structural element. This discussion is followed by a comparison of HDM results with those reached by human decision-makers and finally by a description of various tests of internal consistency performed on the HDM. Appendix C contains a listing of the HDM program and a description of its major subroutines and functions.

GENERAL STRUCTURE OF THE HDM MODEL

The decisions required to operate a company in the ABES environment were described in Chapter II and are illustrated in Fig. A-1. The problem described in this chapter is the design of a heuristic decision-making model, based on the theory of business decision-making presented in the previous chapter, which will operate one or more ABES companies, but which conceptually is not limited to making only the decisions required by ABES.

The general approach in the definition of HDM is as follows:

- Define a set of objective functions related to those ABES results which can be measured and forecast.

- Derive a set of policy functions and include in their domain the decisions which must be made to operate an ABES company.
- Develop a forecasting model which will provide a forecast of result values from a set of decision values.

Then, operation of the HDM model consists of the following major steps:

- Generate successive, feasible sets of decisions (i.e., a set of decisions which falls within boundaries specified by the policy functions).
- Forecast the results of these decisions.
- Evaluate and score these results against the set of objective functions.
- Select and implement that set of decisions whose forecast results produce the best score.

Within this sequence two types of decisions are developed: non-programmable or those derived from policy functions, and programmable or those derived from decision rules or procedures. In this model, we are most concerned with the decision-making system associated with policy-derived decisions as opposed to the development of specific decision rules or procedures.

The decision-making model contains subprograms to develop the following:

1. Resource procurement decisions – determine total hires, fires, subcontracting, overtime, and schedule deviation for the ensuing period.
2. Resource allocation decisions – allocate resources to specific contracts.
3. Internal investment decisions – determine amount to be spent on education and training, internal research, and facilities expansion.
4. Results forecast – forecast result variables.
5. Measurement and evaluation of results – evaluate forecast results in terms of objectives.
6. Contract selection and bid decisions – select contracts to bid and determine a bid price.

All these subprograms will be referred to by these numbers throughout this dissertation. Decisions associated with Subprograms 1 and 3 are policy-derived;

decisions associated with Subprograms 2 and 6 are decision-rule or procedure derived. Subprograms 4 and 5 are forecast and evaluation ones. The flowchart (Fig. 5) depicts the successive operations in the development of decisions and the forecast and evaluation of results. The numbers within the blocks designate the subprograms.

Policy-Derived Decisions. Resource procurement decisions (Subprogram 1) and Internal Investment decisions (Subprogram 3) are derived from policy functions as follows. Successive sets of decisions are randomly generated within constraints defined by policy functions. The results of these decisions are predicted by the forecast functions and are evaluated in terms of the objectives. The set of decisions producing the best results is saved and later implemented. Because resource procurement and internal investment decisions are interdependent within one decision cycle, these sections form one decision unit (that associated with the internal business environment), whereas contract selection and bidding form the other (that associated with the external business environment).

Procedure-Derived Decisions. Resource allocation (Subprogram 2) and bid decisions (Subprogram 6) are derived from decision rules or procedures. In the former case, net manhours available, as determined from the resource procurement policy functions, are allocated to contracts according to a procedure which tends to level schedule differences and profit margin differences among contracts. Specifically, number of hours is assigned according to schedule discrepancy and type of hours (regular time, overtime, or subcontracting) is assigned according to profit margin. The cheapest type of hours is assigned to contracts with the lowest profit margins.

Bid decisions are also developed by procedure. First that combination of contracts which will produce the best backlog loading relative to a growth objective over a specified planning horizon is selected and then bid prices for the selected contracts are developed based on the amount of backlog and the immediate history of award success.

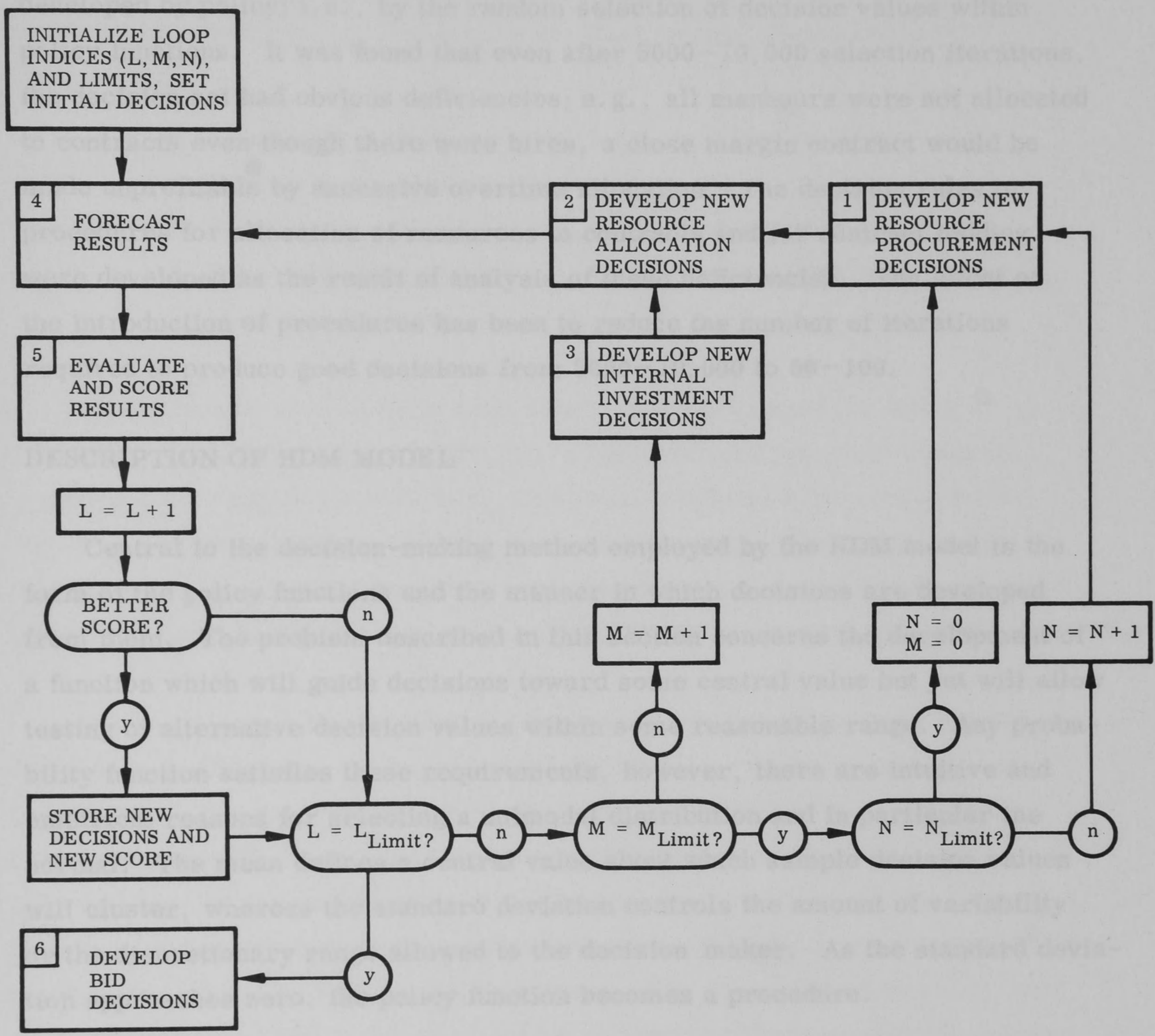


Fig. 5 Decision Development

Derivation of Procedures. In a preliminary model, all decisions were developed by policy; i.e., by the random selection of decision values within policy functions. It was found that even after 5000−10,000 selection iterations, the decision set had obvious deficiencies; e.g., all manhours were not allocated to contracts even though there were hires, a close margin contract would be made unprofitable by excessive overtime allocation. The decision rules or procedures for allocation of resources to contracts and for contract bidding were developed as the result of analysis of these deficiencies. The effect of the introduction of procedures has been to reduce the number of iterations required to produce good decisions from 5000−10,000 to 50−100.

DESCRIPTION OF HDM MODEL

Central to the decision-making method employed by the HDM model is the form of the policy functions and the manner in which decisions are developed from them. The problem described in this section concerns the development of a function which will guide decisions toward some central value but yet will allow testing of alternative decision values within some reasonable range. Any probability function satisfies these requirements, however, there are intuitive and empirical reasons for selecting a unimodal distribution and in particular the normal. The mean defines a central value about which sample decision values will cluster, whereas the standard deviation controls the amount of variability or the discretionary range allowed to the decision maker. As the standard deviation approaches zero, the policy function becomes a procedure.

In operation, a sample value is drawn from each distribution, each value representing a decision. These values, together with decision values derived from decision-rules or procedures, constitute a single tactical operating plan. The specific policy function parameter values for mean and standard deviation used were selected subjectively after reviewing the results of a variety of possible values during checkout of the HDM model.

Resource Procurement and Allocation Decisions (Subprograms 1 and 2). If demand for labor exactly balances the supply, it follows that no additional labor need by procured. If demand differs from supply, there are four alternatives:

- Change the size of the labor force by hiring or firing
- Relieve some of the demand with overtime
- Relieve some of the demand with subcontracting
- Allow schedule performance to adjust the difference between supply and demand

The procedure used by HDM first determines the demand for labor by calculating the number of productive hours required next period to complete contracts according to the schedule. This total is adjusted for expected efficiency to obtain the number of hours necessary to apply. The supply of labor is determined by adjusting the labor hours available last period by the expected labor turnover. Any difference must be supplied by the preceding four alternatives.

To determine a feasible solution, random values are drawn from four normal distributions with mean μ_i and standard deviation σ_i where σ and μ are parameters. The four values are normalized and multiplied by the difference between supply and demand to obtain the contribution of hours from each of the alternatives. At this point, there is a tentative determination of hires, fires, overtime, subcontracting, and schedule adjustment decisions; all but the last are explicit decisions required by ABES program. The hours represented by these decisions are allocated to contracts by the allocation procedure described above so as to equalize schedule differences and profit margin differences among contracts. Figure 6 is a flow chart of the resource procurement and allocation section of the HDM model. Subroutines ACALC and ASSIGN in Appendix C depict the specific program steps followed.

The results of this tentative set of decisions are forecast and measured against the objectives to develop an overall score or measure of effectiveness (MOE). The MOE is compared with the best previous MOE; if better, it is saved

PROCUREMENT POLICY FUNCTIONS

I	FUNCTION	MEAN	STD. DEV.
1	HIRES	μ_1	σ_1
2	FIRES	μ_2	σ_2
3	SUB/CTR	μ_3	σ_3
4	OVERTIME	μ_4	σ_4
5	SCHED. AHEAD	μ_5	σ_5
6	SCHED. BEHIND	μ_6	σ_6

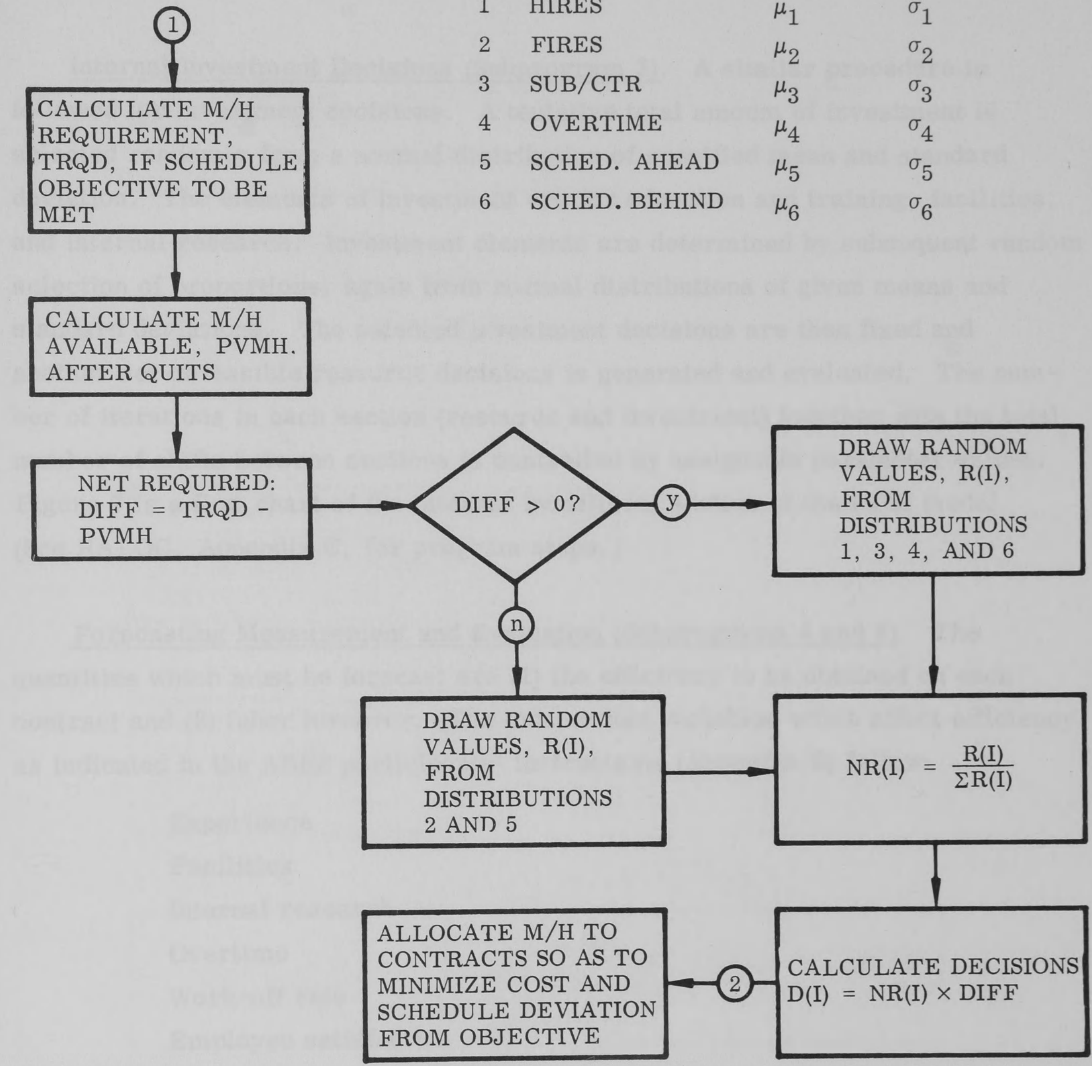


Fig. 6 Resource Procurement and Allocation Decisions (Subprograms 1 and 2)

together with the associated decisions; if worse, it is discarded and another set of decisions generated. A fixed number of iterations is performed. (See EVAL and SCORE, Appendix C for program steps.)

Internal Investment Decisions (Subprogram 3). A similar procedure is followed for investment decisions. A tentative total amount of investment is selected randomly from a normal distribution of specified mean and standard deviation. The elements of investment are for education and training, facilities, and internal research. Investment elements are determined by subsequent random selection of proportions, again from normal distributions of given means and standard deviations. The selected investment decisions are then fixed and another set of feasible resource decisions is generated and evaluated. The number of iterations in each section (resource and investment) together with the total number of shifts between sections is controlled by assignable parameter values. Figure 7 is a flow chart of the internal investment section of the HDM model. (See RALOC, Appendix C, for program steps.)

Forecasting Measurement and Evaluation (Subprograms 4 and 5). The quantities which must be forecast are (1) the efficiency to be obtained on each contract and (2) labor turnover. The independent variables which affect efficiency as indicated in the ABES participants' instructions (Appendix B) follow:

Experience
Facilities
Internal research
Overtime
Work-off rate
Employee satisfaction
Employee turnover
Learning curve
Education and training budget

For purposes of analysis these items are grouped as follows:

X_1 Investment – facilities, internal research, education and training budget

X_2 Over-application of labor – excess work-off rate

INTERNAL INVESTMENT POLICY FUNCTIONS

I	FUNCTION	MEAN	STD. DEV.
7	EDUCATION AND TRAINING	μ_7	σ_7
8	FACILITIES	μ_8	σ_8
9	INTERNAL RESEARCH	μ_9	σ_9
10	TOTAL INVESTMENT	μ_{10}	σ_{10}

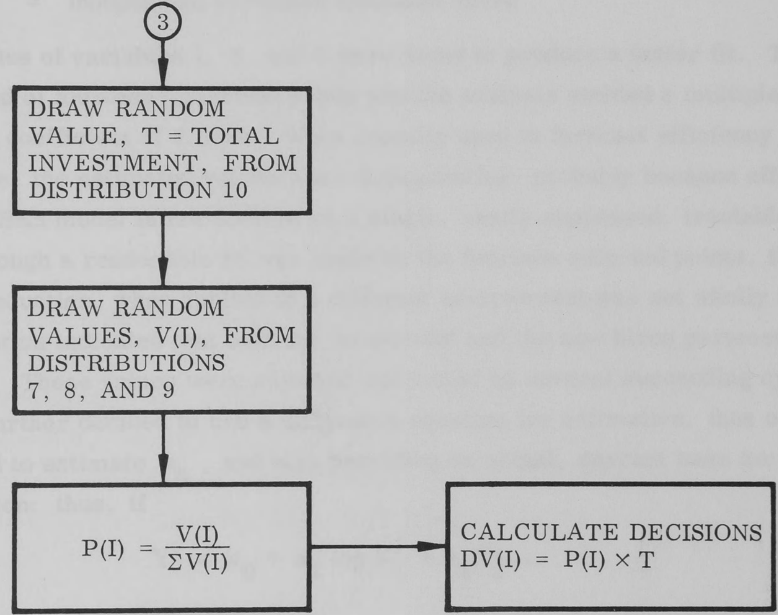


Fig. 7 Internal Investment Decisions (Subprogram 3)

X_3 Experience

X_4 New hires

X_5 Proportional completion — learning curve

Multiple regression analysis was performed using the BIMD 06 routine and an estimating equation of the form

$$Y = a + a_1 \log X_1 + a_2 X_2 + a_3 \log X_3 + a_4 X_4 + a_5 \log X_5$$

where

Y = efficiency, the dependent variable

a_i = estimated parameter values

X_i = independent variables indicated above

Log values of variables 1, 3, and 5 were found to produce a better fit. The data consisted of fourteen historical points and the analysis yielded a multiple correlation coefficient of 0.9998. When actually used to forecast efficiency in a test case, the estimated values were disappointing, probably because efficiency in the ABES model is not derived as a single, easily expressed, tractable function, and although a reasonable fit was made on the fourteen selected points, the estimating equation, when applied to a different environment was not wholly adequate. Observation indicated that both the investment and the new hires parameters were too low. These values were adjusted and tested on several succeeding cycles. It was further decided to use a difference equation for estimation, thus eliminating the need to estimate a_0 , and also providing an actual, current base for each estimation: thus, if

$$Y' = a_0 + a_1 \log X_1' + a_2 X_2' \cdots$$

and

$$Y'' = a_0 + a_1 \log X_1'' + a_2 X_2'' \cdots$$

then

$$Y'' - Y' = a_1(\log X_1'' - \log X_1') + a_2(X_2'' - X_2') \cdots$$

or

$$\Delta Y = a_1 \log(X_1'/X_1') + a_2 \Delta X_2 \ldots$$

See subroutine EFF in Appendix C for a program statement of this function.

Labor turnover, the second factor which must be forecast, was estimated in a similar manner from

$$Q = a_0 + a_1 X_1 + a_2 X_2 + \frac{a_3}{X_3}$$

where

$X_1 = \frac{\text{market wage paid}}{\text{average wage paid}}$

$X_2 = \frac{\text{highest wage paid last period}}{\text{average wage paid}}$

X_3 = investment per manhour

Q = percentage quits

a_i = estimated parameter values

Errors in estimation of labor turnover are costly only if high; i.e., if it is estimated that thirty workers will quit and actually only twenty quit, scheduling based on this estimate, will yield ten unscheduled workers. If the error is in the opposite direction, "emergency hires" are hired and the cost is far less. As a result the turnover estimating equation was purposely biased to adjust each estimate downward by p%. Thus the estimating equation has the form

$$\Delta Q = (1 - p)(a_1 \Delta X_1 + a_2 \Delta X_2 \; a_3/\Delta X_3)$$

See subroutine QTFCST in Appendix C for a program statment of this function.

The existence of an objective implies a means of forecasting, measuring, and evaluating results in terms of it. The results which are used to measure the effectiveness of decisions are as follows:

1. Expected indirect cost per hour applied
2. Expected schedule status
3. Expected labor efficiency

4. Expected direct cost per hour produced
5. Expected direct cost to sales ratio

Indirect cost per hour is measured as education and training cost plus internal research expense divided by total hours available. Schedule status is measured as

$$\frac{1}{\sum S_i}\left[\sum S_i\left\{N_i - \frac{R_i}{U_i}\right\}\right]$$

where

U = initial uniform hourly requirement per period
N = number of periods remaining until deadline
R = actual hours still to be completed
S = original size in hours
i = contract index

Thus the measure of schedule status is a size-weighted average of schedule deviation. A zero value indicates on-schedule; minus value, a behind-schedule status; a plus value, ahead-schedule status.

Direct labor cost per productive manhour is calculated by adjusting the observed value last period by expected changes in facilities, subcontracting, overtime, and wage rate. Direct cost to sales (bid price) is expected direct cost divided by expected sales.

Once forecast and measured as described, the result values are entered into objective functions in which case a specific goal value is compared with the measured results and a score, V, is calculated as follows:

$$V = \left(\frac{M - G}{T - G}\right)^w$$

where

V = score
M = measure of results
G = goal
T = limit value
w = weighting parameter

The measure of the results is first tested to assure that

$$t_1 \le M \le t_2$$

Failure at this point causes an additional set of feasible decisions to be generated and tested. If the above condition holds then the evaluating limit, T, is selected as follows:

$$T = \begin{cases} t_1 \; ; \; t_1 \le M \le G \\ t_2 \; ; \; G \le M \le t_2 \end{cases}$$

The MOE is calculated as the mean of the individual scores. The set of decisions producing the minimum MOE is selected and implemented. Figure 8 is a flow chart of the measurement and evaluation section of HDM. See Subroutine SCORE in Appendix C for a program statement of this procedure.

Bid Decisions (Subprogram 6). The bidding sector uses a different procedure than do the resource and investment sectors. In this case, experience in terms of award to bid rate and situation in terms of backlog are used to adjust the bid prices of those contracts selected for bid. Contracts are selected for bid on the basis of load desirability. The load desirability factor, K, for a given set of contracts is calculated as follows:

$$K = \sum_{i=1}^{L} (B_i - W_i)^2 / L$$

where

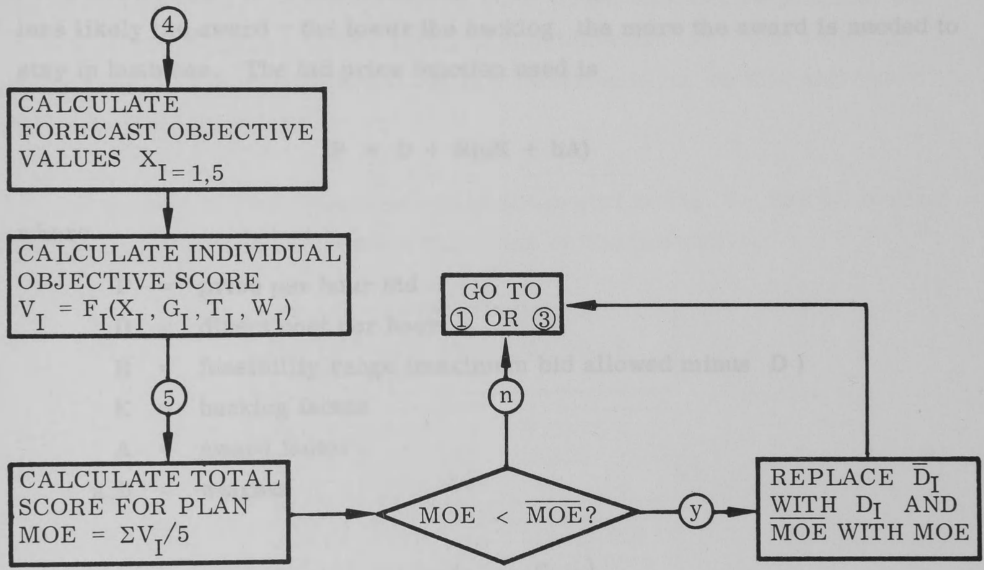
B_i = production requirement in period i if a particular contract set is awarded.

W_i = productive manhours available in period i if growth objective, g, is achieved: $(1 + g)\, W_{(i-1)}$

L = planning horizon

OBJECTIVE FUNCTIONS

I	FUNCTION	GOAL	LIMIT	WEIGHT
1	INDIRECT COST	G_1	T_1	W_1
2	SCHEDULE STATUS	G_2	T_2	W_2
3	EFFICIENCY	G_3	T_3	W_3
4	DIRECT COST	G_4	T_4	W_4
5	COST STATUS	G_5	T_5	W_5



$\overline{MOE}$ AND $\overline{D}_I$ REFER TO THE PREVIOUS BEST SCORE AND DECISIONS.

Fig. 8 Measurement and Evaluation (Subprograms 4 and 5)

The load desirability factor for a given set of contracts is thus the mean deviation between the labor demand of that set of contracts (plus those already awarded) and the desired supply of labor as specified by the growth objective divided by the planning horizon. All subsets are so evaluated (including the null subset) and that producing the minimum K is selected for bidding.

Bid price selection is done in the two steps: a feasible range is defined and then a bid price is selected within it. The upper and lower limits of the feasibility range are established by the maximum allowable bid and direct cost per hour. Within this range, it is desirable to bid as high as possible considering the likelihood of award and criticality of backlog; i.e., the higher the bid, the less likely the award – the lower the backlog, the more the award is needed to stay in business. The bid price function used is

$$P = D + R(aK + bA)$$

where

P = price per hour bid

D = direct cost per hour

R = feasibility range (maximum bid allowed minus D)

K = backlog factor

A = award factor

a, b = weights

$$K = \text{Min}\left([n/t_1]^c, 1\right)$$

where

n = number of periods of backlog already awarded

t_1 = objective for periods of backlog

c = control parameter

Similarly,

$$A = \mathrm{Min}\left([r/t_2]^d , 1\right)$$

where

r = ratio of contracts awarded to contracts bid

t_2 = objective value for this ratio

d = control parameter

Thus as backlog falls below objective or as award rate falls below objective, the bid price is reduced toward D . As backlog increases, indicating a secure position or as award rate increases, indicating a strong competitive position, bid price is adjusted upward toward the maximum allowable bid. The weighting parameters a and b control the relative influence of the backlog and award rate factors on bid price.

The procedure of bid development is illustrated in Fig. 9. See Subroutine DBID in Appendix C for a program statement of this procedure.

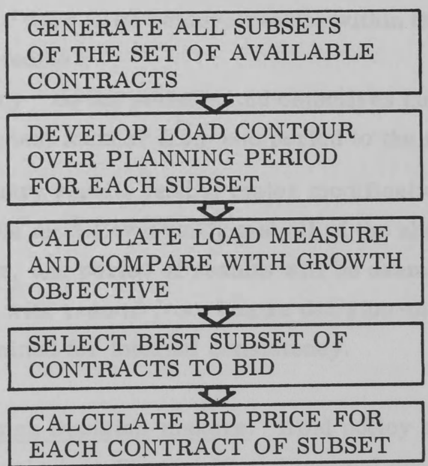


Fig. 9 Decision Development – Contract Selection and Bidding

In summary, the HDM model requires specification of a series of policies which guide and constrain decisions and a set of objectives against which forecast results are measured. The decision process involves the generation of successive complete sets of decisions or plans, the results of which are forecast and evaluated in terms of the defined objectives. Of all plans so generated, the best is retained and implemented. The policy functions take the form of constrained normal distributions, with specified means and standard deviations, from which sample values are drawn, each value representing a decision. These values, together with decision values derived from decision rules or procedures constitute an operating plan. The objective functions, against which the forecast results are evaluated, have a variety of forms which produce a score value for each result. The best plan is that which produces the minimum mean score.

TESTING THE HDM MODEL

The HDM model was tested for the following:

- Reasonableness – are the decisions reasonable in the sense that they could have been made by a cognizant human being?
- Adequacy – does HDM achieve results within the range of those achieved by human teams?
- Consistency – do the policies and objectives guide the decision-making in a consistent manner from one period to the next?

Although preliminary results lead to major modification of policy and objective functions, the HDM model eventually met all of the above criteria. To illustrate the test procedure, one period of results will be examined in some detail and will be compared with results from human decision-makers. Following this, HDM will be examined for internal consistency.

HDM vs. Human Decision-makers. HDM policy and objective functions were set at standard levels (see Chapter V) and tactical operating plans were selected based on 64 iterations of decision generation in research and development (R&D) and 32 iterations in production. In other words, 64 R&D plans and 32 production plans were evaluated in selecting a set of decisions for implementation. Table 1 summarizes the successive selection of plans and gives the value of the plan in terms of objectives. It will be recalled that a minimum score indicates minimum deviation from objective.

Table 1

EVALUATION AND SELECTION OF OPERATING PLANS

R&D			Production		
Iteration	Score	Improvement	Iteration	Score	Improvement
2	0.1188		2	0.0324	
6	0.0624	0.0564	4	0.0242	0.0082
20	0.0605	0.0019	7	0.0186	0.0056
24	0.0604	0.0001	9	0.0103	0.0083
26	0.0603	0.0001	11	0.0085	0.0018
44	0.0598	0.0005			
56	0.0595	0.0003			
59	0.0594	0.0001			

The decisions selected from R&D Cycle 59 of and Production Cycle 11 were then executed. In Table 2 the financial results of these decisions for Period 2 are compared with those made by a group of managers. This particular period was the first in which decisions are explicitly made in the exercise. It is evident that the HDM-operated company earned more on sales (6.8 vs. 5.3%) than the best of the manager teams. Direct profit as a percentage of sales is frequently used as a measure of operating efficiency. In this regard, the decision-maker likewise surpassed all other groups (20.7 vs. 19.4%). The difference in profit percentage, between the decision-maker and Company 1, is explained by the higher investment in education and training and in internal research by Company 1 and by certain economies of scale inherent in the ABES model. HDM had higher sales than Company 1 because of the large amount of subcontracting it did (15.5 vs. 13.4%). As a result various fixed operating costs were spread over a large base of sales resulting in lower proportionate administrative costs for HDM.

Table 2

FINANCIAL RESULTS[(a)]: HDM VS. FIVE HUMAN TEAMS

Item	HDM	Company				
		1	2	3	4	5
Sales	100.0	100.0	100.0	100.0	100.0	100.0
Direct Labor	40.1	43.0	50.7	45.9	47.0	51.9
Facilities	1.7	1.5	1.7	1.7	1.6	1.9
Subcontract	15.5	13.4	5.6	10.2	8.9	0.0
Other Direct	22.0	22.9	24.9	24.5	24.6	29.2
Operating Profit	20.7	19.4	17.1	17.7	17.9	19.0
Education and Training	0.7	1.4	0.6	0.5	0.6	0.5
Internal Research	0.3	0.4	0.0	1.0	0.8	0.4
Administration	4.3	4.8	5.4	5.4	5.5	5.6
Other Indirect	1.3	1.4	1.5	1.5	1.4	1.7
Income Taxes	7.3	5.9	5.0	4.8	5.0	5.6
Net Profit	6.8	5.5	4.6	4.5	4.6	5.2

(a)Results are expressed as percentages of sales.

The comparison just described was based on Period 2 results. It was desired to compare the results of HDM and human decision-makers over a longer period of operations. The objective variables used in this comparison were average cost to the customer (sales), and average direct cost of production. Because sales costs tend to vary inversely to competition whereas cost of production tends to vary inversely with internal efficiency, if HDM resulted in lower average cost (sales) to the customer, and also lower cost of production, then it had produced not only a more competitive environment, but also had resulted in more efficient operations.

Table 3 summarizes the results of 8 periods of results with human decision makers operating companies in the ABES environment (the duration of one Executive Decision Making Class) with a similar eight periods when companies were operated by HDM.

Table 3

SALES, COST, AND PROFIT PER PRODUCTIVE MANHOUR:
HDM VS. FIVE HUMAN TEAMS (8-PERIOD AVERAGES)

Item	HDM	Company					
		Avg.	1	2	3	4	5
R&D							
Sales	7.911	8.093	8.276	8.261	8.020	8.043	7.863
Direct Cost	7.139	7.360	7.577	7.501	7.303	7.325	7.096
Operating Profit	0.722	0.733	0.699	0.760	0.717	0.718	0.767
Production							
Sales	7.491	7.565	7.775	7.300	7.588	7.429	7.730
Direct Cost	5.690	6.104	6.145	6.193	6.203	6.052	5.927
Operating Profit	1.801	1.461	1.630	1.107	1.385	1.377	1.803

It can be seen that HDM not only bid lower than the average of the five companies, in both R&D and production, but that it had sufficiently lower direct costs of production to more than compensate for the reduced unit sales which resulted in greater average profit per hour. Furthermore, HDM performed better than or as well as even the best human team (Company 5). These results are typical of those observed throughout testing when comparing HDM to human decision-makers.

HDM – Internal Consistency. In addition to comparing the results of HDM with those of human decision-makers to examine qualities of reasonableness and adequacy, various tests were conducted on HDM to test for internal consistency. Because HDM is based on a sequence of generating plans, forecasting results, evaluating results in terms of objectives and selecting the best plan so generated, several conditions are important to the proper functioning of HDM:

- Forecasts should be consistent with results.

- Successively selected operating plans should be consistent with improved goal performance.
- Changes in policy patterns should produce different but rational results.

Agreement between forecast and actual results was tested by calculating mean and maximum difference for each of the objective values for several test runs. Table 4 illustrates this test.

Table 4

DIFFERENCE BETWEEN FORECAST AND ACTUAL VALUES OF OBJECTIVE VARIABLES

Variable	Mean Value		Difference	
	Forecast	Actual	Maximum	Average
Indirect Cost	0.579	0.550	0.070	0.029
Schedule	-0.120	-0.102	0.069	0.018
Efficiency	0.967	0.968	0.028	-0.001
Direct Cost	7.014	7.042	-0.084	-0.028
Cost Status	0.840	0.842	-0.011	-0.002

To summarize Table 3, the average difference between forecast and actual indirect cost was \$0.029 per manhour, schedule was 0.018 periods, efficiency was -0.1 percentage points, direct cost was -\$0.028, and cost status was -0.2 percentage points.

Table 5 shows three successive plans which were selected by HDM in one test run. The top section indicates the decisions which were generated; the lower portion contains the forecast results and the HDM score of those results. The difference between Plan 3 and Plan 1 in terms of decisions is that there are fewer hires, less subcontracting, less overtime, more planned schedule slippage, and more internal investment, particularly in education. The differences among forecast results indicates higher indirect cost, greater schedule slippage, higher efficiency, lower direct cost and better cost performance.

Table 5

DECISIONS AND EVALUATIONS FOR THREE SUCCESSIVE HDM PLANS

Variables	Goal	Plan 1		Plan 2		Plan 3	
		Fcst.	Score	Fcst.	Score	Fcst.	Score
Indirect Cost	0.500	0.577	0.015	0.574	0.014	0.698	0.102
Schedule	0.050	-0.170	0.154	-0.206	0.183	-0.213	0.190
Efficiency	0.995	0.952	0.013	0.995	0.009	0.964	0.002
Direct Cost	6.749	7.176	0.271	7.160	0.253	7.122	0.213
Cost Status	0.800	0.876	0.578	0.874	0.551	0.870	0.485
Average Score			0.206		0.202		0.198

Decisions	Plan 1	Plan 2	Plan 3
Hires	114.4	84.0	95.8
Subcontract	218.0	208.9	190.3
Overtime	11.5	1.1	0.2
Slip Schedule	116.7	147.1	153.2
Education	0.118	0.143	0.261
Facilities	0.118	0.143	0.261
Total Investment	0.140	0.146	0.286

In other words, HDM found it advantageous, in this instance, to trade increased indirect cost and poorer schedule performance for greater efficiency and lower direct cost. The trade was accomplished by reducing new hires, subcontracting and overtime, and by increasing internal investment and planned schedule slippage.

This examination is illustrative of hundreds of similar tests which were conducted on HDM plans. In each case changes in forecast were reconciled to changes in decisions before any particular HDM procedure was accepted.

The last test remains for Chapters V and VI in which a variety of policy patterns were examined in a factorial experiment.

Chapter V

THE EXPERIMENT

Thus far the ABES model, which describes an environment in which hypothetical aerospace companies compete, and the HDM model, which can make the decisions necessary to operate the companies, have been described. In this chapter, five strategic policies are formulated within HDM. An experiment was then conducted in which each policy combination controlled the operation of the ABES model over 15 periods each of which represents a quarter year. The results (measured as the mean value of the 15 periods) for the various strategic policy combinations are compared and evaluated by use of analysis of variance techniques.

In each 15-period sequence two companies compete: an experimental company (Company 1) and a control company (Company 2). It is necessary to include a control company because ABES is an interactive model, and consequently many of the results would be meaningless without a competitive element. The control company was operated by HDM at the low level for all policies. Figure 10 depicts results, in terms of sales and net profit, for both companies operating under identical policy conditions (low level). Over the 15 periods, mean values are as follows:

	Company 1	Company 2
Mean Sales	9380.6	9376.9
Mean Net Profit	431.2	442.6

STRATEGIC POLICIES TO BE EXAMINED

Previous discussion has centered on tactical policies, i.e., policies which define the decision space for a single class of decisions. It is more usual in a company to state what have been discussed as strategic policies or objectives.

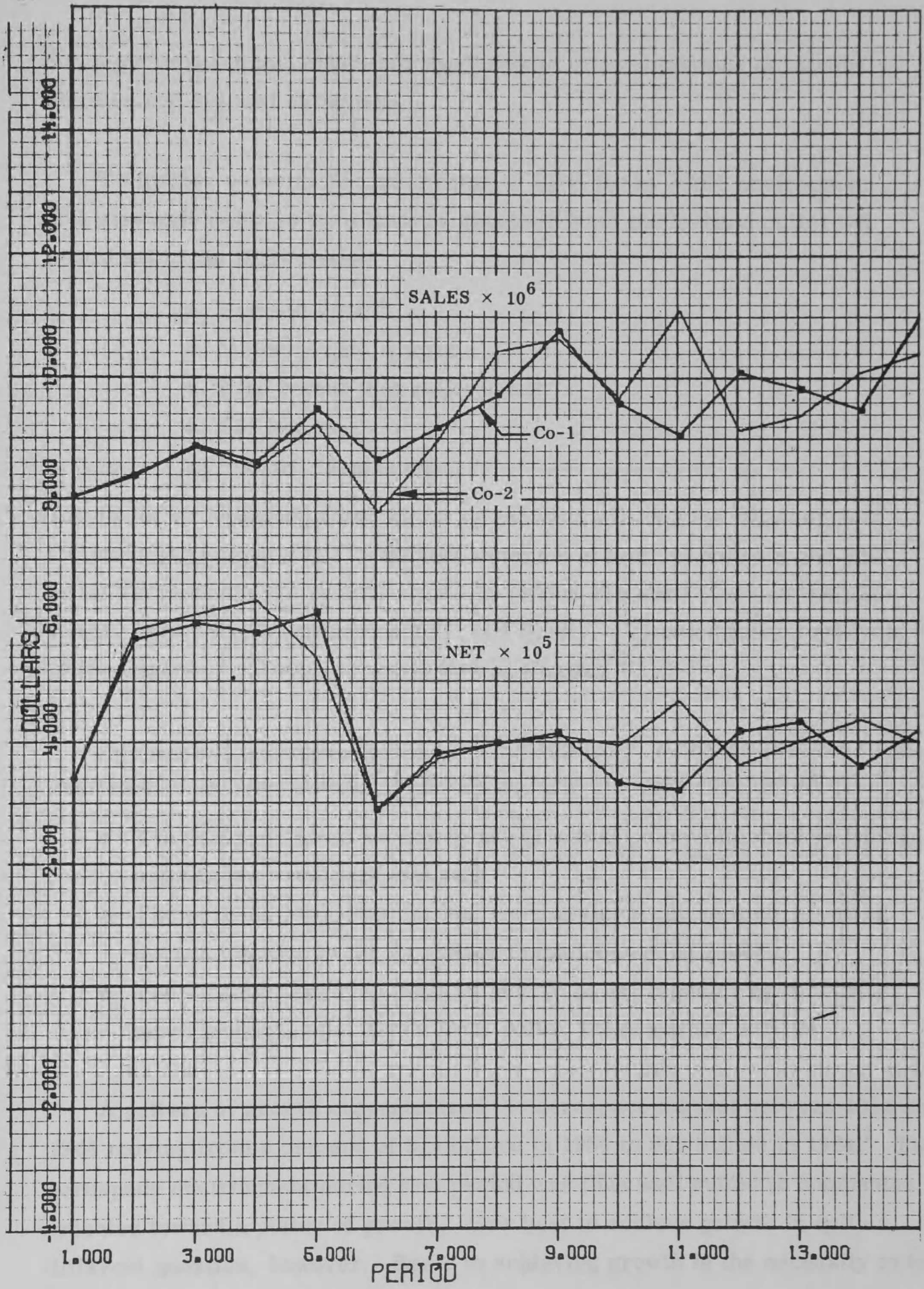


Fig. 10 Comparison of Sales and Net Profit: Standard

Strategic policies and objectives may consist of combinations of tactical policies and tactical objectives.

To further examine the functioning of HDM in the ABES environment, five strategic policies have been synthesized from the tactical policy set contained in the HDM model:

- Planned growth
- Maintain employment
- Hire rather than subcontract
- Bid lower
- Internal investment

The basis for selecting these strategic policies will be presented; each of the strategic policies will be defined in terms of tactical policies and will be illustrated with the results of one 15-period sequence in which the particular policy was introduced singly; and finally, a detailed formal analysis of the experimental results will follow in Chapter VI.

Selection of Strategic Policies. In selecting the strategic policies to be examined in the experiment, the following criteria were considered:

- The policies should be exemplary of actual policy alternatives which exist in the aerospace industry.
- The policies should be derived from decision patterns observed in manager teams in the Executive Decision-making course.
- The strategic policies must be able to be represented by or synthesized from the specific tactical-policy set contained in HDM.

A pattern of growth characterized the aerospace market between 1954 and 1964 moving from a demand of $12 billion in 1954 to $22 billion in 1964.[1] The aerospace environment during this period was thus well suited to companies oriented toward a policy of growth. How best to achieve growth is quite a different question, however. Basic to achieving growth is the necessity to bid

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[1]Miller, Thomas G. Jr., Strategies for Survival in the Aerospace Industry, Arthur D. Little, U.S.A. 1964, p. 15.

on increasing amounts of work. Beyond this, a diversity of policies exist in aerospace companies in terms of internally sponsored research, maintenance of labor force, pricing policies, and subcontracting policies. The strategic policies selected for experimental treatment represent some of the alternatives available to aerospace companies.

As might be expected, these same policies were frequently employed by managers in the Executive Decision-making course. Growth and market domination were the most frequently and consistently stated objectives. Most usually the goal was stated in terms of an annual percentage increase in either sales or personnel. Many of the successful companies also employed more or less explicit policies governing bid price, internal investment, employment, and subcontracting.

The final criterion for selecting the strategic policies to be examined in the experiment is a necessary one if these policies are to be precisely defined. Synthesis of the strategic policies and objectives is discussed in the following section.

The selection of these particular strategic policies is not meant to imply that they are the only such policies which could have been defined. They were selected, rather, to examine the phenomenon of corporate growth which has fascinated and baffled economists, executives, and investors for as long as business organizations have existed.[2]

SYNTHESIS OF STRATEGIC POLICIES

Three classes of tactical policies were described in the previous chapter:

- Workforce management and production scheduling (hiring, firing, overtime, subcontracting, and contract performance schedule)

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[2] Lovewell, Paul J., and Young, Robert B., "The Importance of Environment in Company Growth," presented at Financial Analysts Seminar, Beloit College, Beloit, Wisconsin, August 22–23, 1960.

- Internal investment (education and training expenditures, facilities management, and internally-sponsored research and development)
- Contract bidding (selection of contracts to be bid and bid price)

Each of the strategic policies will be described in terms of these tactical policies and will be illustrated with the results of one 15-period sequence in which the particular policy was introduced singly. A detailed, formal analysis of the results will follow in a later section.

Planned Growth. This policy is controlled by adjustment of a parameter which determines the work level objective for next period called the aspiration work-level factor (AWF). Because the set of contracts selected for bid is that combination producing a minimum deviation squared between the AWF and the total demand level of the contract set (summed over the number of periods in the planning horizon), if AWF is increased each period, a greater number of contracts are likely to be bid than if it is held constant. The model was tested with AWF at various levels between 1.00 and 1.10 and found to perform well with AWF = 1.047. With the planned growth policy present (high level), AWF is set to 1.047 representing an aspiration of 4.7% growth per period; with the planned growth policy absent (low level), AWF is set to unity. Figure 11 is a plot of sales and net profit of Company 1 operating with all policies at the low level (Co-1C) and Company 1 operating under a policy of planned growth (Co-1X). Means for sales and net profit over the 15 periods are as follows:

	Company 1X	Company 1C
Mean Sales	11787.6	9380.6
Mean Net Profit	518.8	431.2

A policy of planned growth, thus resulted in an average of 2407.0 more sales and 87.6 more profit than a non-growth policy.

Maintain Employment. This policy causes a company to base its AWF on the work force on hand as opposed to the pre-defined growth rate of 1.047 used in the previous case. Thus, if a company hires to meet a peak in demand (as

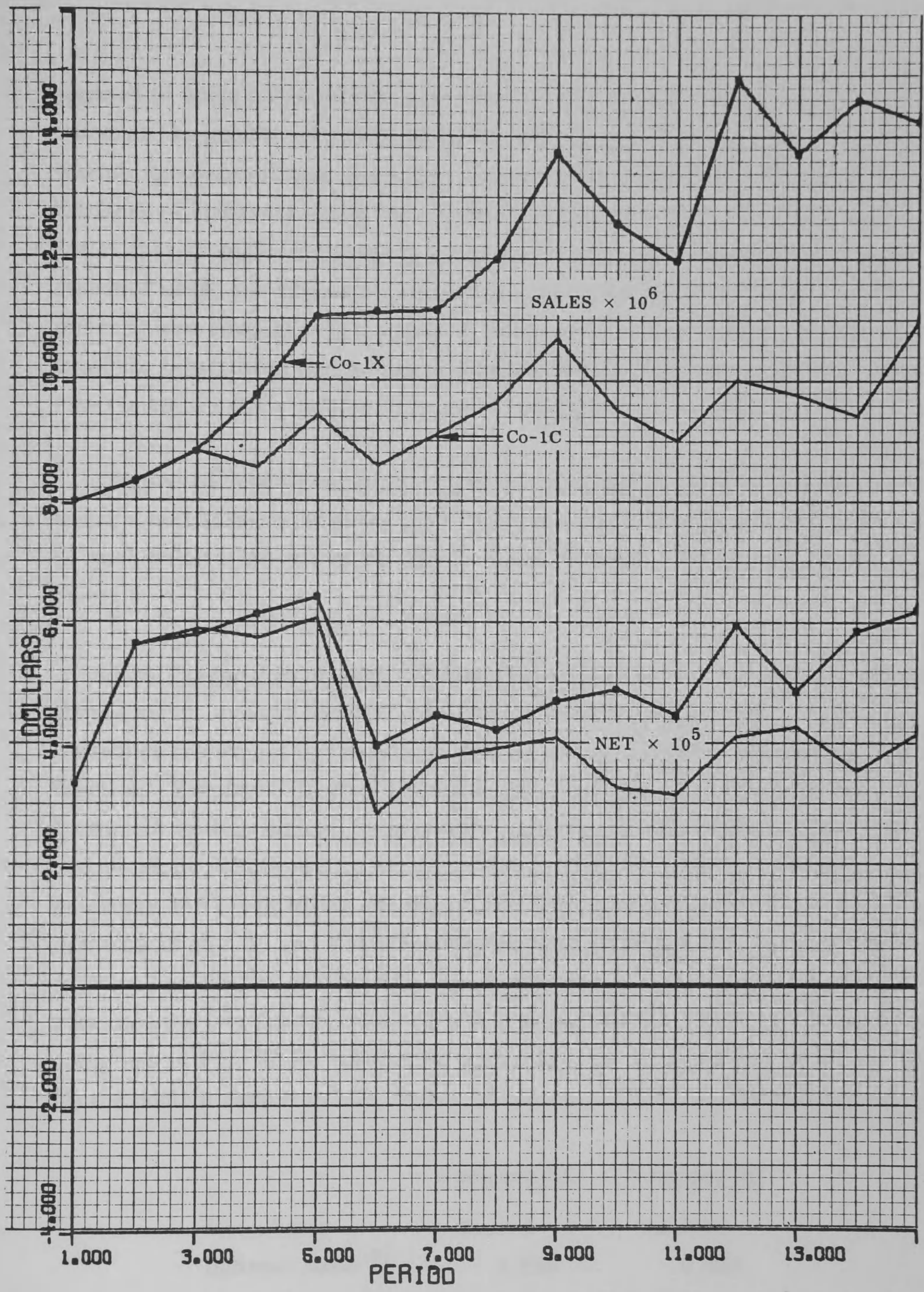

Fig. 11 Comparison of Sales and Net Profit: Planned-Growth Case

opposed to using subcontracting or overtime), this policy will cause it to increase the number of contracts bid so as to sustain the existing work force. It could be expected that this policy would result in lower layoffs and in higher numbers of contracts being bid. Because of the relatively low level of the policy that apportions demand between new hires and subcontracting, in the standard case, the maintain-employment policy can be expected to have little effect unless coupled with a policy of high hiring. At the control or standard level the labor force was assigned a weight of 0.0 in influencing AWF; in the experimental case a value of 0.5 was assigned to this weight.

Figure 12 depicts sales and net profit of Company 1 (Co-1X) operating under a maintain-employment policy compared with Company 1 (Co-1C) with no such policy. As can be observed, the results are identical for the two cases.

Hire Versus Subcontract. Demand peaks may be met with some combination of hires, subcontracting, overtime or schedule adjustment. This policy increases the weight on the hiring function at the expense of the subcontract function. Employed singly, it could be expected that this policy would increase firing, as well as hiring, in an environment of fluctuating work level. As a consequence of the vacillating labor force, indirect costs can be expected to be higher and profit lower. In the standard or control case the hire function has a mean of 0.10 and a standard deviation of 0.05 whereas the subcontract function has a mean of 0.60 with a standard deviation of 0.20. This policy reverses the two distributions. Plots of sales and net profit over 15 periods are given in Fig. 13 for (1) the experimental case of this policy (Co-1X), and (2) the control case (Co-1C). Mean values for various results are as follows:

	Company 1X	Company 1C
Mean Sales	9467.3	9380.6
Indirect Ratio[(a)]	0.069	0.054
Mean Net Profit	363.0	431.2
Mean Hires	0.071	0.040
Mean Layoffs	0.020	0

(a) Ratio of indirect expenses to sales.

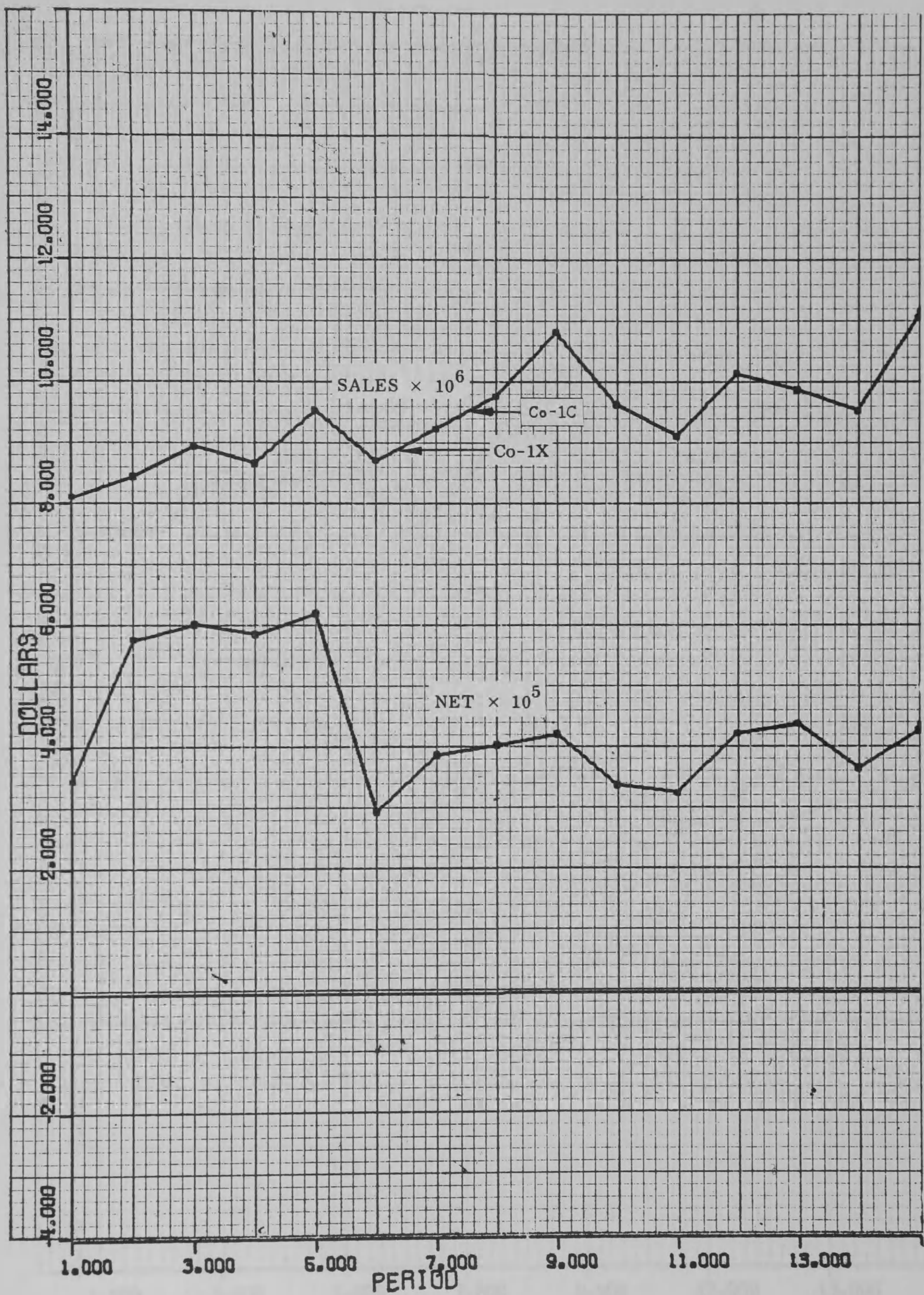

Fig. 12 Comparison of Sales and Net Profit: Maintain-Employment Case

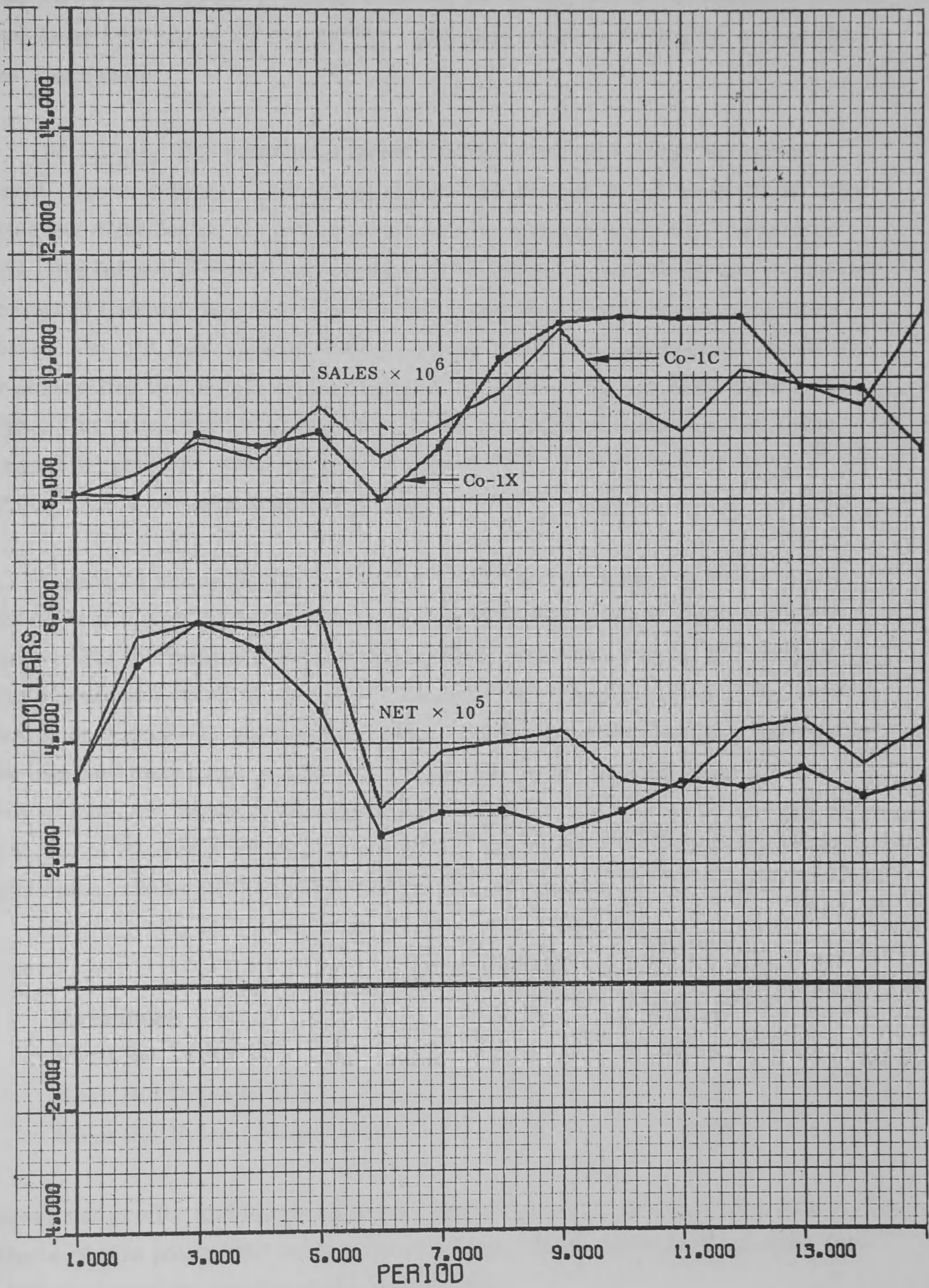

Fig. 13 Comparison of Sales and Net Profit: Hires vs. Subcontract

Thus this policy resulted in nearly double the hiring, and increased layoffs from zero to an average of 2% per period. Although sales were higher, net profit was decreased.

Bid Lower. Bid price is selected randomly within a range defined by direct cost as a lower limit and maximum allowed bid as an upper limit. The selection distribution is skewed upward (toward the upper limit) if previous bids have tended to result in awards and if backlog is sufficient; and is skewed downward (toward the lower limit) if the converse of these two propositions holds. The bid lower policy causes a lower bid for any given status condition by controlling the degree of skewness of the price selection distribution; the higher the value, the lower the bid. In the standard or control case, these control parameters were assigned a value of 0.2 whereas in the experimental case they were assigned a value of 0.4.

Figure 14 is a plot of sales and net profit for the experimental (Co-1X) and control (Co-1C) sequences with this policy implemented singly. This policy, like the maintain-employment policy, has little overall effect when implemented by itself at the value indicated. The reason is that in the experimental environment, the company which is satisfied with the status quo and is not imposed upon by an aggressive competitor finds survival easy and thus always remains highly biased toward the upper limit of the bidding range irrespective of the slight effect to the contrary imposed by the bid-lower policy parameter. Some of the results from this policy are illustrated below:

	Company 1X	Company 1C
Mean Sales	9196.0	9380.6
Mean Net Profit	427.8	431.2
Mean Bid Price (R&D)	8.35	8.37
Mean Bid Price (Production)	6.96	7.02

Sales, net profit, and bid price are slightly lower as a result of this policy. The effects of this policy will be seen more clearly in the later section which formally analyzes the results of the experiment.

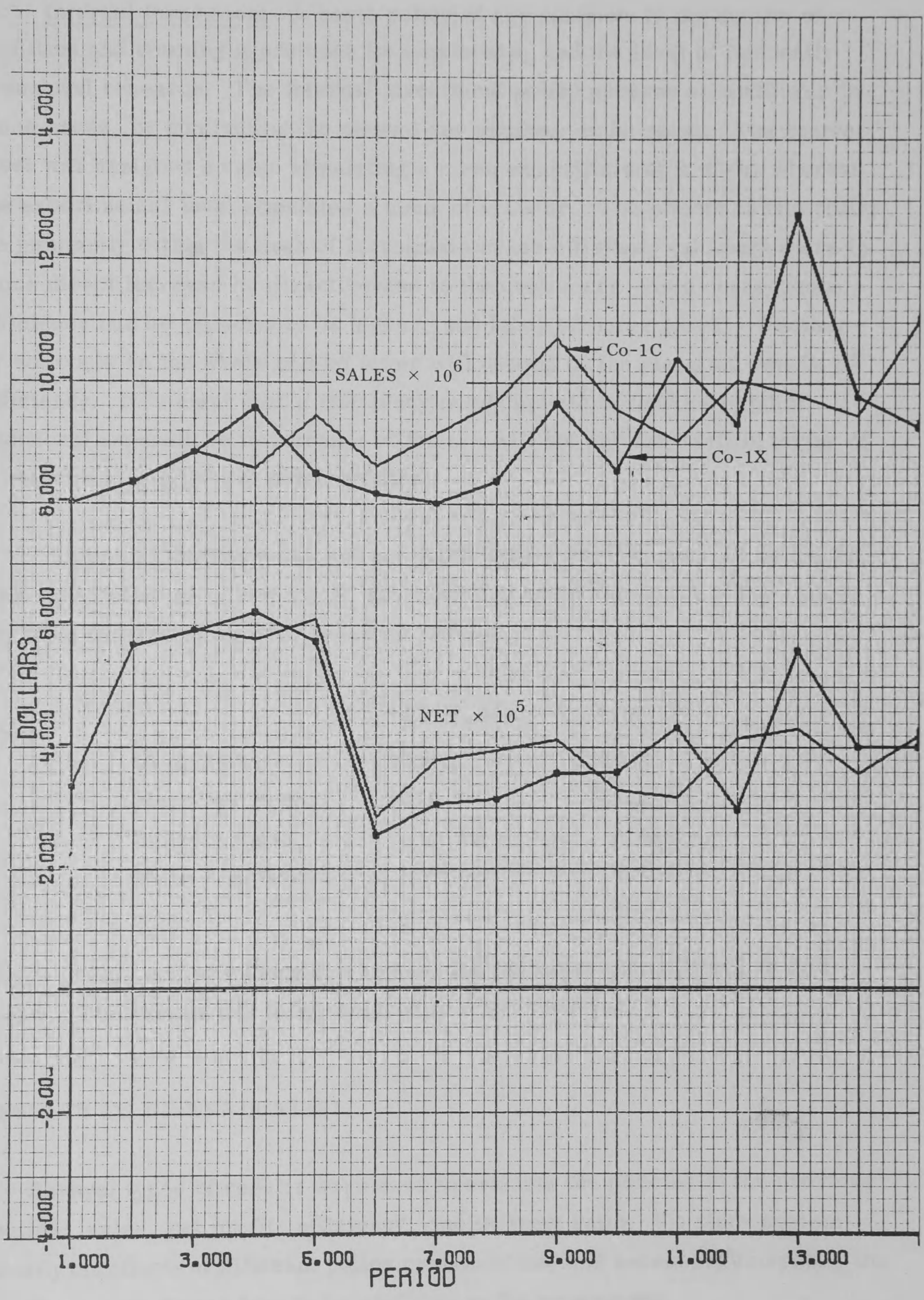

Fig. 14 Comparison of Sales and Net Profit: Bid Less Only Case

Internal Investment. A basic policy of any company is the quality of facilities and training it provides its employees, and the level of internally sponsored research. The internal investment policy governs expenditures in these areas, by controlling the amount per manhour to be spent. The control level was assigned a value stipulating a mean expenditure of 0.40/hr whereas the experimental level stipulates a mean of 0.50/hr. The effects of this policy lie primarily within the area of increased worker efficiency (although there is some direct increase in attractiveness to the customer). As a consequence, efficiency can be expected to be higher, and labor turnover lower. Whether or not costs on the whole will be lower will depend on the marginal benefit of efficiency. It is clear that if efficiency is asymptotic beyond some point, additional expenditure to increase efficiency will not pay for itself in terms of greater productivity and reduced costs.

Figure 15 depicts sales and net profit series for Company 1X operating under the policy and Company 1C not operating under the policy. The following table illustrates various observed results:

	Company 1X	Company 1C
Mean Sales	9714.6	9380.6
Mean Net Profit	470.6	431.2
Indirect Ratio	0.057	0.054
Mean Efficiency	0.967	0.936

Sales, profit, and efficiency are higher, for the experimental level of this policy. The results are fully analyzed in a later section.

RESULTS TO BE EVALUATED

Several types of results were used to evaluate the policies in the previous section: sales, net profit, efficiency, and indirect ratio. To study systematically the effects of different policy combinations it is necessary to specify the results or output variables to be analyzed in the experiment.

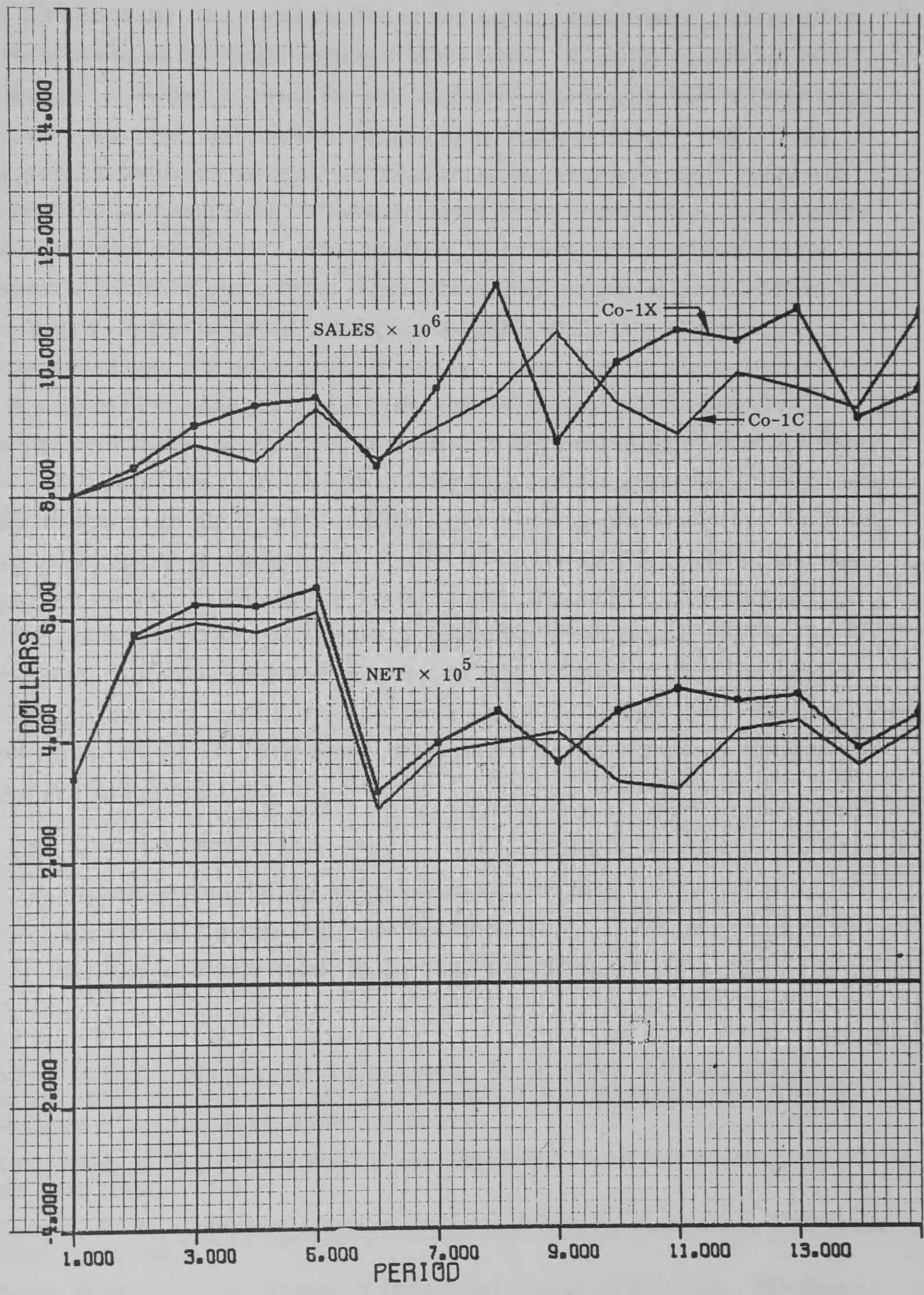

Fig. 15 Comparison of Sales and Net Profit: Internal-Investment Case

Traditionally, the maximization of net revenue (net profit) is assumed by economists to be the single objective of the firm.[3] Recently, questions have arisen as to whether profit is the sole objective of business, and whether maximization describes the process engaged in by business firms. Some of the suggested substitutes include maximization of long-run survival,[4] which may be restated as maximizing the security level of the organization, and maximization of sales subject to a profit constant.[5] An extensive discussion of the historical evolution and current status of this controversy is given by Cyert and March[6] in the course of developing the goals which they suggest, i.e., goals associated with production, inventory, sales, market share, and profit. It is suggested that the goals of a firm, and the appropriate measures of a firm's performance depend on both the type of business engaged in by the firm, and the point of view of the measurer. Appropriate measures for an aerospace R&D company are likely to differ from those of a soap manufacturer. Satisfactory performance is likely to differ in definition among stockholders, management, employees, customers, and government. To define a single measure is to beg realism; to define a universally applicable set of measures is to beg precision. Too frequently the measures as well as the problems are defined according to known methods for solution rather than the converse. The measures which will be used to evaluate the effects of policy changes in the experiment are as follows:

- Financial Results

  (1) Sales (total, R&D, and production)

  (2) Direct Expense (R&D and production)

  (3) Direct Profit (total, R&D, and Production)

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[3]Allen, R.G.D., Mathematical Economics, St. Martins, London, 1957, pp 608–617; Henderson, J.M., and Quandt, R.E., Microeconomic Theory, McGraw-Hill, New York, 1958, pp 42–75.

[4]Rothschild, K.W., "Price Theory and Oligopoly," Economic Journal, 42, 297–320 (1947).

[5]Baumol, W.J., Business Behavior, Value and Growth, Macmillan, New York, 1959, pp 45–53.

[6]Cyert, R.M. and J.G. March, A Behavioral Theory of the Firm, Prentice-Hall, Edgewood Cliffs, N.J., 1963, pp 4–26.

(4) Net Profit (total)
(5) Direct Profit/Sales (R&D and production)
(6) Net Profit/Sales (total)
(7) Net Profit/Investment (total)

- Performance Results (R&D and production)
  (1) Efficiency of labor
  (2) Customer price paid per hour
  (3) Schedule status

- Competitive Results (R&D and production)
  (1) Share of the market—sales
  (2) Share of the market—backlog
  (3) Average periods of backlog
  (4) Awards to bids ratio

The purpose of these measures is to allow detailed examination of the effects of the various policy changes to be implemented in the experiment.

Financial Results. These measures are derived according to accepted accounting principles (as indicated in Table A-1). Net profit (net earnings) is not developed for each plant (R&D and Production) because of the necessarily arbitrary manner in which indirect costs (administrative expense and interest expense) must be allocated. Direct profit is to be considered the same as operating profit, and represents sales less direct expenses (labor, direct overhead and facilities, and materials). Net profit results after deduction of indirect expenses and income taxes (at 52%) from total direct profit.

These measures, in summary form, are those most traditionally used for evaluating the operating performance of a company by management, stockholders, and the general public.

Performance Results. In the aerospace business the customer for virtually the entire output of the industry is the federal government. In such a monopsonistic environment, knowledge and evaluation of the performance variables which are in the customer's interest are important to effective company mangement, as well as being essential to effective industry management. The measures included in performance results, were selected to provide the basis for evaluating various policy combinations from the point of view of both the customer and internal management control.

Efficiency, the first performance measure considered, measures the average productivity of labor over all contracts worked during the 15-period sequences. In general, higher efficiency leads to lower direct costs per standard hour.

CPFF contracting gives the customer a direct interest in the costs of his suppliers, and policies which affect them. Price to the customer measures the amount the government, on the average, has to pay per standard hour of performance. In cost plus fixed fee contracts (R&D plant in the case of ABES), this measure is indicative of the producer's cost; in fixed-price contracts (Production plant in the case of ABES), this measure indicates the degree of competition in the industry.

Schedule performance measures the average schedule condition of all contracts over the 15-period sequences. Ability to perform consistently on or ahead of schedule is a significant factor in deciding awards. Recently in the aerospace industry, schedule has become an element of award or penalty in incentive-fee contracts.

Competitive Results. Besides the measures of absolute status, it is necessary for mangement to evaluate its position relative to that of the industry. These measures have been selected to provide a comparative basis for performance evaluation.

Market share measures the average proportion of (1) sales and (2) backlog for Company 1 to total sales and backlog in the industry. Average backlog is the ratio of backlog (in standard hours) to labor force (in standard hours).

It, in effect, measures the number of periods the company can remain in business with the present labor force and backlog.

The final item of this set of measures is award ratio, which is defined as the ratio of awards to bids. Award ratio is a major indicator of a company's attractiveness to the customer. A highly attractive company is able to bid higher, schedule incoming work more smoothly, and endure economic recession longer than an unattractive company.

THE EXPERIMENTAL DESIGN

The experimental factors consist of the five policies thus far described:

- Planned growth
- Maintain employment
- Hire rather than subcontract
- Bid lower
- Internal investment

Three categories of results have also been described:

- Financial results
- Performance results
- Competitive results

An experimental study of the changes in results attributable to changes in policies will now be described. A useful methodology for such a study is the factorial experimental design. The input variables (in this case the policies) are known as factors, the output variables (in this case the results) are known as effects. The factorial experiment defines a procedure for systematically varying the factors (policies) to allow inferences to be drawn about the influence of the factors, separately and in combination, on the effects (results).

Each factor is specified at two levels: a control or normal level and an experimental level. With five factors, 32 experimental sequences are required to test all combinations of all factors ($2^5 = 32$). This is termed a full replicate of a factorial design.

If the results attributable to some of the factor combinations can, a priori, be deemed negligible, a smaller number of experimental sequences is required. Such a design is known as a fractional factorial design. It was decided to estimate the five main effects (those effects resulting from each factor acting in isolation) and the ten first-order interactions (those effects resulting from any two factors acting in combination). As a result the effects attributable to the interaction of three or more factors, if any exist, will be confounded with the main effects and first-order interactions.

Imposition of the foregoing limitations on the analysis of the results allows a reduction in the total number of experimental sequences from 32 to 16. This design is termed a 1/2 fractional replicate of a 2^5 factorial design. Assumption that experimental error terms are independently and normally distributed with mean 0 and variance σ^2 is necessary to allow the significance of the effects to be tested.

The notation used in describing the experiment follows that suggested by Davies.[7] To delineate the factor combinations in an experiment, the presence of a small letter (a, b, c, d, e because this experiment deals with five factors) indicates the presence of the factor at the high or experimental level, whereas its absence indicates the factor is included at the low or control level. Treatment combination acde, for example, indicates factors a, c, d, and e are present at experimental levels whereas factor b is included at its control level. The symbol (1) indicates all factors at control levels. Capital letters will be used in a similar manner to refer to the effects; e.g., AC is an effect resulting from the interaction of factors a and c.

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[7] Davies, O. L., (ed.), The Design and Analysis of Industrial Experiments, Hafner Publishing Co., New York, 1954.

The particular design employed is given by Davies, and is as follows:

Number	Treatment Combination	Number	Treatment Combination
1	(1)	9	de
2	ae	10	ad
3	be	11	bd
4	ab	12	abde
5	ce	13	cd
6	ac	14	acde
7	bc	15	bcde
8	abce	16	abcd

From the 16 treatment combinations there are 16 sets of responses, one set for each treatment. The consequent 16 degrees of freedom are allocated as follows:

	Degrees of Freedom
Estimation of Mean	1
Estimation of Main Effects	5
Estimation of First-Order Interactions	6
Estimation of Error	4
	16

The responses are analyzed utilizing standard techniques of analysis of variance in which the total sum of squares for the experiment is assigned among the various effects.[8] An estimate of experimental error variance, σ^2, was made

[8]The procedure is discussed in detail in Davies, ibid, pp. 263−271; R. L. Anderson and T. A. Bancroft, Statistical Theory in Research, McGraw-Hill Book Co., Inc., New York, 1952, pp. 267−287; W. G. Cochran and G. M Cox, Experimental Designs, John Wiley & Sons, New York, 1950, pp. 39−85. The analysis of variance calculation was carried out using a IBM 7090 FORTRAN computer program written by G. K. Hutchinson which was modified to allow error variance estimation utilizing a selected combination of effect mean squares.

by combining four interaction mean squares deemed to have non-existent or negligible effects in a manner suggested by Davies.[9]

The statistical significance of the effects was tested using an F-ratio test.

An experiment consisting of 16 individual sequences was conducted, and the main and first-order interaction effects of the five policy factors were examined. The design followed as a 1/2 replicate of a 2^5 fractional factorial design with subsequent analysis of variance. The results are discussed in the next chapter.

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[9] Davies, O. L., op cit., p. 287.

Chapter VI

ANALYSIS OF EXPERIMENTAL RESULTS

The chapter discusses the results of the experiment described in Chapter V. Each of the 16 experimental sequences consisted of 15 periods of operation of Company 1 with some given combination of five policies, in competition with Company 2, which always was operated with all policies at the control level. Means and standard deviations for each 15-period sequence were calculated for a variety of output or results variables which were classified into three categories:

- Financial effects
- Performance effects
- Competitive effects

In this chapter the average behavior of Company 1 over 16 experimental sequences will be characterized and effects which can be attributed to the policy changes accomplished during the course of the experiment will be examined.

FINANCIAL EFFECTS

Table 6 is an abbreviated financial statement showing the average values for Company 1 over the entire experiment of 16 sequences.

Table 6

AVERAGE FINANCIAL STATUS
IN THOUSANDS OF DOLLARS

	Total	%	R&D	%	Production	%
(1) Sales	11,104.4	100.0	5,840.9	100.0	5,263.5	100.0
(2) Direct Expenses	9,466.5	85.3	5,275.0	90.3	4,191.5	79.6
(3) Direct Profit	1,637.9	14.7	565.8	9.7	1,072.0	20.4
(4) Net Profit	450.3	4.1				

It can be seen that whereas R & D contributes more heavily to sales (0.522 vs. 0.478), production contributes more heavily to profit (direct: 0.654 vs. 0.346). In aerospace, R & D is often undertaken not as an end in itself but rather for the production work expected as follow-on. As a result, it would not be feasible to trade off R & D in favor of more lucrative production contracts.

Variability in the financial series (as measured by standard deviation) was as follows:

	Total	%	R&D	%	Production	%
Sales	1,252.8	10.1	825.8	14.2	486.1	9.2
Direct Profit	148.8	9.1	77.8	13.7	80.5	7.5
Net Profit	39.8	8.8				

On the average, R&D sales and direct profit were more variable than production sales.

Total Company. Table 7 summarizes the financial effects of the different policy combinations for the Company 1 as a whole. It can be seen that Policies A and C significantly affect all the financial measures presented in Table 7. These effects can be summarized as follows:

Consequence	Sales	Direct Profit	Net Profit	Return on Sales	Return on Investment
Highly favorable	A, C	A, C	A		A
Somewhat favorable	B	E	B, E		
Somewhat adverse			AC	A	
Highly Adverse			C	C	C

Although Policies A and C are both highly favorable to sales and direct profit, the high indirect expense associated with C has a highly unfavorable effect on net profit. Policy A somewhat reduces return on sales but significantly increases return on investment.

Table 7

FINANCIAL EFFECTS – TOTAL COMPANY

(Dollars in Thousands)

Description	Effect	Sales (1)	Profit Direct (3)	Profit Net (4)	Net Profit as a Percentage of Sales (6)	Net Profit as a Percentage of Investment (7)
Mean	x̄	11,104.4	1,637.9	450.3	4.210	5.240
Standard Deviation	σ	1,252.8	148.8	39.8	0.410	0.300
Main Effects						
Planned Growth	A	1,970.1!	201.7!	41.5!	-0.263*	0.300!
Maintain Employment	B	607.0*	86.0*	22.0*	-0.013•	0.175?
Hire vs. Subcontract	C	1,073.7!	145.7!	-45.1!	-0.738!	-0.325!
Bid Less	D	-113.3	-31.6•	-15.7	-0.063	0.125
Internal Investment	E	211.0	77.8?	21.6*	0.113?	0.150?
First-Order Interactions						
Planned Growth and						
Maintain Employment	AB	-428.7?	-37.2	-0.3	0.113?	
Hire vs. Subcontract	AC	-432.1?	-54.0	-25.7*	-0.013•	-0.200*
Bid Less	AD	292.1	46.2•	15.2•	0.013	0.100
Internal Investment	AE	-288.1•	-49.5	-13.0•	-0.013•	-0.125
Maintain Employment and						
Hire vs. Subcontract	BC	290.8	12.8	-4.1	-0.113?	-0.025•
Bid Less	BD	183.3•	22.0•	1.6•	-0.038	0.025•
Internal Investment	BE	124.0•	6.0	2.0	0.013•	— •
Hire vs. Subcontract and						
Bid Less	CD	31.2•	-7.5•	-3.6•	-0.063	-0.025•
Internal Investment	CE	215.0	43.2	16.4	0.063	0.150?
Bid Less and						
Internal Investment	DE	313.7	27.9	-2.4	-0.113	

! Highly significant (P < 0.1%)
* Probably significant (0.1% < P < 5%)
? Possibly significant (5% < P < 10%)
• Mean squares used for error estimate

These effects can be explained in terms of the ABES model. Policy A implies growth through subcontracting, as opposed to hiring. Because the bid levels were considerably higher than the subcontract rates, profit can be made on subcontracting. Growth through hiring implies a commensurate buildup of facilities, education and other indirect expenses. As a result, although direct profit was increased, net profit suffered from this policy. Policy B increased sales and direct profit in proportion; Policy E increased efficiency more than sufficiently to offset its cost.

Because the company consists of two sectors, R&D and production, it is necessary to explore the policy effects within each sector to understand the effects on the company as a whole.

Research and Development. Table 8 summarizes the financial effects of the different policy combinations for the R&D sector of the company. It should be recalled that within the ABES model, all R&D contracts are of the CPFF or cost reimbursement type.

It is apparent that Policies A and C most significantly affect the financial status of the R&D sector of the company. Both policies increase sales, direct expenses, and direct profit but reduce the direct profit to sales ratio, Policy C causing a greater decrease in this ratio than Policy A. Policy B has questionable effect but if it exists is favorable both in direct profit and in direct profit ratio.

These effects can be summarized as follows:

Consequence	Sales	Direct Expense	Direct Profit	Profit/Sales
Highly favorable	A, C		A	
Somewhat favorable			C	
Somewhat adverse				A
Highly adverse		A, C		C

A policy of hiring to work off a fluctuating work load leads to inefficiency because new hires, in the ABES model, tend to be less efficient on the average

Table 8

FINANCIAL EFFECTS – R & D
(Dollars in Thousands)

Description	Effect	Sales (1)	Direct Expense (2)	Direct Profit (3)	Profit/Sales (%) (5)
Mean	x̄	5840.9	5275.0	565.8	0.0931
Standard Deviation	σ	825.8	748.0	77.8	0.0007
Main Effects					
Planned Growth	A	1158.2 !	1048.8 !	109.4 !	-0.05*
Maintain Employment	B	394.2 ?	354.2 ?	39.9 ?	0.03 ?
Hire vs. Subcontract	C	770.7 !	702.0 !	68.7*	-0.10 !
Bid Less	D●	-72.7	-65.0	-7.7	-0.01
Internal Investment	E	243.0	221.0	22.0	-0.03
First-Order Interactions					
Planned Growth and					
Maintain Employment	AB	-344.1 ?	-311.1 ?	-33.0 ?	
Hire vs. Subcontract	AC	-211.9	-188.6	-23.3	-0.04*
Bid Less	AD●	223.6	200.6	23.0	0.02
Internal Investment	AE	-132.4	-121.2	-11.2	0.03 ?
Maintain Employment and					
Hire vs. Subcontract	BC	397.6 ?	360.2 ?	37.4 ?	-0.02
Bid Less	BD●	184.4	166.5	18.0	
Internal Investment	BE●	37.9	34.3	3.6	
Hire vs. Subcontract and					
Bid Less	CD	183.6	165.4	18.2	0.01
Internal Investment	CE	75.8	70.2	5.6	-0.03
Bid Less and					
Internal Investment	DE	329.7 ?	297.8 ?	32.0	

! Highly significant (P < 0.1%)
* Probably significant (0.1% < P < 5%)
? Possibly significant (5% < P < 10%)
● Mean squares used for error estimate

than the existing labor force. This reduction in efficiency directly affects the direct profit ratio by increasing direct expenses in greater proportion than sales. Subcontracting is slightly more expensive, apparently, than work by the existing labor force, but somewhat less espensive than new hires.

It seems reasonable for Policy B to have the favorable effect observed in Table 8 because this policy would tend to increase workload according to the availability of current work force while still working off peaks in demand with subcontracting.

Production. Table 9 summarizes the financial effects of the different policy combinations for the production sector of the company. It should be recalled that within the ABES model, all such contracts are of the fixed price type.

As was the case in R&D, Policies A and C have highly significant effects on sales, direct expense, and direct profit. In this case, however, Policy C has, at worst, no effect on the direct profit to sales ratio. It can be seen also that Policy B probably affects sales and direct expense, and possibly direct profit. In addition there is a highly significant effect on the direct profit to sales ratio by Policy E. An interesting interaction between Policies A and C occurs which reduces sales and also direct expense. These effects can be summarized as follows:

Consequence	Sales	Direct Expense	Direct Profit	Profit/Sales
Highly favorable	A, C		A	E
Somewhat favorable	B	AC	C, E	
Somewhat Adverse	AC	B		
Highly adverse		A, C		A

Although a policy of growth is favorable to expansion of sales and direct profit, it increases direct expense disproportionately. Subcontracting is apparently more expensive, even for working off demand peaks, than is new hiring (Policy C) which does not adversely affect the direct profit to sales ratio while at the same time increases direct profit. (Considering, however, that Policy C increased indirect expenses by 239.6 of which 95.8 is attributable to production,

Table 9

FINANCIAL EFFECTS – PRODUCTION
(Dollars in Thousands)

Description	Effect	Sales (1)	Direct Expense (2)	Direct Profit (3)	Profit/Sales (%) (5)
Mean	$\bar{x}$	5263.5	4191.5	1072.0	0.2042
Standard Deviation	σ	486.1	419.2	80.5	0.0097
Main Effects					
Planned Growth	A	811.9 !	719.6 !	92.3 !	-1.38 !
Maintain Employment	B	212.9*	166.8*	46.0 ?	0.01
Hire vs. Subcontract	C	303.0 !	225.0 !	77.0*	0.22
Bid Less	D ●	-40.3	-16.8	-23.9	-0.29
Internal Investment	E	-31.6	-87.4	55.8*	1.17 !
First-Order Interactions					
Planned Growth and					
Maintain Employment	AB	-84.6	-80.4	-4.2	0.25 ?
Hire vs. Subcontract	AC	-220.2*	-189.5	30.7	0.30 ?
Bid Less	AD ●	68.5	45.4	23.2	0.18
Internal Investment	AE	-155.6 ?	-117.4 ?	-38.2 ?	-0.21
Maintain Employment and					
Hire vs. Subcontract	BC	-106.8	-82.2	-24.6	-0.03
Bid Less	BD ●	-1.1	-5.1	4.0	0.05
Internal Investment	BE ●	86.2	83.0	3.2	-0.25
Hire vs. Subcontract and					
Bid Less	CD	-152.4 ?	-126.7 ?	-75.7	0.07
Internal Investment	CE	139.2 ?	101.6	37.6 ?	0.15
Bid Less and					
Internal Investment	DE	-16.0	-12.0	-4.0	0.02

! Highly significant ($P < 0.1\%$)
* Probably significant ($0.1\% < P < 5\%$)
? Possibly significant ($5\% < P < 10\%$)
● Mean squares used for error estimate

whereas the contribution to direct profit from Policy C was only 77.0, the final effect on net profit was probably unfavorable.)

PERFORMANCE EFFECTS

Performance measures were listed and discussed in the preceeding chapter.

Research and Development. Table 10 summarizes the performance effects of the different policy combinations for the R&D sector of the company. It can be seen that Policy A is unfavorable to schedule and to customer price paid per hour, whereas Policy C reduces efficiency and increases price paid per hour, but improves schedule. Policy E, consistent with previous observations, improves efficiency, reduces price paid per hour and perhaps improves schedule performance. The only noticeable interaction is one between A and C which reduces customer price paid per hour.

These effects can be summarized as follows:

Consequence	Efficiency	Price Paid	Schedule
Highly favorable	E	C	
Somewhat favorable		E, AC	C
Somewhat adverse	C		
Highly adverse		A	A

The efficiency effects and corresponding changes in cost per hour to the customer are understandable in light of previous discussion. The schedule effects are somewhat subtler since there is no policy which directly affects schedule performance. Why then should a policy of growth adversely affect and a policy of hiring favorably affect schedule performance? The reason lies in the mechanism of the heuristic decision making program (HDM). It will be recalled that if there is an excess demand for labor (a peak), four alternatives exist: hire, subcontract, work overtime, and slip schedule. Random decision

Table 10

PERFORMANCE EFFECTS – R & D

Description	Effect	Efficiency of Labor (%) (1)	Customer Price Paid per hour (2)	Schedule Periods Ahead (+) or Behind (-) (3)
Mean	$\bar{x}$	90.57	7.916	-0.090
Standard Deviation	σ	0.95	0.120	0.040
<u>Main Effects</u>				
Planned Growth	A	-0.54	0.136 !	-0.049 !
Maintain Employment	B	-0.19	0.035 ?	-0.007●
Hire vs. Subcontract	C	-0.81*	-0.159 !	0.042*
Bid Less	D	0.04●	0.010●	0.001●
Internal Investment	E	1.46 !	-0.067*	0.023
<u>First-Order Interactions</u>				
Planned Growth and				
Maintain Employment	AB	-0.11	-0.016	0.004
Hire vs. Subcontract	AC	0.06	-0.061*	0.018
Bid Less	AD	-0.09●	0.020●	0.008●
Internal Investment	AE	0.14	-0.013●	0.003●
Maintain Employment and				
Hire vs. Subcontract	BC	-0.65 ?	0.043 ?	-0.018
Bid Less	BD	-0.09●	-0.007●	0.014
Internal Investment	BE	-0.11	0.033	-0.013
Hire vs. Subcontract and				
Bid Less	CD	-0.01●	0.030	0.007
Internal Investment	CE	0.06	0.003	-0.017
Bid Less and				
Internal Investment	DE	-0.19	0.011	0.005

! Highly significant (P < 0.1%)
* Probably significant (0.1% < P < 5%)
? Possibly significant (5% < P < 10%)
● Mean squares used for error estimate

sets are generated from among these alternatives by the policy functions. Each set satisfies the peak demand, but with a different mix of the four alternatives (although the mix is roughly guided by the means of the policy functions). The results of each set are forecast by the forecasting section of the program and are evaluated within the evaluation section. The best set is then selected. As a result, in the case of a growth policy (Policy A) in which costs are already strained, schedule is traded for the more costly alternatives to satisfy peaks. This also explains why mean R&D schedule is - 0.09 periods. Because of the lower profitability in R&D, schedule slippage has a greater relative attraction than in production where profit margins are wide. Likewise in the case of Policy C, there tended to be a surplus of labor on schedule dips. The alternatives for a dip in demand are (1) layoff personnel or (2) work ahead on schedule. The HDM made the tradeoff in favor of working ahead on schedule as opposed to layoffs.

Production. Table 11 summarizes the performance effects for the production sector of the company. Policies C and E and probably Policies A and B significantly affect efficiency in production: A and C adversely, and B and E favorably. There is, however, no consequent reduction in customer price paid per hour because of the fixed price (as opposed to CPFF for R&D) nature of production contracts. The only policy which definitely reduces price paid per hour is D, bid lower. Schedule is favorably affected by Policy C.

These effects can be summarized as follows:

Consequence	Efficiency	Price Paid	Schedule
Highly favorable	E		C
Somewhat favorable	B		
Somewhat adverse	A		
Highly adverse	C	D	

Efficiency of the labor force can be better maintained in an expanding market by selective hiring to meet peak demands and then bidding contracts to sustain employment (Policy B), than by a rapid, planned increase in backlog and sales (Policy A). Internal investment (Policy E) is a most effective way of improving efficiency. Customer price paid per hour on fixed price contracts is primarily

Table 11

PERFORMANCE EFFECTS – PRODUCTION

Description	Effect	Efficiency of Labor (%) (1)	Customer Price Paid per hour (2)	Schedule Periods Ahead (+) or Behind (-) (3)
Mean	$\bar{x}$	98.74	7.222	0.031
Standard Deviation	σ	1.37	0.027	0.042
Main Effects				
Planned Growth	A	-0.33*	0.010	0.013
Maintain Employment	B	0.48*	0.014?	0.003●
Hire vs. Subcontract	C	-0.58!	0.016?	0.064!
Bid Less	D	0.17●	-0.037	-0.016●
Internal Investment	E	2.57!	-0.007	0.026?
First-Order Interactions				
Planned Growth and				
Maintain Employment	AB	-0.03	-0.004●	-0.010
Hire vs. Subcontract	AC	0.07	-0.012	0.027?
Bid Less	AD	-0.23	0.015?	-0.015●
Internal Investment	AE	0.03●	0.008	0.033●
Maintain Employment and				
Hire vs. Subcontract	BC	0.03●	-0.014?	0.012
Bid Less	BD	-0.22	0.004●	0.006
Internal Investment	BF	-0.22	0.010	0.012
Hire vs. Subcontract and				
Bid Less	CD	0.12●	0.001●	0.010
Internal Investment	CE	-0.17	0.008	0.002
Bid Less and				
Internal Investment	DE	-0.12	-0.005●	0.013

! Highly significant ($P < 0.1\%$)
* Probably significant ($0.1\% < P < 5\%$)
? Possibly significant ($5\% < P < 10\%$)
● Mean squares used for error estimate

related to a company's bidding policy (Policy D), and the competitive state of the market. As the company objectives were defined in the experiment, there was an attractive tradeoff between working ahead of schedule and laying off of personnel.

COMPETITIVE EFFECTS

Competitive measures were listed and discussed in Chapter V.

Research and Development. Table 12 summarizes the competitive effects of the various policy combinations for the R&D sector of the company. It can be seen that market share in terms of both output (sales) and backlog was increased by Policies A and C.

Average periods of backlog is the ratio of average backlog to available man-hours and thus indicates the number of periods a company can stay in business with no additional contracts. This is one indicator of the security objective in a company. It can be seen that Policy C adversely affected this measure whereas Policy A improved it. The interaction of A and C worked to reduce the ratio.

Bid success is a highly desirable attribute in the aerospace industry. It enables the scheduling of new work to couple with the phase out of old work. It enables a company to select the lucrative contracts and those which most match its capability image. The only strongly significant policy in increasing award success in R&D was Policy C.

The effects of these policies can be summarized as follows:

Consequence	Market Share: Sales	Market Share: Backlog	Periods of Backlog	Awards to Bids
Highly favorable				C
Somewhat favorable	A, C	A, C		
Somewhat adverse			AC	
Highly adverse			C	

Table 12

COMPETITIVE EFFECTS – R & D

Description	Effect	Market Share Sales (1)	Market Share Backlog (2)	Average Periods of Backlog (3)	Awards to Bid Ratio (4)
Mean	x̄	0.553	0.555	3.639	0.626
Standard Deviation	σ	0.045	0.004	0.484	0.078
<u>Main Effects</u>					
Planned Growth	A	0.047*	0.039*	0.311*	-0.033
Maintain Employment	B	0.017	0.013	0.016	-0.002●
Hire vs. Subcontract	C	0.059*	0.067*	-0.874!	0.121!
Bid Less	D	0.009●	-0.014	0.004●	0.024
Internal Investment	E	0.016	0.014	-0.081?	0.002
<u>First-Order Interactions</u>					
Planned Growth and					
Maintain Employment	AB	-0.020	-0.014	0.019	-0.035
Hire vs. Subcontract	AC	0.002	0.001●	-0.231*	-0.046
Bid Less	AD	0.007●	0.004	-0.019	0.043
Internal Investment	AE	-0.004	-0.004●	-0.004●	-0.032
Maintain Employment and					
Hire vs. Subcontract	BC	0.022	0.019	0.004●	0.007
Bid Less	BD	0.004●	0.002●	-0.061	0.010●
Internal Investment	BE	0.004●	0.003●	0.084?	-0.029
Hire vs. Subcontract and					
Bid Less	CD	0.018	0.020	0.049	0.012
Internal Investment	CE	-0.001	-0.005	0.041	0.027●
Bid Less and					
Internal Investment	DE	0.026?	0.019	-0.011●	0.010●

! Highly significant ($P < 0.1\%$)
* Probably significant ($0.1\% < P < 5\%$)
? Possibly significant ($5\% < P < 10\%$)
● Mean squares used for error estimate

It might be expected that Policies A and C would increase market share in light of their highly favorable effect on sales. The adverse effect of Policy C on periods of backlog is attributable to the increased workforce obtained under this policy (thus decreasing the denominator of this ratio). Policy A increased the measure by increasing the numerator of this ratio.

The increase in awards to bids from Policy C is not immediately explainable. If other effects of this policy are examined it can be seen that cost to the customer is increased and efficiency is reduced. The explanation lies in one of the award factors in the ABES model (and in the aerospace industry, for that matter). Not infrequently in the award of a CPFF contract consideration is given to the effect on the competitors of not receiving the award. (This is particularly true in the case of similar technical capability among competitors.) Policy C, through building up the work force and reducing the backlog ratio, moves the company in the direction of jeopardy; a fact which strongly influenced the award of contracts during the experiment.

Production. Table 13 summarizes the competitive effects of the various policy combinations. Policy A increased market share in sales and backlog, substantially increased average periods of backlog and decreased the awards to sales ratio. Policy C had fewer effects in production than in R&D, the most noteworthy being a decrease in average periods of backlog, and an increase in the awards to sales ratio. An interaction effect of Policies B and C significantly reduced the award ratio. The competitive effects can be summarized as follows:

Consequence	Market Share: Sales	Market Share: Backlog	Periods of Backlog	Awards to Bids
Highly favorable	A	A		C
Somewhat favorable			A	
Somewhat adverse				
Highly adverse			C	A, BC

As in the case with R&D, one might expect Policy A (growth) to affect market share, sales and backlog, from its effect on sales. Policy C decreased the backlog to manpower ratio (periods of backlog) by increasing the denominator of this ratio. The reduced average backlog made the company a more attractive competitor in

Table 13

COMPETITIVE EFFECTS – PRODUCTION

Description	Effect	Market Share: Sales (1)	Market Share: Backlog (2)	Average Periods of Backlog (3)	Awards to Bid Ratio (4)
Mean	x̄	0.537	0.535	3.545	0.549
Standard Deviation	σ	0.030	0.031	0.502	0.094
Main Effects					
Planned Growth	A	0.048 !	0.051 !	0.350*	-0.085 !
Maintain Employment	B	0.013?	0.010	0.013•	-0.002•
Hire vs. Subcontract	C	0.014?	0.001	-0.912?	0.054*
Bid Less	D	-0.001	-0.001•	-0.023•	-0.015
Internal Investment	E	-0.003	-0.010	-0.102?	-0.018
First-Order Interactions					
Planned Growth and					
Maintain Employment	AB	-0.010	-0.010	-0.103?	0.015•
Hire vs. Subcontract	AC	-0.011	0.001•	-0.095	-0.029
Bid Less	AD	0.006•	0.001	-0.047	-0.016
Internal Investment	AE	-0.014?	-0.011	0.075	-0.052
Maintain Employment and					
Hire vs. Subcontract	BC		0.008•	0.068	-0.113
Bid Less	BD	0.005•	0.004	0.007•	0.018•
Internal Investment	BE	0.003•	0.010	0.095	-0.018•
Hire vs. Subcontract and					
Bid Less	CD	-0.017?	-0.018?	-0.015•	-0.015
Internal Investment	CE	0.017?•	0.005•	–	0.049
Bid Less and					
Internal Investment	DE	0.003	0.016?	0.012	-0.071

! Highly significant ($P < 0.1\%$)
* Probably significant ($0.1\% < P < 5\%$)
? Possibly significant ($5\% < P < 10\%$)
• Mean squares used for error estimate

terms of deprivation, but not so much as in the case of R&D (0.121 vs. 0.054). The interaction effect of Polices B and C to reduce the awards ratio probably resulted from the combined effects of hiring and bidding to maintain employment. The coupling of policies caused a greater number of contracts to be bid, increasing the denominator of the awards ratio.

SUMMARY

Although the influence of the various policy combinations have been examined in three categories: financial effects, performance effects, and competitive effects, it yet remains to examine the significant effects across all three categories. Before implementing any policy one wishes to know the complete effect of the policy on the business, not just the effects in one particular area of business. Table 14 summarizes the significant consequences of the policies.

Policy A (planned growth) is highly favorable to sales, direct profit and net profit in both R&D and production. Because of a somewhat adverse effect on efficiency, the direct profit to sales ratio is reduced (to a greater extent in production than in R&D), and net profit to sales (return on sales) is reduced although return on investment is substantially increased. Awards ratio is substantially reduced.

Policy B (maintain employment) has a somewhat favorable effect on total sales and net profit by increasing sales and efficiency in production.

Although Policy C (hire vs. subcontract) had a highly favorable effect on sales and direct profit, the inefficiency of new hires reduced the direct profit to sales ratio and the indirect expenses associated with hiring (and increased layoffs) more than offset the favorable effects in net profit, and those measures associated therewith (return on sales and return on investment). Highly favorable and somewhat favorable effects resulted on the awards ratio and R&D market share measures. The security of the company, as measured by average periods of backlog, was decreased by this policy.

Policy D (bid less) had little effect except on the price of production contracts, which was reduced. Because such a reduction was not accompanied by an increase

Table 14

SUMMARY OF POLICY CONSEQUENCES

	Favorable		Adverse	
	Highly(!)	Somewhat(*)	Somewhat(*)	Highly(!)
		Total Company		
<u>Financial Effects</u>				
Sales	A, C	B		
Direct Profit	A, C	B		
Net Profit	A	B, E	AC	C
Return on Sales			A	C
Return on Investment	A		AC	C
		Research and Development		
<u>Financial Effects</u>				
Sales	A, C			
Direct Profit	A	C		
Direct Profit/Sales			A, AC	C
<u>Performance Effects</u>				
Efficiency	E		C	
Unit Price	C	E		A
Schedule		C		A
<u>Competitive Effects</u>				
Market Share-Sales		A, C		
Market Share-Backlog		A, C		
Average Backlog		A	AC	C
Awards Ratio	C			
		Production		
<u>Financial Effects</u>				
Sales	A, C	B	AC	
Direct Profit	A	C, E		
Direct Profit/Sales	E			A
<u>Performance Effects</u>				
Efficiency Effects	E	B	A	C
Unit Price				D
Schedule				
<u>Competitive Effects</u>				
Market Share-Sales		A		
Market Share-Backlog		A		
Average Backlog		A		C
Awards Ratio	C			A, BC

! Highly significant (P < 0.1%)
* Probably significant (0.1% < P < 5%)
? Possibly significant (5% < P < 10%)

in the award ratio, Policy D in the environment of the experiment and to the degree implemented, had no desirable effect.

Policy E (internal investment) had a somewhat favorable effect on net profit by increasing efficiency more than sufficiently to pay for itself. A further benefit was the resultant reduction in the price charged to the customer in R&D which increases competitive strength.

The interaction of Policies A and C caused somewhat adverse reductions in net profit, return on investment, direct profit to sales (R&D), average backlog (R&D) and sales (production). The interaction of Policies B and C had a highly adverse effect on the awards ratio in production.

The effects of policy changes on financial and performance measures is complex and varied. Some effects can be anticipated; others are likely to be overlooked. In the definition of a policy management must have a clear appreciation of at least the important effects of the policy. It must be able to measure these effects against defined objectives, and artfully trade a slightly adverse effect on one objective for a needed improvement in another objective.

Although the policies, and the ABES model presented in this dissertation are hypothetical, the ability to select and evaluate operating plans in real life with the precision illustrated herein appears to be highly desirable.

Chapter VII

SUMMARY, CONCLUSIONS, AND AREAS FOR FURTHER RESEARCH

This chapter will summarize the work and results described in previous chapters, discuss the implications of the findings to the field of management, and finally describe areas for further investigation suggested by the research.

SUMMARY OF WORK ACCOMPLISHED

A computer model of the aerospace business environment (ABES) was developed and validated by means of participation and critical evaluation from over 300 aerospace management personnel from various aerospace companies. Participant reaction to the environment defined by the ABES model provided an early basis for modification and improvement of the model. The computer program for the ABES model has been widely disseminated in industry by International Buisness Machines Corporation as the result of a license agreement.

Observation of the approaches to decision-making employed by the various management teams led to the formulation of a theory of business decision-making which was explicitly expressed in the Heuristic Decision-Maker program. Briefly, the HDM contains a policy section which defines the decision selection space, a decision generation section to develop operating plans (complete sets of decisions), a forecasting section to predict results from operating plans, and an evaluation section containing a set of objective functions to evaluate the forecast results of selected operating plans and to select the best plan generated. This model was validated by comparing the results of its decisions with those resulting from human decision-makers, by comparing forecast results with actual results, and by examining changes in results related to changes in policies.

Development of a decision-making program based on the explicit definition of policies and objectives allows the formal investigation of specific operating strategies. These strategic policies and goals, or "strategies," are expressed in terms of tactical policies and objectives; the distinction between tactical and strategic processes being that the former are directly quantifiable whereas the latter are synthesized from and expressed in terms of the former. An investigation was then conducted by means of a one-half replicate of a 2^5 factorial experiment which evaluated factors associated with the phenomenon of corporate growth.

SUMMARY OF CONCLUSIONS AND RESULTS

Conclusions and results of this research will be discussed in the following categories:

- Development of management models
- Uses of management models
- Insight into and structuring of reality through management models
- Feasibility of decision-making models to assist in management planning

Both objective and subjective results and conclusions will be summarized here in an attempt to provide not only demonstrable conclusions, but also the author's opinions that were developed during the course of this research. Testing of some of these opinions will be discussed in the last section of this chapter.

The Development of Management Models. A frequent question asked concerning the major functional relationships contained in the ABES model relates to the validity of these functions. The problem is how to describe a relationship which is not in general measurable. In many such relationships, the functional elements or arguments of the relationship are frequently known and often there is agreement concerning extreme values of the function. In such cases it is possible to define an appropriate generalized function containing adjustable parameters which control the shape of the function within any desired range. Experience with the model then provides a basis for "tuning" the function by adjusting the parameters which affect its internal shape based on analysis of the results it produces. Such a procedure was employed with several of the functions contained in ABES model.

The use of experienced humans in the process of model development suggested that models are better evolved than created. Model creation involves a process analogous with recall in psychological learning theory, whereas subjective model

The use of a model structure such as that in the HDM requires the explicit definition of information elements. The factoring of a strategic objective into its constituent tactical objectives requires the ability to measure the results variables related to the tactical objectives. Specification of the required results variables, on the output side, and the decision variables on the input side, largely defines the information system required for management planning and control.

A variety of uses was made of the ABES model by several major aerospace companies who were invited to participate by mail in one extended exercise (24 periods or 6 simulated years). One company used the exercise to bring together members of a newly-formed division management team to give them experience in working together prior to activation of the division. Another company used the exercise to experiment with a proposal-award forecasting model they had developed. It was later reported that this same forecasting model had predicted the loss of a major supersonic fighter contract, but that the forecast was not accepted by management. Still another company developed management display and charting techniques which were later incorporated in a management chart room.

Although the literature is replete with theory and hypothesis in the realm of business policy and organization, there are relatively few such ideas being carried to the degree of precision necessary for programming on a computer. The computer model consequently seems to offer a desirable vehicle for specifying and testing behavioral science theory. The literal nature of the interpretation of a computer program requires precise, unambiguous, and consistent definition of terminology and logic in the statement of a theory.

Insight and Structuring of Reality. Frequently experience with a well-conceived model provides insights into reality. Because the model is designed to react in a realistic manner, results which are clearly contrary to reality require explanation and correction. The development of corrective modification often requires the formulation of additional hypotheses about reality. As an example, the contract awards function in the ABES model did not initially include consideration of a company's financial status in the awarding of a contract. Operation of the model with human decision-makers soon produced a situation in which one company consistently bid below costs on production contracts. The fixed price nature of these contracts led to a virtual monopoly of production work by this company — a company that was clearly going out of business. A review of the real world analog revealed the existence of a list of financially acceptable companies maintained by the government to prevent the occurrence of this type of unstability.

Another type of insight can occur through inference from or experimentation with the model. Although the experiment described elsewhere in this dissertation is primarily concerned with examination of the growth phenomenon, variation of the policy function parameters suggested an interesting hypothesis related to the role of policies and planning. It was observed during checkout of the HDM model that the wider the specified variance in the policy functions, the greater the number of iterations or plans that were required to be generated for any particular score or level of achievement, but the better the score which could ultimately be achieved if more iterations or plans were developed. The parallel in real life suggests that in an environment which allows latitude or discretion in managerial decision making, the less constraining the policies are, the less efficient will be the planning process but the better the ultimate plan is likely to be (given the capability of developing and evaluating a large number of plans).

A final example of an insight provided in the development of the HDM model concerns the nature of measurement and evaluation of business data. In order to objectively measure the results of plan or forecast it was necessary to specify goal points and a utility function around the goal point (actually a disutility function in the case of HDM). In no case was it possible to evaluate results except relative to a stated goal. It is thus suggested that evaluation of business variables must be accomplished in a relative as opposed to an absolute manner. Thus if evaluation is to take place, goals must exist either in an implicit, explicit, *a priori* or *a postieri* manner. If goals are to be used to guide and direct business operations they must be explicit and *a priori*.

Feasibility of Planning Models. The previous three subsections summarized the more general conclusions resulting from the development of ABES and HDM models. This subsection will summarize the results relating to testing of the

HDM model on an environmental model designed for use by human decision-makers, and the conduct of an experiment to evaluate the effects of various growth-oriented strategies.

First, it is somewhat surprising that a loosely-structured decision-making model should function at all, much less function in a controlled and reasonable fashion producing results that are at least no worse than those produced by teams of managers. In other words, the HDM model does not contain a set of explicit decision rules which specify the action to be taken for various environmental or company status conditions. Nor does the model contain a calculation algorithm in the sense of a linear programming model. Its structure is a general one, not dependent on the peculiarities of the ABES environment. Herein lies the significance of the HDM model.

The results of model validation indicate that HDM operates in a reasonable manner in the sense that it produced results which were superior to those produced by a sample of human decision-makers, it was able to forecast objective variables with a maximum average error of 5.2% (indirect cost) and mean error overall objective variables of 1.5%, and it was observed to make trade-offs among its objective variables in the selection of operating plans which were consistent with the specified objectives under which it was operating. Finally a factorial experiment which examined the phenomenon of corporate growth demonstrated not only a very useful technique for the evaluation of specific strategic policies, but also led to several interesting conclusions previously summarized.

IMPLICATIONS OF FINDINGS TO MANAGEMENT

Some of the implications of the findings indicated in the previous section may be readily apparent, some are not so obvious. They will be summarized, nonetheless, as they relate to methodology of management science; theory of management; and teaching, research, and decision-making applications in industry.

Methodology of Management Science. A major developing tool of the management scientist is the mathematical and/or computer model. Usually a single model is developed which includes one portion describing the environment to be studied, and another providing the decision rules to operate the model. It is suggested as a result of this research that the model builder consider separating his task into two phases: (1) an environmental model phase, which includes human beings to perform the decision function and to subjectively validate the environmental model and (2) a decision phase in which the decision function is simulated after study of the humans fulfilling the decision-making role in the modeled environment. Too frequently the decision function is specified as a set of simple decision rules or is based on intuition or limited observation. In nearly all but the most elemental business problems, simple decision rules are neither operationally feasible nor acceptable to the manager responsible for their implementation.

The development of real-time systems and associated display devices suggests that a greater degree of interaction will occur between the manager and the computer.[1] Segmenting the model into both an environmental section and a decision section which can be operated by human beings or by a decision-making program should provide a useful methodology to model builders in management science.

The Theory of Management. The results of this research suggest strongly that net profit is not a sufficient measure of success for the selective evaluation of alternative operating plans unless it can be factored into measurable tactical objectives. There seem to be several reasons for the insufficiency. In the first place, it is frequently impossible to forecast the incremental net profit implications of a particular decision value (such as facilities purchase). Also, short-term net profit can always be increased by increasing risk (e. g., by discontinuing insurance). It is necessary, instead, to factor this strategic objective into tactical objectives if it is to serve in the selection of operating plans. This research further suggests that it is useful to consider policies as functions

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[1] Teichroew, D., "Data Display in Business Information Systems," Bulletin of the Stanford Graduate School of Business, 32, No. 3 (1963).

which define decision space, a role which makes the planning process more efficient by limiting the manager's realm of selection. Decision rules can be considered as policy functions with zero variance.

Selection of plans and retrospective measurement of success is thus based on the evaluation of results relative to a set of objective functions. Definition of both objectives and their derived policies consequently becomes part of the management function as opposed to their position in previous theory which suggests that the objectives of the firm tend to be absolute in nature, and that they are imposed external to management's realm of control. Guidance and control of the enterprise within the relativist view of objectives, as presented herein, is exercised through the selection and definition of objectives and policies.

The generality of structure of HDM, and its success in operating companies under a variety of conditions within the ABES environment suggest the plausibility of developing a similarly-structured model to assist in the generation and evaluation of operating plans in actual environments.

Other Implications. Additional implications for the results exist with respect to teaching, decision-making, and research in industry.

The expectation of greater interaction between the manager and the computer places an enormous training burden on industry. The decision-making process will need to be more formalized as will management planning and control functions. The enthusiastic acceptance of the ABES environment by participating managers suggests the use of these models to train managers in this interactive process. Environmental models can be designed to represent particular areas of responsibility. Such models could assist both in training the manager of the future, and in defining the informational needs of the individual fulfilling this role.

In place of decision-maker, the manager now becomes an objective/policy formulator. Policies are pretested with the aid of an environmental model and a decision generator. The manager is assisted in the evaluation of plans by an explicit set of objective functions.

Management research will play a major role in any such evolution. Although the results of this investigation indicate the feasibility of using a decision-making model in a hypothetical environment, it yet remains to demonstrate the feasibility of such an approach in reality. The precise position the manager will take in such an environment is yet to be defined, as are the tools he will need, such as display devices, computers, communication facilities, and other hardware devices; and mathematical techniques, analysis procedures, information handling methods, and other software. The availability of technology for storing masses of event data, for communicating over vast distances, and for interacting directly with the data handling power of the computer offers the potential for a dramatic change in the definition of the management function. The degree to which this technology comes to be utilized will depend upon management research which is conducted currently. It is believed that the methodology presented in this investigation can offer guidelines to such a research program.

AREAS FOR FURTHER INVESTIGATION

The implications of the results of this study presented in the previous section will remain conjecture until an extensive program of further research can be undertaken. It is the purpose of this final section of the dissertation to outline specific investigations it is hoped can be undertaken to explore some of the implications which have been discussed. These investigations include six programs or tasks:

- Development of objective methods for validating behavioral models such as ABES and HDM
- Implementation of HDM in competition with managers within the ABES environment
- Operation of HDM with managers defining objectives and policies within the ABES environment
- Adaptation of ABES for real-time operation by managers
- Development of an experimental planning laboratory utilizing HDM and ABES
- Adaption of experimental planning laboratory to actual industrial application

The comparative results presented in Chapter IV did not include HDM operating in competition with humans, although the ABES environment was similar in both cases. Such operation is planned for the Spring of 1966 in the Executive Decision-Making course, using managers who have previously had experience with ABES to operate the other companies. This exercise will test HDM in a humanly competitive environment to see if it can adapt to the variety of conditions often experienced in an ABES exercise. It will further provide the human managers a basis of comparison for the results of their companies.

Following this test session it is planned to make the HDM program available to manager-participants of the course, which will allow them to define policies and objectives within the ABES environment. It is hoped that the formal discipline required in the selection and assignment of policy parameter values will be useful experience which will carry over to the execution of their real-life responsibilities.

Currently, as a result of computer technology available at the time of its development, ABES operates in a batched-mode of processing (i. e., a complete set of decisions must be made before any are processed). In real-life there is often a premium for the ability to make prompt decisions in a current and timely manner. Furthermore, it is planned to make available a variety of supplemental analyses which can be called out from the computer on a real-time basis. It is hoped that this application will not only make ABES a more useful and realistic tool, but that it will also acquaint management with the use of on-line computers for decision-making.

Finally, it is hoped to replace the ABES model with a realistic functional model of some element of the aerospace business. Such a configuration will become an experimental management planning laboratory for testing simulation models, information systems, information storage and retrieval techniques, display technology, and manager-computer interraction.

Chapter VIII

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Appendix A

TECHNICAL DETAILS OF THE COMPUTER PROGRAMS

The following four computer programs were used in the experiment discussed in Chapters V and VI:

- Aerospace Business Environment Simulator (ABES) program
- Heuristic Decision-Making (HDM) program
- Summarize and plot program
- Factorial analysis program

Descriptive details of these programs and their interrelationships are presented in this appendix.

ABES Program. The ABES model was designed and programmed by the author as the first part of this dissertation. Subsequently the ABES model was used in a management development course entitled, Executive Decision-Making. The computer program is written in FORTRAN, contains 13 subroutines, consists of about 4000 FORTRAN statements or 15,000 machine language instructions, and requires about 1 min/period of operation. Examples on input decisions for Period 1 and the resulting output reports are given in Fig. A-1 and Table A-1.

For the experiment, the original program was modified to iterate sequentially through a specified number of periods using decisions generated by the HDM program or developed by human beings. It was further modified to punch summary cards each period which contain the values of 65 operating variables. Table A-2a lists the values of 5 such variables for one 15 period operating sequence. These values serve as input to the summarize and plot program described below.

The ABES program has been used by over 300 Lockheed managers in the Executive Decision-Making course, and by Executives and managers in numerous other aerospace and non-aerospace companies as the result of a license agreement with IBM. This exposure provided valuable reaction for improving the ABES model, and also provided the conceptual basis for the design elements of the HDM program.

IDENTIFICATION				MANPOWER			FACILITIES	DEBT
Decision Form Code [1] [3]	Next Period [4] [6]	Company Number [7] [9]	R&D (001) Prod (002) [10] [12]	Hire (+) Fire (-) [13] (units) [22]	Ed & Training Expenditure [23] (1000's) [32]	New Hourly Wage Rate [33] (dollars) [42]	Build (+) Sell (-) [43] (1000's) [52]	Add Debt (+) Retire Debt (-) [53] (1000's) [62]
0 0 1	001	004	001		20.0		+100.0	
			002	+30.0	10.0		+ 75.0	

IDENTIFICATION				CONTRACT PERFORMANCE			CONTRACT BIDS	
Decision Form Code	Next Period	Company Number	Contract Number	Regular Time (1000's)	Overtime (1000's)	Subcontracting (1000's)	Bid ($ per hr. or total in 1000's)	Presentation (1000's)
0 0 2	001	004	004	352.5				
			014	123.0		100.0		
			024	490.6	100.0			

x Numbers within squares indicate card columns for key punching.

Fig. A-1 Input Decisions

Table A-1

ABES OUTPUT REPORTS

P R O F I T   A N D   L O S S

	DOLLARS		PERCENT	
TOTAL SALES		$ 8049807.		100.00
TOTAL DIRECT LABOR	$ 3834770.		47.64	
TOTAL DIRECT MATERIALS	1702463.		21.15	
TOTAL DIRECT FACILITIES	132584.		1.65	
TOTAL DIRECT OVERHEAD	273831.		3.40	
TOTAL SUBCONTRACTING	812000.		10.09	
TOTAL DIRECT EXPENSES		6755648.		83.92
OPERATING PROFIT		1294159.		16.08
EDUCATION AND TRAINING	30000.		0.37	
INTERNAL RESEARCH	25866.		0.32	
INTEREST EXPENSE	120000.		1.49	
ADMINISTRATIVE EXPENSE	409840.		5.09	
MISCELLANEOUS EXPENSES	1990.		0.02	
TOTAL INDIRECT EXPENSES		$ 587696.		7.30
TOTAL EXPENSES		7343343.		91.22
GROSS PROFIT		706463.		8.78
INCOME TAXES		367361.		4.56
NET EARNINGS		$ 339102.		4.21

C A S H   F L O W

REVENUE FROM OPERATIONS	$ 8109263.	
CASH FROM SALE OF ASSETS	0.	
NEW BORROWINGS	0.	
TOTAL RECEIPTS		$ 8109263.
TOTAL CASH EXPENSES	$ 7577954.	
PLANT INVESTMENT	175000.	
DEBT RETIREMENT	0.	
TOTAL DISBURSEMENTS		7752954.
NET CASH FLOW		$ 356309.

F I N A N C I A L   C O N D I T I O N

CASH	$ 2506308.	
RECEIVABLES	4940544.	
FACILITIES (NET)	4292250.	
TOTAL ASSETS		$11739102.
DEBT	$ 6000000.	
EQUITY AND SURPLUS	5739102.	
TOTAL DEBT AND EQUITY		$11739102.

M I S C E L L A N E O U S   D A T A

	R + D	P R O D	T O T A L
FACILITIES	2716000.	1576250.	4292250.
DEPRECIATION	84000.	48750.	132750.
MEN AVAILABLE	953.	981.	1934.
M/H AVAILABLE	476500.	490500.	967000.
EMERG HIRES	0.	0.	0.
QUITS LAST PD	37.	39.	76.
BKLG RATIO	0.18	0.17	0.17
OUTPUT RATIO	0.25	1.00	0.43
TURNOVER RATE	0.0374	0.0382	
AVE WAGE RATE	4.000	3.017	
AVE INT RATE			0.0200
INT RESEARCH MH			1000.

Table A-1 (cont'd)

C O N T R A C T   S T A T U S   R E P O R T

CTR/ FCTN	BID TOTAL	BID PER PMH	SALES TO DATE TOTAL	SALES TO DATE PER PMH	DIR COST TO DATE TOTAL	DIR COST TO DATE PER PMH	MANHOURS LAST PERIOD APPLIED	EFFIC	PRODUCED	COST	REMAINING PMH	PDS
4 2	6100000.	9.000	2316841.	8.057	2079279.	7.231	352500.	0.816	287560.	7.231	612440.	2
14 3	7200000.	9.000	1722681.	8.782	1546935.	7.886	223000.	0.880	196169.	7.886	603830.	3
24 5	20000000.	8.000	4010284.	8.000	3129434.	6.243	590600.	0.849	501286.	6.243	1998710.	4

FUNCTION CODE
- 2--R+D, SPACE SYSTEMS
- 3--R+D, MISSILE SYSTEMS
- 4--PROD, SPACE SYSTEMS
- 5--PROD, MISSILE SYSTEMS

D E C I S I O N S   L A S T   P E R I O D

OPERATING DECISIONS--	R + D	PRODUCTION
MEN HIRED	0.	30.
MEN FIRED	0.	0.
FACILITIES BUILT	100000.	75000.
FACILITIES SOLD	0.	0.
ED AND TR EXP	20000.	10000.
R/T MANHOURS APPLIED	475500.	490600.
C/T MANHOURS APPLIED	0.	100000.
SUBCONTRACTED M/H	100000.	0.
WAGE RATE	4.00	3.00
DEBT ADDED/RETIRED	0.	0.

I N D U S T R Y   P R O C U R E M E N T   C O S T S

	R+D	PROD
WAGE RATE	4.23	3.54
SUBCONTRACTING	8.12	6.06
INTEREST RATE		.0200

C O N T R A C T   I N F O R M A T I O N - - REQUESTS FOR PROPOSAL

CONTRACT NUMBER	FUNCTION	PRODUCT	TOTAL PMH REQUIRED	DEADLINE PERIOD	AVERAGE PD M/H RQT	MAXIMUM BID	MAXIMUM BID/PMH
31	PROD	SPACE SYS	1800000.	8	300000.	14040000.	7.800
32	R+D	SPACE SYS	300000.	5	100000.	2670000.	8.900
33	PROD	MISSILE SYS	1800000.	8	300000.	13590000.	7.550
34	R+D	MISSILE SYS	700000.	9	100000.	6160000.	8.800
35	PROD	MISSILE SYS	1200000.	8	200000.	9420000.	7.850
36	R+D	SPACE SYS	1200000.	6	300000.	10860000.	9.050

C O M P A N Y   I N F O R M A T I O N

COMPANY 1

PROFIT AND LOSS		FINANCIAL CONDITION		OTHER ITEMS	R+D	PROD
SALES	8050.	NET CASH	2506.	BACKLOG(M/H)	1216.	1999.
DIRECT EXP	6756.	RECEIVABLES	4941.	SUBCTR	100.	0.
OPER PRO	1294.	NET PLANT	4292.	MEN	953.	981.
OTHER EXP	955.	TOTAL DEBT	6000.	MANHOURS	477.	491.
NET PRO	339.	TOTAL EQUITY	5739.	WAGE RATE	4.00	3.00

COMPANY 2

PROFIT AND LOSS		FINANCIAL CONDITION		OTHER ITEMS	R+D	PROD
SALES	8050.	NET CASH	2506.	BACKLOG(M/H)	1216.	1999.
DIRECT EXP	6756.	RECEIVABLES	4941.	SUBCTR	100.	0.
OPER PRO	1294.	NET PLANT	4292.	MEN	953.	981.
OTHER EXP	955.	TOTAL DEBT	6000.	MANHOURS	477.	491.
NET PRO	339.	TOTAL EQUITY	5739.	WAGE RATE	4.00	3.00

Table A-2

INFORMATION FLOW

SALES	NET	D-PCT	I-PCT	N-PCT	PD
8378.7	570.6	.7926	0.0655	0.0681	2
8870.3	595.6	.8044	0.0557	0.0671	3
8600.8	580.1	.8024	0.0570	0.0674	4
9481.1	614.0	.8121	0.0530	0.0648	5
8644.4	287.6	.8726	0.0581	0.0333	6
9175.3	382.0	.8662	0.0471	0.0416	7
9714.2	397.8	.8670	0.0477	0.0410	8
10768.7	415.6	.8679	0.0517	0.0386	9
9579.0	332.1	.8653	0.0625	0.0347	10
9052.5	319.4	.8682	0.0583	0.0353	11
10086.4	417.7	.8682	0.0455	0.0414	12
9817.2	433.3	.8648	0.0433	0.0441	13
9474.6	360.4	.8676	0.0531	0.0380	14
11016.1	422.1	.8761	0.0441	0.0383	15

a. RESULTS OF STANDARD CASE (15 PERIODS, 5 VARIABLES)

	SUM	MEAN	SIGMA
SALES	140709.094	9380.606	808.093
NET	6467.400	431.160	104.094
D-PCT	12.735	0.849	0.029
I-PCT	0.816	0.054	0.008
N-PCT	0.696	0.046	0.013

b. SUMMARY OF STANDARD CASE (5 VARIABLES)

	SALES	NET	D-PCT	I-PCT	N-PCT
00000	9380.6	431.160	0.849	0.054	0.046
10001	11478.0	489.020	0.851	0.057	0.044
01001	9913.0	476.633	0.842	0.057	0.048
11000	11787.6	518.773	0.851	0.054	0.045
00101	10626.1	454.533	0.840	0.070	0.043
10100	12312.0	417.113	0.853	0.072	0.036
01100	11368.6	417.700	0.850	0.070	0.038
11101	12422.4	460.367	0.849	0.071	0.039
00011	8921.1	418.513	0.844	0.058	0.047
10010	11857.9	500.340	0.854	0.054	0.044
01010	9251.0	430.800	0.847	0.056	0.047
11011	11950.9	517.647	0.849	0.057	0.045
00110	9478.1	369.313	0.849	0.069	0.040
10111	12352.9	434.320	0.851	0.073	0.037
01111	12016.2	437.900	0.849	0.073	0.038
11110	12553.4	430.933	0.853	0.071	0.036

c. SUMMARIES OF ALL 16 CASES (5 VARIABLES)

HUMAN OR HDM DECISIONS FIG. A-1

ABES PROGRAM

OPERATING REPORTS TABLE A-1

SUMMARIZE AND PLOT PROGRAM

GRAPHIC OUTPUT FIG. 7

FACTORIAL ANALYSIS PROGRAM

FACTORIAL ANALYSIS TABLE A-3

HDM Program. This program was patterned after the decision-making characteristics observed in the many management sessions which utilized ABES. Output from the program consists of decisions similar to those illustrated in Fig. A-1. The decisions are located in core for use by the ABES program. The program itself is written in FORTRAN, contains 15 subroutines, and consists of about 5000 FORTRAN instructions or about 16,000 machine language instructions. When coupled with the ABES program on the IBM 7090, core was exceeded so the two programs were configured as a "chain" program with three "links". In such an assemblage, each link of the program chain is called into core separately for operation.

One experimental sequence of 15 periods requires approximately 15 min computing time on the IBM 7090 computer. Processing of the 16 experimental sequences thus required approximately 4 hr.

Summarize and Plot Program. This program accepts as input the summary cards punched by the ABES program (see Table A-2a). Three output options are provided: plot, print, and punch, which can be selected at execution time. Plot causes a tape to be written which plots specified series on a CALCOMP plotter (see Fig. 7), and print causes a summary report of a 15-period sequence to be printed, containing means and standard deviation measures of the 65 analysis variables for both the experimental (Company 1) and the control (Company 2) company (see Table A-2b). Punch causes cards to be punched containing means and standard deviations for the 65 analysis variables. These cards are in a format which is accepted by the factorial analysis program (see Table A-2c).

This program contains about 500 FORTRAN statements and requires less than 1 min of IBM 7090 time to process the summary data from a single 15-period sequence.

Factorial Analysis Program. This program is a slightly modified version of a FORTRAN program written by G. K. Hutchinson. The program contains about 250 FORTRAN statements and calculates the main effects and first-order interactions of all factors for each dependent variable. The program also calculates the F ratio and indicates the level of significance for each variable. An example of the output is illustrated in Table A-3.

Table A-3

RESULTS OF FACTORIAL ANALYSIS
(5 variables)

SALES, MEAN AVERAGE VALUE 11104.3622 STD.DEV. 1252.7997

FACTOR	DEG.FREEDOM	F RATIO	SIGNIFICANCE
PLANNED GROWTH	1	105.47766	0.001
MAINTAIN EMPLOYMENT	1	10.01509	0.010
HIRE VICE SUBCONTRACT	1	31.33082	0.001
BID LOWER	1 *	0.34918	0.
INTERNAL INVESTMENT	1	1.21484	0.
PLANNED GROWTH			
MAINTAIN EMPLOYMENT	1	4.99416	0.050
HIRE VICE SUBCONTRACT	1	5.07487	0.050
BID LOWER	1 *	2.31923	0.
INTERNAL INVESTMENT	1	2.25576	0.
MAINTAIN EMPLOYMENT			
HIRE VICE SUBCONTRACT	1	2.29863	0.
BID LOWER	1 *	0.91338	0.
INTERNAL INVESTMENT	1 *	0.41821	0.
HIRE VICE SUBCONTRACT			
BID LOWER	1	0.02650	0.
INTERNAL INVESTMENT	1	1.25569	0.
BID LOWER			
INTERNAL INVESTMENT	1	2.67530	0.

* ERROR ESTIMATE 4

FACTOR PLANNED GROWTH

	SALES, MEA	NET PROFIT	DIRECT RAT	INDIRECT R	RETURN ON
MAIN EFFECTS	1970.0500	41.4951	0.0051	0.0002	-0.0026
FIRST ORDER INTERACTIONS					
MAINTAIN EMPLOYMEN	-428.6749	-0.3234	-0.0016	-0.0010	0.0011
HIRE VICE SUBCONTR	-432.1249	-25.6734	-0.0006	0.0010	-0.0001
BID LOWER	292.1251	15.1834	-0.0006	-0.0005	0.0001
INTERNAL INVESTMEN	-288.1000	-13.0514	0.0011	-0.0002	-0.0001

FACTOR INTERNAL INVESTMENT

MAIN EFFECTS	211.4249	21.6001	-0.0039	0.0020	0.0011
FIRST ORDER INTERACTIONS					
PLANNED GROWTH	-288.1000	-13.0514	0.0011	-0.0002	-0.0001
MAINTAIN EMPLOYMEN	124.0499	1.9851	0.0009	-0.0002	-0.0001
HIRE VICE SUBCONTR	214.9501	16.4151	-0.0001	-0.0007	0.0006
BID LOWER	313.7499	-2.3516	0.0014	0.0007	-0.0011

All computations were performed at the Stanford Computation Center utilizing the IBM 7090 computer and, on occasion, the CalComp plotter.

Appendix B

ABES PARTICIPANTS' MANUAL

This appendix contains a copy of the participants' instructions for the Aerospace Business Environment Simulator. The manual, originally published as Lockheed report 5-10-61-4A, Rev. 5 November 1963, is included in its entirety except for the front matter.

A copy of this manual may be requested from L. Dudey, IBM Corporation, 9045 Lincoln Blvd., Los Angeles, California.

FOREWORD

The Aerospace Business Environment Simulator was developed by the author on the staff of the Associate Director of Research (Information Processing), Lockheed Missiles & Space Company, as part of a continuing program of research in the application of quantitative techniques and electronic data processing to the problems of management.

The reader who desires to gain only general knowledge of the operation of the simulation exercise can do so by reading the Introduction (Section I) and the "General" paragraphs which begin each of the other sections. A thorough understanding will, of course, require an examination of the entire manual. The critical reader may notice small arithmetic errors in some of the tabular figures. These errors are the result of "rounding off" various calculations. Since these errors are small, they will have no significance in the exercise.

The manual is intended to present only the general ground rules for participating in the simulation exercise. It is a rule book, not a treatise on business strategy. Each participating management team is expected to organize its own company, to formulate its own policies, to utilize the information presented in its own way; in short, each team member must exercise his own innate ingenuity and initiative in deducing and inferring facts and relationships from the somewhat sketchy information he will be provided about the behavior of the simulated environment. These difficulties, however, are similar to those faced in actuality by the management of any company.

Acknowledgement is due Glenn A. Black of Technical Publications for his tireless assistance and thorough editing of successive drafts of this manual. The cooperation and enthusiasm of the Lockheed management participants in the course, "Executive Decision-Making" has added to the realism of the simulator immeasurably.

SECTION I

INTRODUCTION

1.1 GENERAL.

1.1.1 Traditionally, management is charged with planning, organizing, directing, and controlling the operations of a business. Such planning must be accomplished in an uncertain environment; effort must be organized without a full knowledge of the capability of that effort; action must be directed although the full impact of that action is unknown; and operations must be controlled with incomplete and often inaccurate information concerning the status of those operations. The fact that management does function effectively under these complex circumstances is remarkable. One explanation seems to be that through experience managers develop an intuitive process which enables them to evaluate a wide range of possible courses of action without overt consideration of the many variables involved.

1.1.2 In a way somewhat analogous to the manner in which a Link trainer is used to provide simulated flying experience, the Aerospace Business Environment Simulator may be used to provide practice in performing the above-mentioned management actions. The simulated environment is supplied by a computer program which contains mathematical descriptions of many important relationships found in the actual Aerospace industry. Teams of management personnel gain experience by operating competing companies within this simulated environment.

1.1.3 Participation in this simulation exercise will not teach a series of rules for success, but rather will provide opportunities for the team members to use the available information to the maximum, to formulate broad policies on the basis of this information, and to gain experience in decision making without the attendant hazard of financial loss. The relative success of the competing teams depends in large measure on the initiative and ingenuity of the individual members.

1.2 PATTERNS OF PAST PERFORMANCE.

1.2.1 In past exercises, the pattern of success and failure of participating management teams has to some extent paralleled that which often occurs in real life. The profit of simulated companies has varied from a high of about ten percent return on investments to near bankruptcy. Successful companies have tended to rely heavily on retained earnings rather than on borrowed funds to finance expansion. They have usually been selective in choosing proposals on which to bid, and their bids have generally been sufficiently high to recover all direct costs, a portion of indirect costs, and a reasonable profit. In addition, they have tended to develop plans and policies rather than meeting each situation as a new problem.

1.2.2 Less successful management teams, on the other hand, have tended to be too competitive in bidding, often ignoring indirect costs and profit. An initial influx of new contracts required them to rapidly expand facilities, manpower, and debt. Costs increased more than anticipated, causing the overrunning of closely bid contracts. Successive quarters of unprofitable or marginally profitable operation placed further burdens on their financial structures and made them less attractive contenders for future contract awards. At some point, the spiral of increasing operating costs and decreasing competitive attractiveness became inescapable. At that time, the sale of assets (at fifty cents on the dollar value) was forced to meet fixed obligations.

1.3 GAME PROCEDURE.

1.3.1 Each period (a simulated quarter year), the participating teams submit sets of decisions to the computer (an IBM 7090). The decisions interact with the environmental model programmed into the computer. The results of this interaction are then printed as operating reports which are distributed to the teams. The figure below symbolizes this process.

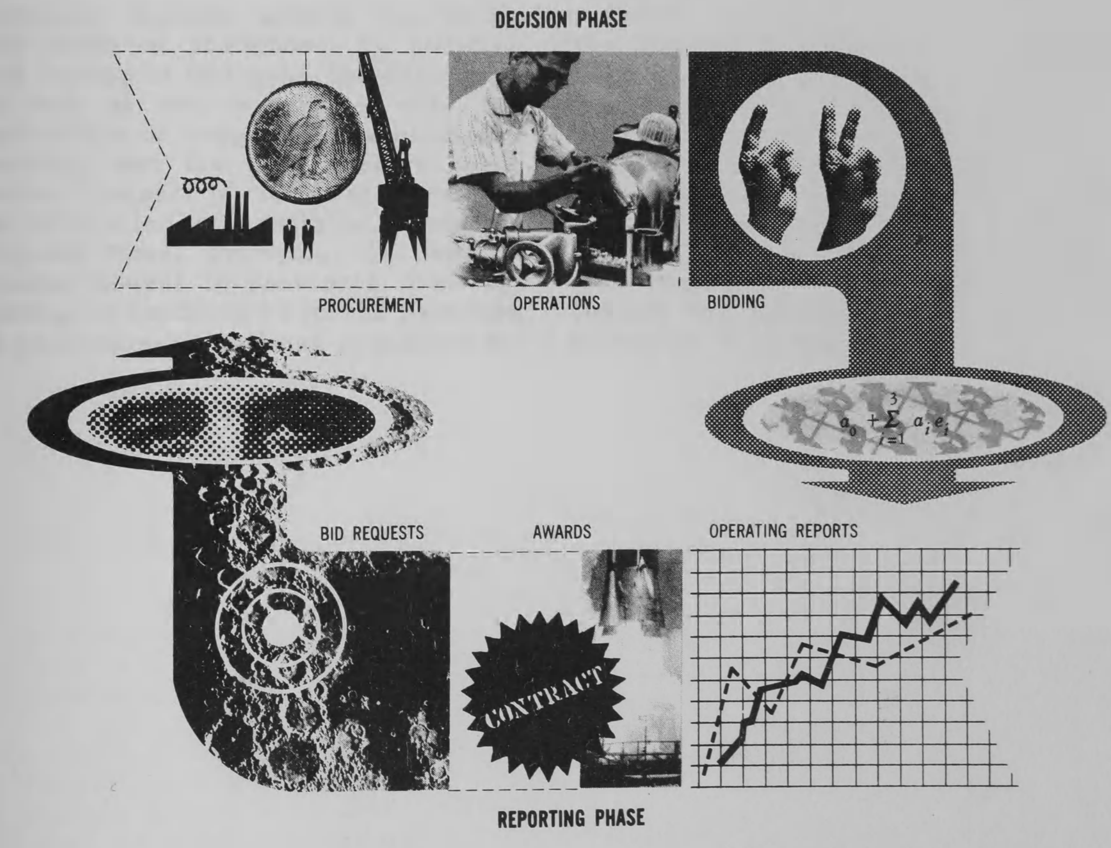

Fig. 1-1 Aerospace Business Environment Simulator

1.3.2 There are two somewhat independent functional areas of effort with which the teams are concerned: Research and Development, and Production. Within each functional area there are two products: Space Systems and Missile Systems. For each functional area, there are three types of decisions to be made each period:

- Resource changes (acquisition and disposal of resources)
- Contract performance (application of manhours to contracts)
- Contract bidding (decisions involved in obtaining new business)

Resource changes involve the hiring and firing of personnel, the building and selling of facilities, the borrowing of cash or the retiring of debt, the application of budget to education and training, and the adjustment of wage rates. Contract performance refers to the allocation of available manhours (regular time, overtime, or subcontracted hours) to contracts. Contract bidding is concerned with the selection of proposals from those presented for bid and with the development and submission of a competitive bid. Arbitrarily, all Research and Development contracts are assumed to be cost plus fixed fee (CPFF), and all Production contracts are fixed price. Each of these decision areas is discussed in detail in the following sections of the manual.

1.3.3 The results of the interaction of these decisions with the environmental computer model are distributed in the form of reports to each simulated company. These reports include operating reports, reflecting the financial results of the previous period's operations; requests for bid, describing work desired by the Government; and contract awards, indicating companies to whom contracts have been given. The information found in these reports serves as a basis for teams to evaluate their past performance and to formulate future plans. The receipt of the reports signals the end of one period and sets the stage for the next period. This cycle continues from period to period for the duration of the simulation exercise. Samples of both the operating reports and the decision forms appear in Section VI of the manual.

SECTION II

RESOURCE CHANGES

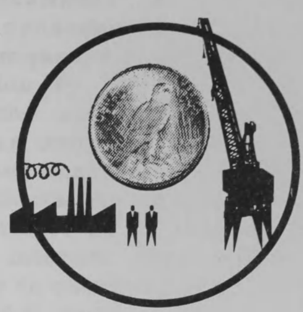

Fig. 2-1 Resource Changes

2.1 GENERAL.

2.1.1 Resources provide the basis for a company's performance capability. In the simulation exercise, resources consist of men (or manhours), facilities, and cash. Men and facilities are either of a Research and Development or Production type. These functional areas are essentially independent of each other. That is, Production men and facilities cannot be used for effort on Research and Development contracts and vice versa. Cash, of course, has no functional identity. Resources can be increased or decreased for any period by an appropriate entry on the decision form (Table 6-10).

2.2 PLANNING RESOURCE CHANGES.

2.2.1 There are costs associated with procuring, carrying, and disposing of resources (manpower, facilities, and cash). Resource planning involves a determination of the resource level which will provide maximum capability at minimum cost.

2.2.2 MANPOWER. The two major considerations in planning manpower level changes are labor turnover and anticipated contract requirements. When employee satisfaction is maximum, labor turnover will be approximately two percent per quarter. There are administrative costs associated with all changes in manpower level. Such costs tend to be highest for hires and lowest for quits. Both hires and fires tend to be less efficient, and quits tend to be more efficient, than in-plant employees. Since fluctuations in manpower levels involve expense and affect efficiency, prudent managers hire only to replace quits or, in the event of a permanent increase, to bring the staff up to the required strength. For temporary surges or for peak demands, managers will do well to consider overtime or subcontracting. The application and cost of these types of manhours, in a contract effort, are discussed in paragraphs 3.2.2 and 3.3.2, respectively.

2.2.2.1 <u>Education and Training</u>. Education and training affects employee satisfaction and productivity. The adverse effects of an inadequate expenditure in this area are particularly noticeable in the case of Research and Development personnel. In general, a policy which leads to a consistent level of expenditure is more satisfactory than one in which the level fluctuates.

2.2.2.2 <u>Wage Rates</u>. The Research and Development and Production wage rates may be changed at the discretion of the management teams. Any great discrepancy between the company's average wage rate (Table 6-4) and the prevailing market rate (Table 6-7) results in an increased rate of employee turnover with an attendant loss of efficiency.

2.2.3 FACILITIES. Facilities include both space and equipment and are considered to cost one dollar per unit. The ratio of facilities in dollar value to the number of employees has an effect on company efficiency. Facilities are assumed to depreciate physically and nominally at a rate of three percent per quarter (12 percent per year). An optimum ratio of facilities to manpower should be determined, and a policy of expenditure which maintains this ratio is desirable. Since facilities can be sold for only fifty cents of the dollar value, expansion should be carefully considered.

2.2.4 CASH AND DEBT. The fixed charges associated with debt make any company so financed more susceptible to the vicissitudes of the business cycle. As a consequence, it is a general practice to measure a company's financial condition by its ratio of debt to equity. In the simulation exercise, a ratio of near unity is considered to be normal. The financial condition of a company affects its ability to obtain money (as reflected in administrative costs), its interest rate, and its attractiveness in obtaining new contracts. With a normal ratio, a company pays approximately the prime interest rate (Table 6-7). If a company underestimates its cash needs, it can incur a negative cash balance at the end of a period. The cost of this negative cash balance is always higher than the cost of a comparable amount of money borrowed at the beginning of a period in anticipation of need.

2.3 METHOD FOR ENTERING RESOURCE CHANGE DECISIONS.

2.3.1 The method for entering these decisions is presented in paragraph 5.2, Section V.

SECTION III

CONTRACT PERFORMANCE

Fig. 3-1 Contract Performance

3.1 GENERAL.

3.1.1 The objective of contract performance is to complete a contract manhour requirement by the end of the stated deadline period. A company's attractiveness on future awards is diminished by overrunning bids or by slipping schedules. Conversely, a company becomes more attractive by completing contracts ahead of the deadline and bid price. Contract performance consists of applying (scheduling) estimated available manhours to contracts by making an appropriate entry on the decision form (Table 6-11). Applied manhours are converted to productive manhours at a certain rate of efficiency. Productive manhours serve as the basis for calculating sales. If, for example, a contract calls for 500,000 manhours and a company has completed 250,000 productive manhours on that contract, the company is considered to have sold half of the product or to have performed half of the contracted service. This does not mean that the company has been paid. The asset reflection of Sales prior to cash payment is in receivables (Table 6-3). Accounts receivable are converted to cash with a delay of about eight weeks for Research and Development and of about twelve weeks for Production contracts.

3.2 PLANNING MANHOUR ALLOCATIONS.

3.2.1 Each company receives a quarterly statement (Table 6-6) which informs it of contract awards. The current status of all in-house contracts is given in Table 6-5. The contract performance decision form (Table 6-11) is used for allocating manhours to contracts. Regular time, overtime, and subcontracted manhours may be applied to contracts under the limitations prescribed below: Regular time manhours can be applied without restriction up to the total number of manhours available within a function (Research and Development or Production). Overtime hours may be applied to each contract in a quantity not to exceed half of the regular manhours applied on the contract. Subcontracted hours may be applied in quantities up to the Average Productive Manhours Required per Period as listed in Table 6-6. Regular time is more efficient than overtime; subcontracted time has an efficiency factor of unity.

3.2.2 ALLOCATING AVAILABLE MANHOURS. Within either function, the men available for work in any period are equal to the number available last period plus hires and minus fires and quits. The manhours available are equal to men times 500 (the number of manhours per man per quarter).

3.2.2.1 Over-Allocating. If more manhours are applied to contracts within a function than there are manhours available for that function, the difference is made up by emergency hires. This calculation is effected by the computer and appears in Table 6-4. Emergency hires are less efficient and demand a higher wage than normal hires.

3.2.2.2 Under-Allocating. If fewer manhours are allocated to contracts than are available, the difference is counted as internal research for Research and Development personnel and appears opposite "Internal Research" in Table 6-1 and opposite "Internal Research Manhours" in Table 6-4. The difference is counted as idle labor for Production personnel (included opposite "Miscellaneous Expenses" in Table 6-1). Internal research tends to improve company efficiency; whereas, idle Production labor contributes nothing but expense.

3.2.3 CONTRACT EFFICIENCY. Contract efficiency is of prime importance in planning contract performance. Contract efficiency is in reality a statement of the effectiveness of the applied manhours. Within a given function, efficiency is affected by a number of elements:

- Previous experience on a similar function or product area
- Quantity of facilities available per man (see paragraph 2.2.3)
- Company policy governing internal research (see paragraph 3.2.2.2)
- Type of labor applied (regular time, overtime, and subcontracted time) (see paragraph 3.2.1)
- Number of manhours applied
- Employee turnover (para. 2.2.2)
- Employee satisfaction
- Learning curve

3.2.3.1 Efficiency Factors. Included in this paragraph is a discussion of only those above-listed factors which are not discussed elsewhere (as indicated by a cross reference). "Previous Experience" in related function or product areas will tend to increase efficiency on any given contract. As the "Number of Manhours" applied to a contract in a period gets very large, additional manhours tend to become successively less efficient. It is assumed that the higher "Employee Satisfaction," the more efficient the employee. A "Learning Curve" reflects the fact that hours applied at the end of contracts tend to be more efficient than those applied at the beginning.

3.3 CONTRACT PERFORMANCE COSTS.

3.3.1 Certain types of costs accrue from work on an actual contract: labor, materials, facilities, etc. These are called direct costs. Certain costs in addition to the direct costs occur in the operation of any company. These are called indirect costs. Some indirect costs are independent of any specific contract, but vary with the relative activity of the company; others have a relationship to the nature of the contracts on which the company is working. Indirect costs include such items as administrative expense, interest expense, internal research, etc.

3.3.2 DIRECT COSTS. A summary of the direct (and indirect) costs for each period is presented in the Profit and Loss statement (Table 6-1). Direct costs result from the application of manhours to contracts. These are:

- Total Direct Labor
- Total Direct Materials
- Total Direct Facilities
- Total Direct Overhead
- Total Subcontracting

Cumulative total direct costs for each contract are presented in Table 6-5 under "Total Direct Cost to Date." The total direct expenses for all contracts in a period appear opposite "Total Direct Expenses" in Table 6-1.

3.3.2.1 Direct Labor. The cost of total direct labor (Table 6-1) equals the company's average hourly wage rate for a function (Table 6-4) times the number of manhours applied to the contracts within that function, plus any overtime premium (Table 6-5).

3.3.2.2 Direct Materials. Materials cost (Table 6-1) occurs in proportion to the applied manhours times the efficiency (i.e., in proportion to productive manhours). This charge averages between two to three dollars per productive manhour for both Research and Development and for Production contracts.

3.3.2.3 Direct Facilities. Facilities are allocated to contracts in direct proportion to applied manhours. This is done automatically by the computer. The cost for such Direct Facilities (Table 6-1) is depreciation which amounts to three percent per period. The depreciation cost appearing in Table 6-4 is the total for the company, including the cost of facilities used for indirect effort.

3.3.2.4 Direct Overhead. Direct Overhead (Table 6-1) is the cost of supervising Direct Labor. This charge does not usually exceed twenty cents per hour of Direct Labor; however, this charge fluctuates with changes in the number of manhours applied to individual contracts.

3.3.2.5 Subcontracting. Total subcontracting cost (Table 6-1) is equal to the product of the subcontracting rate (Table 6-8) and the number of manhours subcontracted. The subcontracting rate includes all of the direct costs enumerated above for the subcontracted hours. This rate varies from period to period as the demand for subcontracting varies within the industry.

3.3.3 INDIRECT COSTS. The profit and loss statement (Table 6-1) includes the indirect costs as well as the abovementioned direct costs. The indirect costs are:

- Education and Training
- Internal Research
- Interest Expense
- Administrative Expense
- Miscellaneous Expenses

Indirect costs are the incidental expenses of running a business as distinguished from the expenses directly involved in satisfying a contract.

3.3.3.1 Education and Training. Education and training is effected by allocating funds to this activity on the decision form (see paragraph 2.2.2.1).

3.3.3.2 Internal Research. Internal research is performed by applying fewer than the manhours available in Research and Development (see paragraph 3.2.2.2). The charge for internal research in Table 6-1 includes the cost of these manhours and a proportional share of facilities and overhead.

3.3.3.3 Interest Expense. Interest expense is the cost of borrowed money. The company debt appears in Table 6-3 and the average interest rate paid during the last quarter appears in Table 6-4. The product of debt and this interest rate is equal to the Interest Expense. The interest rate indicated in Table 6-4 should not be confused with the interest rate presented in Table 6-7. The rate in Table 6-7 is the prime interest rate for the industry. The financial condition of the company determines the rate at which money will actually be loaned to the company. The actual rate always equals or exceeds the prime rate.

3.3.3.4 Administrative Expense. These expenses depend on the size and nature of a company's activity. Each executive decision involves some administrative expense. Included are the costs involved in operating the following departments:

- Cost estimation and bid development
- Personnel administration (hiring firing, etc.)
- General accounting, wage administration, contract accounting, etc.
- Plant construction and maintenance
- Expediting

3.4 SALES.

3.4.1 The purpose of contract performance is to create sales. Sales represent a contractual obligation for payment. Sales are determined by the number of productive manhours performed on contracts. Sales on individual contracts appear cumulatively in Table 6-5 under "Total Sales to Date." This figure represents the total cost to the Government; it is this figure which is compared to the bid to determine the cost of overruns in the case of Research and Development contracts. A history of overrunning costs on Research and Development contracts reduces the attractiveness of the company for future contract awards.

3.4.2 RESEARCH AND DEVELOPMENT SALES. Sales for Research and Development contracts may be calculated by means of the following formula:

Sales = (Direct Costs) + (.04 Direct Labor Costs) + Fee
+ .04 Subcontracting - Disallowance

where:

Direct Costs	= Total Direct Expenses (recorded in Table 6-1)
.04 Direct Labor Costs	= Allowance above Direct Costs for Indirect Expenses
.04 Subcontracting	= Allowance above Direct Costs for Indirect Expenses Associated with Subcontracting
Fee	= Fixed Fee (7% of Bid)

Payment is made to the company in proportion to performance on the contract. There is a lag between sales (completion of a portion of the contract) and the actual receipt of cash from sales. The lag is approximately eight weeks for Research and Development contracts. During the interim period before payment, sales appear in Table 6-3 opposite "Receivables."

3.4.3 PRODUCTION SALES. Sales for Production Contracts may be calculated by means of the following formula:

$$\text{Sales} = \frac{\text{Productive Manhours}}{\text{Total Manhours Required}} \times \text{Bid Price}$$

where:

Productive Manhours	=	Applied manhours times efficiency factor (Table 6-5)
Total Manhours Required	=	The total productive manhours required for a certain contract (listed in Table 6-8 for proposed contracts and in Table 6-6 for awarded contracts)
Bid Price	=	The bid price listed for winning company appears in Table 6-6.

Payment is made to a company in proportion to performance on the contract. The lag between sales and the actual receipt of cash for Production sales is approximately twelve weeks. During the interim period before payment, sales appear opposite "Receivables" in Table 6-3.

3.5 METHOD FOR ENTERING CONTRACT PERFORMANCE DECISIONS.

3.5.1 The method for entering these decisions is discussed in paragraph 5.3, Section V.

SECTION IV

CONTRACT BIDDING

Fig. 4-1 Contract Bidding

4.1 GENERAL.

4.1.1 Each period the Government solicits bids for certain functions and products (Table 6-8). The Government's requests for bid specify the desired function and product, the total productive manhour requirement, the deadline period, and the maximum bid which will be entertained. For every such bid request, each management team must decide whether or not to bid, how much to bid, and how much to spend in presenting the bid. The amount of the bid together with the amount to be spent in presenting the bid are to be entered on the decision form (Table 6-11).

4.1.2 Many considerations which govern the decisions of whether or not to bid and how much to bid are the same. Each team must evaluate the financial condition of their company, decide whether the company has a capability in the functional or product area of the bid, determine whether the proposed contract falls within the corporate objectives, estimate the potential profit of the contract, and anticipate the action of his competitors. The cost of bid presentation should depend primarily upon the complexity of the contracted function and product.

4.2 DEVELOPING THE BID.

4.2.1 Once a company has decided to present a bid, the manager must determine what amount to bid. Factors which control the amount of the bid are these: the company's internal costs, its backlog relative to its productive capacity, the anticipated cost changes, the contract type (Research and Development or Production), the anticipated action of competitors, and the maximum allowable bid.

4.2.2 Internal costs are of two kinds: direct (operating) costs and indirect (incidental) costs. Direct costs vary with the level of operating effort and result from participating in a contract effort. Indirect costs are those incidental to operating any business and represent the support required to maintain any efficient operating effort. For an individual contract, the bid price should exceed the sum of the direct costs by an amount sufficient to pay a portion of the indirect costs and to provide a margin of profit. Obviously, the total sales resulting from all contracts in a given period must exceed the sum of direct and indirect costs if the company is to be profitable. The "Contract Status Report" (Table 6-5) shows the status of each in-house contract. The difference between the "Direct Cost to Date" entry and the "Sales to Date" entry represents the cumulative direct profit on each contract to date. This figure reveals the profitability of past operations and provides a basis from which a bid may be developed. No bid may exceed the maximum allowable bid listed in Table 6-8.

4.2.3 Some insight into the bidding policies of competing companies can be gained by studying their "Bid Decisions" for past quarters as listed in Table 6-6. Some insight into the operating policies of competing companies can be gained by analyzing the information presented in Table 6-9.

4.2.4 One method of developing a bid figure is to:

- Determine direct cost per productive manhour (direct costs for similar contracts provide a general guide, see Table 6-5)
- Multiply estimated direct cost per productive manhour by the manhour requirement of the contract
- Arbitrarily decide the overhead loading percentage required to recover indirect costs plus profit
- Add the overhead loading rate to the first figure

The computer will accept either a total bid figure (as above) or a per manhour bid. If a per manhour figure is bid, it is necessary to apply an overhead loading figure to the estimated direct cost per productive manhour figure. See Section V for the method of entering bids on the decision sheet.

4.2.5 The necessity for a careful consideration of cost in the case of fixed-price (Production) contracts is apparent when it is realized that additional costs in excess of bid bring about a direct reduction of profit. In the case of cost-plus-fixed-fee (Research and Development) contracts, the company is guaranteed a profit. However, a history of overrunning bid prices reduces the company's attractiveness for future awards.

4.3 PRESENTATION EXPENSE.

4.3.1 The amount to be spent on presenting a bid depends primarily on the complexity of the device or service required by the Government. Two other factors are involved in determining presentation costs: How urgently does the company need this contract? What is the anticipated effort of competitors? Research and Development contracts are considered to involve more complex work than do Production contracts. Space Systems are more complex than are Missile Systems. The factors involved in developing a bid (see paragraph 4.2) will indicate an answer to the first question. Table 6-9 shows the relative status of each company; this information indicates how urgently other companies may need a contract. Figure 4-1 presents a very general idea of what proposal presentations cost.

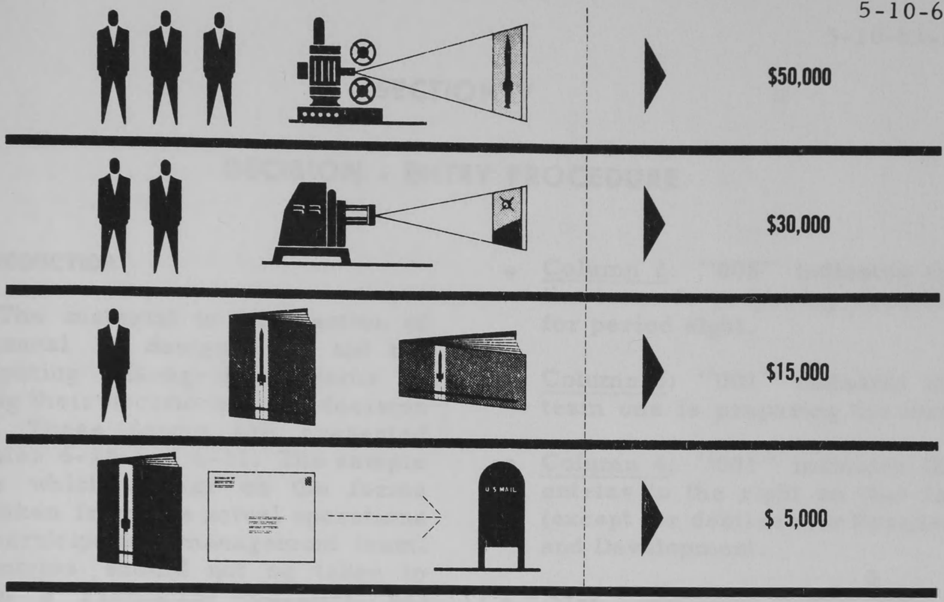

Figure 4-1 Presentation Expense

4.4 METHOD FOR ENTERING CONTRACT BIDDING DECISIONS.

4.4.1 The method for entering these decisions is discussed in paragraph 5.4, Section V.

4.5 CONTRACT AWARDS.

4.5.1 In addition to the dollar bid submitted by a company, a number of other factors are considered by the Government before a contract is awarded. These additional factors include:

- Available manpower
- Experience in the function or product area of the contract
- History of overrunning or underrunning Research and Development contracts
- History of meeting, beating, or slipping deadlines
- Present average cost per productive manhour on Research and Development contracts
- Financial condition (ratio of debt minus cash to equity, Table 6-3)
- Present backlog (the lower the backlog, the more attractive the company)
- History of investment in Internal Research
- Hardship in terms of idle labor or layoffs if contract is not awarded
- Quality of the presentation relative to the complexity of the proposal

4.5.2 All of the above factors do not carry the same weight in the determination of contract awards. Since Research and Development contracts are cost plus fixed fee, for such contracts, a history of low-cost performance tends to be more important than the actual price bid on a particular contract. In Production contracts, however, bid price is of prime importance. Internal research assumes a greater importance in the awarding of Research and Development contracts than in the case of Production contracts. Finally, Research and Development experience in a given product area tends to influence the awarding of Production contracts in the same product area; the **converse,** however, is not true.

SECTION V

DECISION - ENTRY PROCEDURE

5.1 INTRODUCTION

5.1.1 The material in this section of the manual is designed to aid the participating management teams in entering their decisions on the decision forms. These forms are presented as Tables 6-10 and 6-11. The sample entries which appear on the forms were taken from the actual operations of a participating management team. The entries should not be taken to indicate a successful operation, but merely as representative figures for illustrating the entry procedures.

5.1.2 Computer input is punched directly from the decision forms. The entries in the first four columns of the decision forms present identifying information. Each of these entries must contain three digits; decimal points or other punctuation marks must not be used. The next three columns (5, 6, and 7) contain the actual decisions. These figures must be stated in thousands (for example, the number 14,381 would be entered as 14.381). Only numerals and decimal points may be entered in any field. ANY OTHER MARK WILL INVALIDATE THE RUN.

5.2 HOW TO ENTER RESOURCE CHANGE DECISIONS.

5.2.1 A set of sample figures is entered in Table 6-10 to indicate how resource changes must be entered on the form.

- Column 1: ''001'' indicates the form code number for the computer program.
- Column 2: ''008'' indicates that the team is preparing decisions for period eight.
- Column 3: ''001'' indicates that team one is preparing the form.
- Column 4: ''001'' indicates that entries to the right on that line (except for debt) are for Research and Development.
- ''002'' indicates that entries to the right on that line (except for debt) are for Production.
- Column 5: ''-220.0'' indicates that 220 Research and Development employees are to be fired next quarter.
- ''+325.0'' indicates that 325 Production employees are to be hired next quarter.
- Column 6: ''5.0'' indicates that \$5,000.00 are to be spent for education and training of Research and Development personnel.
- ''30.0'' indicates that \$30,000.00 are to be spent for education and training of Production personnel.
- Column 7: No entry on the first line indicates that the wage rate from last period is to be continued without change.
- ''3.20'' indicates that the wage rate for Production employees is to be changed to \$3.20 per hour for the next period.

- Column 8: "+500.00" indicates that $500,000.00 worth of Research and Development facilities is to be built next quarter.

- No entry on the second line indicates no change in Production facilities next quarter.

- Column 9: "+500.00" indicates that an additional $500,000.00 worth of debt is to be incurred next quarter. This entry may be made on either line.

5.3 HOW TO ENTER CONTRACT PERFORMANCE DECISIONS.

5.3.1 Contract performance decisions involve applying regular time, overtime, and subcontracted manhours to each contract held by a company. Table 6-11 presents the form for entry of this type of decision. The column entries should be made as follows:

- Column 1: "002" identifies the entry as a contract performance or a bid decision.

- Column 2: "008" identifies the entry as being for period eight.

- Column 3: "002" identifies the company as being company number one.

- Column 4: "037, 042," etc. indicates the contract numbers.

- Column 5: "0.104, 215.0," etc. indicates the number of regular time manhours applied to the contract specified in Column 4 in thousands of manhours.

- Column 6: Entries in this column would indicate overtime hours applied.

- Column 7: Entries in this column would indicate subcontracted hours.

- Column 8 & 9: Entries in these columns are for bidding, see paragraph 5.4.

5.3.2 A summary of the hours applied to each contract during the last period appears in Table 6-5 under "Manhours Last Period." Each figure is the sum of regular time, overtime, and subcontracted manhours applied to the specified contract. Each type of allocation (regular time, overtime, or subcontracted manhours) is listed in Table 6-6 by function (Production or Research and Development).

5.4 HOW TO ENTER CONTRACT BIDDING DECISIONS.

5.4.1 Bidding decision entries are to be made on the form presented in Table 6-11 for each contract in which the company has an interest. The sample entries which appear in Table 6-11 have the significance indicated below:

- Column 1: "002" identifies the entry as a contract performance or bid decision.

- Column 2: "008" identifies the entry as being for period eight.

- Column 3: "001" identifies the company as being company number one.

- Column 4: "037, 042, etc." indicates contract numbers.

- Columns 5, 6, & 7: Entries in these columns are for contract performance, see paragraph 3.5.1.

- Column 8: "4800.0" indicates a total bid of $4,800,000.00 was submitted on contract number 61; "6.89" indicates a per hour bid of $6.89 was submitted on contract number 62. Either type of bid may be submitted.

- Column 9: "5.0" indicates that $5,000.00 was spent to present bids on each contract. This figure need not be the same for each contract.

SECTION VI

FINANCIAL AND OPERATING TABLES

6.1 Tables 6-10 and 6-11 present a hypothetical set of decisions which the computer received at the beginning of period 8 for company 1. The information presented in Tables 6-1 through 6-9 is the balance sheets prepared by the computer reflecting the decisions entered in Tables 6-10 and 6-11.

PROFIT AND LOSS (Table 6-1)

Definition of Terms:

TOTAL SALES: payments due for the progress on all contracts. Sales convert to cash through accounts receivable with a twelve week lag for Production contracts and eight weeks for R&D contracts.

TOTAL DIRECT LABOR: the cost of all labor (regular and overtime) applied to all contracts (R&D and Production) during a period.

TOTAL DIRECT MATERIALS: cost of materials used in contract effort. Materials are not directly controllable by participants but are automatically allocated to contracts in proportion to productive labor. Materials are used at a rate between $2.00 and $3.00 per productive manhour of labor.

TOTAL DIRECT FACILITIES: that portion of the depreciation of facilities used for direct contract effort. Depreciation occurs at a rate of 3% per period.

TOTAL DIRECT OVERHEAD: cost of supervising direct labor.

TOTAL SUBCONTRACTING: cost for subcontracted hours (number of subcontracted hours applied to contracts multiplied by the subcontracting rate presented in Table 6-7).

TOTAL DIRECT EXPENSES: total of direct labor, direct materials, direct facilities, direct overhead, and subcontracting.

OPERATING PROFIT: difference between total sales and total direct expenses.

EDUCATION AND TRAINING: sum of amounts allocated to both R&D and Production.

INTERNAL RESEARCH:
- cost of available R&D personnel not allocated to direct contract effort
- proportionate share of depreciation on R&D facilities
- materials used by these personnel
- portion of R&D overhead

INTEREST EXPENSE: outstanding debt times interest rate. A company's interest rate is redetermined each period.

ADMINISTRATIVE EXPENSE: cost associated with performing the following functions:
- cost estimation and bid development
- personnel (hiring, firing, etc.)
- wage administration, general accounting, contract accounting, etc.
- plant construction and maintenance
- expediting

MISCELLANEOUS EXPENSES: primarily costs of idle production labor and financial costs associated with borrowing cash or retiring debt.

TOTAL INDIRECT EXPENSES: total of education and training, internal research, interest expense, administrative expense, and "miscellaneous" expenses.

TOTAL EXPENSES: sum of direct and indirect expenses.

GROSS PROFIT: difference between total sales and total expenses. A negative difference indicates a loss.

INCOME TAXES: 52 percent of the gross profit. There occurs an immediate and automatic tax loss carry-back on any loss in which case this item will be preceeded by a minus sign.

NET EARNINGS: difference between gross profit and income taxes. A negative difference indicates the net loss after reflection of the tax loss carry-back.

Table 6-1

PROFIT AND LOSS

TOTAL SALES		$ 9922941.		100.00
TOTAL DIRECT LABOR	$ 5877909.		59.24	
TOTAL DIRECT MATERIALS	2598763.		26.19	
TOTAL DIRECT FACILITIES	212917.		2.15	
TOTAL DIRECT OVERHEAD	268894.		2.71	
TOTAL SUBCONTRACTING	0.		0.	
TOTAL DIRECT EXPENSES		8958483.		90.28
OPERATING PROFIT		964458.		9.72
EDUCATION AND TRAINING	35000.		0.35	
INTERNAL RESEARCH	0.		0.	
INTEREST EXPENSE	152364.		1.54	
ADMINISTRATIVE EXPENSE	591928.		5.97	
MISCELLANEOUS EXPENSES	11984.		0.12	
TOTAL INDIRECT EXPENSES		$ 791276.		7.97
TOTAL EXPENSES		9749758.		98.25
GROSS PROFIT		$ 173183.		1.75
INCOME TAXES		90055.		0.91
NET EARNINGS		$ 83128.		0.84

CASH FLOW (Table 6-2)

Definition of Terms:

REVENUE FROM OPERATIONS: total amount of receivables converted into cash during a period.

CASH FROM SALE OF ASSETS: cash received from sale of assets at rate of 50 cents on the dollar value; received in same period as sale.

NEW BORROWINGS: new cash received at current rate of interest; received in same period for which borrowing decision is made.

TOTAL RECEIPTS: total of revenue from operations, cash from sale of assets, and new borrowings.

TOTAL CASH EXPENSES: total expenses (Table 6-1), minus depreciation (Table 6-4), plus income taxes (Table 6-1) equals total cash expenses.

PLANT INVESTMENT: investment in facilities during period, same as decision sheet entry.

DEBT RETIREMENT: amount of debt retired by applying cash during a period. Same as decision sheet entry.

TOTAL DISBURSEMENTS: sum of total cash expenses, plant investment, and debt retirement.

NET CASH FLOW: difference between total receipts and total disbursements. A negative balance indicates cash outflow; a positive balance indicates net cash inflow.

FINANCIAL CONDITION (Table 6-3)

Definition of Terms:

CASH: cash on hand for next quarters operations (equal to balance last period plus net cash flow).

RECEIVABLES: sales not yet converted to cash (lag of about 8 weeks for R&D and 12 weeks for Production contracts).

FACILITIES (NET): depreciated value of facilities (facilities are purchased at beginning of each period and suffer depreciation for full period).

TOTAL ASSETS: sum of cash, receivables, and facilities (net).

DEBT: debt balance last period, plus new borrowing, minus retirement.

EQUITY AND SURPLUS: balance from the previous period plus net earnings (or minus net loss) last period.

TOTAL DEBT AND EQUITY: sum of debt, and equity and surplus.

Table 6-2

CASH FLOW

REVENUE FROM OPERATIONS	$ 9560246.	
CASH FROM SALE OF ASSETS	0.	
NEW BORROWINGS	500000.	
TOTAL RECEIPTS		$ 10060246.
TOTAL CASH EXPENSES	$ 9626880.	
PLANT INVESTMENT	500000.	
DEBT RETIREMENT	0.	
TOTAL DISBURSEMENTS		$ 10126880
NET CASH FLOW		-66634.

Table 6-3

FINANCIAL CONDITION

CASH	$ 2356835.	
RECEIVABLES	5851238.	
FACILITIES (NET)	6884861.	
TOTAL ASSETS		$ 15092934.
DEBT	$ 7500000.	
EQUITY AND SURPLUS	7592934.	
TOTAL DEBT AND EQUITY		$ 15092934.

MISCELLANEOUS DATE (Table 6-4)

Definition of Terms:

FACILITIES: includes net book value of space, working equipment, etc.

DEPRECIATION: depreciation of facilities during last period (3% of facilities value per quarter).

MEN AVAILABLE: actual employees in each function (R&D and Production) available after hires, fires, quits, and emergency hires.

M/H AVAILABLE: men times 500 equals manhours for next period.

EMERG HIRES: make up difference when more manhours are applied to a contract than there are available. Emergency hires are hired at a wage rate about 20% above market rate.

QUITS LAST PERIOD: number of men in each function who quit last period.

TURNOVER RATE: ratio of quits to labor force available before quits.

AVE WAGE RATE: average wage rate of inplant employees during last period.

AVE INT RATE: prime market rate of interest. New borrowings have an interest rate approaching this figure if company's rate of debt to equity is good.

INT RESEARCH MH: results from allocating fewer manhours to R&D contracts than are available, stated in manhours.

CONTRACT STATUS REPORT (Table 6-5)

Definition of Terms:

CTR/FCTN: the first number is the contract number; the second is the function code (this code is explained just below this report).

BID: The first column is the total dollar amount bid; the second column is this total divided by the total productive manhours required by the contract.

SALES TO DATE: the first column is the total payments due or paid to date on the contract; the second column is this total divided by the total productive manhours performed to date on the contract.

DIR COST TO DATE: the first column is the total direct cost accumulated to date on the contract; the second column is this total divided by the total productive manhours performed to date on the contract.

MANHOURS LAST PERIOD: the first column is the number of manhours (regular time, overtime, and subcontracted) applied to the contract last period; the second column is the efficiency factor on that contract last period; the third column is the number of productive manhours performed on the contract last period; the fourth column is the direct cost per productive manhour last period.

REMAINING: the first column indicates the number or productive manhours yet to be performed on the contract; the second column shows the number of periods remaining in which the contract can be performed without overrunning the deadline.

TOT REQUIRED: the first column indicates the total number of productive manhours required by the contract; the second column indicates the initial number of periods over which the contract was to be performed.

Table 6-4
MISCELLANEOUS DATA

	R&D	PROD	TOTAL
FACILITIES	4342113.	2542748.	6884861.
DEPRECIATION	134292.	78642.	212934.
MEN AVAILABLE	1596.	1483.	3079.
M/H AVAILABLE	798000.	741500.	1539500.
EMERG HIRES	5.	37.	42.
QUITS LAST PD	66.	92.	138.
TURNOVER RATE	0.0396	0.0462	
AVE WAGE RATE	4.303	3.297	
AVE INT RATE			0.0203
INT RESEARCH MH			0.

FUNCTION CODE

2--R&D, SPACE SYSTEMS
3--R&D, MISSILE SYSTEMS
4--PROD, SPACE SYSTEMS
5--PROD, MISSILE SYSTEMS

Table 6-5
CONTRACT STATUS REPORT

CTR/	FCTN	BID TOTAL	BID PER PMH	SALES TO DATE TOTAL	SALES TO DATE PER PMH	DIR COST TO DATE TOTAL	DIR COST TO DATE PER PMH	MANHOURS LAST PERIOD APPLIED	EFFIC	PRODUCED	COST	REMAINING PMH	REMAINING PDS	TOT REQUIRED PMH	TOT REQUIRED PDS
37	3	9900000.	8.250	10112466.	8.427	8985441.	7.488	104.	0.865	90.	265.7	0.	-2	1200000.	3
42	3	4950000.	8.250	5087236.	8.479	4592645.	7.654	215000.	0.809	174040.	7.783	0.	0	600000.	4
43	5	2172000.	7.240	2171882.	7.240	1704299.	5.681	5200.	0.908	4720.	8.986	0.	-1	300000.	3
44	5	2868000.	7.170	2867886.	7.170	2186441.	5.466	5100.	0.902	4600.	9.288	0.	-1	400000.	2
46	2	4944000.	8.240	5060777.	8.435	4607432.	7.679	278000.	0.801	222550.	7.849	0.	0	600000.	3
48	3	8240000.	8.240	4795215.	8.653	4267749.	7.701	305000.	0.808	246572.	7.646	445810.	2	1000000.	5
52	5	8508000.	7.090	4543653.	7.090	3662029.	5.714	340000.	0.909	308924.	5.862	559140.	2	1200000.	4
57	5	8625000.	6.900	2339739.	6.900	1967933.	5.803	391000.	0.867	339093.	6.058	910900.	2	1250000.	3
63	3	7100000.	7.889	0.	0.	0.		0.	0.	0.		900000.	3	900000.	3

DECISIONS LAST PERIOD (Table 6-6)

Definition of Terms:

MEN HIRED: number of men hired for R&D and/or Production.

MEN FIRED: number of men fired from R&D and/or Production.

FACILITIES BUILT: facilities built for R&D and/or Production.

ED AND TR EXP: total expenses for education and training.

R/T MANHOURS APPLIED: regular time manhours applied to all contracts last period.

O/T MANHOURS APPLIED: overtime manhours applied to all contracts last period.

SUBCONTRACTED M/H: subcontracted manhours applied to all contracts last period.

WAGE RATE: company wage rate which was specified for last period (hires, of course, come in at the market rate).

DEBT ADDED/RETIRED: amount of cash borrowed or debt paid off last period.

CONTRACT/FUNCTION: contract number and type of function.

WINNING COMPANY: number of company winning contract.

TOTAL PMH REQUIRED: total productive manhours required for contract specified.

AV PMH RQD/PD: average number of productive manhours required for each period.

YOUR BID: total dollar bid and per hour bid.

COST TO PRESENT: amount spent by your company to make bid presentation.

WINNING BID: total dollar bid and per hour bid.

Table 6-6

DECISIONS LAST PERIOD

OPERATING DECISIONS	R & D	PRODUCTION
MEN HIRED	0.	325.
MEN FIRED	220.	0.
FACILITIES BUILT	500000.	0.
FACILITIES SOLD	0.	0.
ED AND TR EXP	5000.	30000.
R/T MANHOURS APPLIED	798104.	741300.
O/T MANHOURS APPLIED	0.	0.
SUBCONTRACTED M/H	0.	0.
WAGE RATE	4.30	3.20
DEBT ADDED/RETIRED	0.	0.

BID DECISIONS

CONTRACT/ FUNCTION		WINNING COMPANY	TOTAL PMH REQUIRED	AV PMH RQD/PD	COST TO PRESENT	YOUR BID TOTAL	YOUR BID PER HOUR	WINNING BID TOTAL	WINNING BID PER HOUR
61	2	5	600000.	150000.	5000.	4800000.	8.000	4830000.	8.050
62	4	3	400000.	100000.	5000.	2756000.	6.890	2640000.	6.600
63	3	1	900000.	300000.	5000.	7200000.	7.889	7100000.	7.889
64	5	5	500000.	100000.	5000.	3395000.	6.790	3400000.	6.800

FUNCTION CODE

2 -- R&D, SPACE SYSTEMS

3 -- R&D, MISSILE SYSTEMS

4 -- PROD, SPACE SYSTEMS

5 -- PROD, MISSILES SYSTEMS

INDUSTRY PROCUREMENT COSTS (Table 6-7)

Definition of Terms:

WAGE RATE: wage rate to be paid for new hires next period.

SUBCONTRACTING: rate charged for subcontracting next period (subcontracting rate includes all direct costs).

INTEREST RATE: prime market rate of interest.

CONTRACT INFORMATION - REQUESTS FOR PROPOSAL (Table 6-8)

Definition of Terms:

CONTRACT NUMBER: number of contract for which bid is requested.

FUNCTION: either R&D or Production effort.

PRODUCT: type of product resulting from effort; Space Systems or Missiles Systems.

TOTAL PMH REQUIRED: total productive manhours required for completion of specified contract.

DEADLINE PERIOD: last period in which a contract may be worked without schedule tardiness. Contract 65, for example, is a two-period contract.

AVERAGE PD M/H RQT: average number of productive manhours required per period to complete within deadline.

MAXIMUM BID: bids above this total bid price are reduced to this maximum before consideration.

MAXIMUM BID/PMH: maximum bid divided by total productive manhour requirement.

Table 6-7

INDUSTRY PROCUREMENT COSTS

	R&D	PROD
WAGE RATE	4.25	3.52
SUBCONTRACTING	8.93	6.61
INTEREST RATE		0.0202

Table 6-8

CONTRACT INFORMATION – REQUESTS FOR PROPOSAL

CONTRACT NUMBER	FUNCTION	PRODUCT	TOTAL PMH REQUIRED	DEADLINE PERIOD	AVERAGE PD M/H RQT	MAXIMUM BID	MAXIMUM BID/PMH
65	R&D	SPACE SYSTEMS	400000.	11	200000.	3336000.	8.340
66	PROD	SPACE SYSTEMS	626600.	11	313300.	4386200.	7.000
67	PROD	MISSILE SYSTEMS	772500.	12	257500.	5639250.	7.300
68	R&D	MISSILE SYSTEMS	786500.	14	157300.	6449300.	8.200
69	R&D	SPACE SYSTEMS	303000.	11	151500.	2514900.	8.300

COMPANY INFORMATION (Table 6-9)

Definition of Terms:

SALES: same figure presented in Table 6-1 opposite "Total Sales."

DIRECT EXP: same figure presented in Table 6-1 opposite "Total Direct Expenses."

OPER PRO: difference between Sales and Total Direct Expenses.

OTHER EXP: the sum of "Total Indirect Expenses" and "Income Taxes" in Table 6-1.

NET PRO: same figure presented in Table 6-1 opposite "Net Earnings."

NET CASH: same figure presented in Table 6-3 opposite "Cash."

RECEIVABLES: same figure presented in Table 6-3 opposite "Receivables."

NET PLANT: same figure presented in Table 6-3 opposite "Facilities (Net)."

TOTAL DEBT: same figure presented in Table 6-3 opposite "Debt."

TOTAL EQUITY: same figure presented in Table 6-3 opposite "Equity and Surplus."

BACKLOG (M/H): total remaining productive manhour requirement on contracts awarded to a company.

SUBCTR: same figure presented in Table 6-6 opposite "Subcontracted M/H."

MEN: same figure presented in Table 6-4 opposite "Men Available."

MANHOURS: same figure presented in Table 6-4 opposite "M/H Available."

WAGE RATE: same figure presented in Table 6-6 opposite "Wage Rate."

NOTE: All dollar and manhour figures are stated in thousands in this table.

Table 6-9

COMPANY INFORMATION

COMPANY 1

PROFIT AND LOSS		FINANCIAL CONDITION		OTHER ITEMS	R&D	PROD
SALES	9923.	NET CASH	2357.	BACKLOG (M/H)	1346.	1470.
DIRECT EXP	8958.	RECEIVABLES	5851.	SUBCTR	0.	0.
OPER PRO	964.	NET PLANT	6885.	MEN	1596.	1483.
OTHER EXP	881.	TOTAL DEBT	7500.	MANHOURS	798.	742.
NET PRO	83.	TOTAL EQUITY	7593.	WAGE RATE	4.30	3.20

COMPANY 2

PROFIT AND LOSS		FINANCIAL CONDITION		OTHER ITEMS	R&D	PROD
SALES	5348.	NET CASH	3155.	BACKLOG (M/H)	393.	0.
DIRECT EXP	4780.	RECEIVABLES	2945.	SUBCTR	0.	0.
OPER PRO	568.	NET PLANT	5465.	MEN	940.	969.
OTHER EXP	757.	TOTAL DEBT	6000.	MANHOURS	470.	348.
NET PRO	-190.	TOTAL EQUITY	5565.	WAGE RATE	4.28	3.30

COMPANY 3

PROFIT AND LOSS		FINANCIAL CONDITION		OTHER ITEMS	R&D	PROD
SALES	5872.	NET CASH	3893.	BACKLOG (M/H)	517.	400.
DIRECT EXP	5259.	RECEIVABLES	2833.	SUBCTR	0.	0.
OPER PRO	613.	NET PLANT	5525.	MEN	1170.	604.
OTHER EXP	562.	TOTAL DEBT	4700.	MANHOURS	585.	302.
NET PRO	51.	TOTAL EQUITY	7551.	WAGE RATE	4.29	3.20

COMPANY 4

PROFIT AND LOSS		FINANCIAL CONDITION		OTHER ITEMS	R&D	PROD
SALES	5860.	NET CASH	2653.	BACKLOG (M/H)	657.	545.
DIRECT EXP	5189.	RECEIVABLES	2879.	SUBCTR	0.	0.
OPER PRO	672.	NET PLANT	4665.	MEN	1158.	566.
OTHER EXP	630.	TOTAL DEBT	3900.	MANHOURS	579.	283.
NET PRO	42.	TOTAL EQUITY	6207.	WAGE RATE	4.35	3.44

COMPANY 5

PROFIT AND LOSS		FINANCIAL CONDITION		OTHER ITEMS	R&D	PROD
SALES	7372.	NET CASH	4084.	BACKLOG (M/H)	869.	926.
DIRECT EXP	6284.	RECEIVABLES	4661.	SUBCTR	0.	0.
OPER PRO	1088.	NET PLANT	4773.	MEN	1060.	1192.
OTHER EXP	972.	TOTAL DEBT	6000.	MANHOURS	530.	596.
NET PRO	116.	TOTAL EQUITY	7517.	WAGE RATE	4.32	3.30

Table 6-10
RESOURCE CHANGES

IDENTIFICATION				MANPOWER			FACILITIES	DEBT
Decision Form Code [1] [3]	Next Period [4] [6]	Company Number [7] [9]	R&D (001) Prod (002) [10] [12]	Hire (+) Fire (-) [13] (units) [22]	Ed & Training Expenditure [23] (1000's) [32]	New Hourly Wage Rate [33] (dollars) [42]	Build (+) Sell (-) [43] (1000's) [52]	Add Debt (+) Retire Debt (-) [53] (1000's) [62]
001	008	001	001	-220.0	5.0		+500.0	
			002	+325.0	30.0	3.20		+500.0

Table 6-11
CONTRACT PERFORMANCE AND BIDS

IDENTIFICATION				CONTRACT PERFORMANCE			CONTRACT BIDS	
Decision Form Code	Next Period	Company Number	Contract Number	Regular Time (1000's)	Overtime (1000's)	Subcontracting (1000's)	Bid ($ per hr. or total in 1000's)	Presentation (1000's)
002	008	005	037	0.104				
			042	215.0				
			043	5.2				
			044	5.1				
			046	278.0				
			048	305.0				
			052	340.0				
			057	391.0				
			061				4800.0	5.0
			062				6.89	5.0
			063				7100.0	5.0
			064				6.79	5.0

x Numbers within squares indicate card columns for key punching.

SECTION VII

INITIAL CONDITION REPORTS

7.1 GENERAL.

7.1 Tables 7-1 to 7-3 present the set of beginning Period 1 reports for a hypothetical Company 4. The status of this company at the end of Period 0 is superimposed on Table 7-1. These reports constitute the initial conditions for all companies. The only difference between companies is in the contract numbers. Whereas Company 4 begins with contracts 4, 14, and 24 (as illustrated in this section), other companies begin with the following contracts:

	Company 1	Company 2	Company 3	Company 5
Beginning Contract Numbers	1	2	3	5
	11	12	13	15
	21	22	23	25

Table 7-4 is the completed decision form for Period 1 that was submitted at the end of Period 0 for all companies. Notice from Table 7-3 that all companies begin the exercise at the end of Period 1 in the same position. Notice also that Table 7-3 contains the contracts to be bid on the Period 2 decision sheets.

Table 7-1
AEROSPACE BUSINESS ENVIRONMENT SIMULATOR - COMPANY REPORTS
COMPANY 4 PERIOD 1

P R O F I T   A N D   L O S S

	DOLLARS		PERCENT	
TOTAL SALES		$ 8049807.		100.00
TOTAL DIRECT LABOR	$ 3834770.		47.64	
TOTAL DIRECT MATERIALS	1702463.		21.15	
TOTAL DIRECT FACILITIES	132584.		1.65	
TOTAL DIRECT OVERHEAD	273831.		3.40	
TOTAL SUBCONTRACTING	812000.		10.09	
TOTAL DIRECT EXPENSES		6755648.		83.92
OPERATING PROFIT		1294159.		16.08
EDUCATION AND TRAINING	30000.		0.37	
INTERNAL RESEARCH	25866.		0.32	
INTEREST EXPENSE	120000.		1.49	
ADMINISTRATIVE EXPENSE	409840.		5.09	
MISCELLANEOUS EXPENSES	1990.		0.02	
TOTAL INDIRECT EXPENSES		$ 587696.		7.30
TOTAL EXPENSES		7343343.		91.22
GROSS PROFIT		706463.		8.78
INCOME TAXES		367361.		4.56
NET EARNINGS		$ 339102.		4.21

C A S H   F L O W

REVENUE FROM OPERATIONS	$ 8109263.	
CASH FROM SALE OF ASSETS	0.	
NEW BORROWINGS	0.	
TOTAL RECEIPTS		$ 8109263.
TOTAL CASH EXPENSES	$ 7577954.	
PLANT INVESTMENT	175000.	
DEBT RETIREMENT	0.	
TOTAL DISBURSEMENTS		7752954.
NET CASH FLOW		$ 356309.

F I N A N C I A L   C O N D I T I O N

CASH	$ 2506308.	
RECEIVABLES	4940544.	
FACILITIES (NET)	4292250.	
TOTAL ASSETS		$11739102.
DEBT	$ 6000000.	
EQUITY AND SURPLUS	5739102.	
TOTAL DEBT AND EQUITY		$11739102.

M I S C E L L A N E O U S   D A T A

	R + D	P R O D	T O T A L
FACILITIES	2716000.	1576250.	4292250.
DEPRECIATION	84000.	48750.	132750.
MEN AVAILABLE	953.	981.	1934.
M/H AVAILABLE	476500.	490500.	967000.
EMERG HIRES	0.	0.	0.
QUITS LAST PD	37.	39.	76.
BKLG RATIO	0.20	0.20	0.20
OUTPUT RATIO	0.20	0.20	0.20
TURNOVER RATE	0.0374	0.0382	
AVE WAGE RATE	4.000	3.017	
AVE INT RATE			0.0200
INT RESEARCH MH			1000.

PERIOD 0 STATUS

$ 2150000.	
5000000.	
4250000.	
	$11400000.
$ 6000000.	
5400000.	
	$11400000.

R & D	PROD	TOTAL
2700000.	1550000.	4250000.
0.	0.	0.
990.	990.	1980.
495000.	495000.	990000.
0.	0.	0.
0.	0.	0.
0.20	0.20	0.20
0.	0.	0.
0.	0.	
4.000	3.000	
		0.
		0.

Table 7-2

AEROSPACE BUSINESS ENVIRONMENT SIMULATOR - COMPANY REPORTS
COMPANY 4 PERIOD 1

C O N T R A C T   S T A T U S   R E P O R T

CTR/		B I D		SALES TO DATE		DIR COST TO DATE		MANHOURS LAST PERIOD				REMAINING		TOT REQUIRED	
	FCTN	TOTAL	PER PMH	TOTAL	PER PMH	TOTAL	PER PMH	APPLIED	EFFIC	PRODUCED	COST	PMH	PDS	PMH	PDS
4	2	6100000.	9.000	2316841.	8.057	2079279.	7.231	352500.	0.816	287560.	7.231	612440.	2	900000.	3
14	3	7200000.	9.000	1722681.	8.782	1546935.	7.886	223000.	0.880	196169.	7.886	603830.	3	800000.	4
24	5	20000000.	8.000	4010284.	8.000	3129434.	6.243	590600.	0.849	501286.	6.243	1998710.	4	2500000.	5

FUNCTION CODE
- 2--R+D, SPACE SYSTEMS
- 3--R+D, MISSILE SYSTEMS
- 4--PROD, SPACE SYSTEMS
- 5--PROD, MISSILE SYSTEMS

D E C I S I O N S   L A S T   P E R I O D

OPERATING DECISIONS--	R + D	PRODUCTION
MEN HIRED	0.	30.
MEN FIRED	0.	0.
FACILITIES BUILT	100000.	75000.
FACILITIES SOLD	0.	0.
ED AND TR EXP	20000.	10000.
R/T MANHOURS APPLIED	475500.	490600.
C/T MANHOURS APPLIED	0.	100000.
SUBCONTRACTED M/H	100000.	0.
WAGE RATE	4.00	3.00
DEBT ADDED/RETIRED	0.	0.

BID DECISIONS--

Table 7-3

AEROSPACE BUSINESS ENVIRONMENT SIMULATOR - INDUSTRY REPORTS PERIOD 1

INDUSTRY PROCUREMENT COSTS

	R+D	PROD
WAGE RATE	4.23	3.54
SUBCONTRACTING	8.12	6.06
INTEREST RATE		.0200

CONTRACT INFORMATION - - REQUESTS FOR PROPOSAL

CONTRACT NUMBER	FUNCTION	PRODUCT	TOTAL PMH REQUIRED	DEADLINE PERIOD	AVERAGE PD M/H RQT	MAXIMUM BID	MAXIMUM BID/PMH
31	PROD	SPACE SYS	1800000.	8	300000.	14040000.	7.800
32	R+D	SPACE SYS	300000.	5	100000.	2670000.	8.900
33	PROD	MISSILE SYS	1800000.	8	300000.	13590000.	7.550
34	R+D	MISSILE SYS	700000.	9	100000.	6160000.	8.800
35	PROD	MISSILE SYS	1200000.	8	200000.	9420000.	7.850
36	R+D	SPACE SYS	1200000.	6	300000.	10860000.	9.050

COMPANY INFORMATION

COMPANY 1

PROFIT AND LOSS		FINANCIAL CONDITION		OTHER ITEMS	R+D	PROD
SALES	8050.	NET CASH	2506.	BACKLOG(M/H)	1216.	1999.
DIRECT EXP	6756.	RECEIVABLES	4941.	SUBCTR	100.	0.
OPER PRO	1294.	NET PLANT	4292.	MEN	953.	981.
OTHER EXP	955.	TOTAL DEBT	6000.	MANHOURS	477.	491.
NET PRO	339.	TOTAL EQUITY	5739.	WAGE RATE	4.00	3.00

COMPANY 2

PROFIT AND LOSS		FINANCIAL CONDITION		OTHER ITEMS	R+D	PROD
SALES	8050.	NET CASH	2506.	BACKLOG(M/H)	1216.	1999.
DIRECT EXP	6756.	RECEIVABLES	4941.	SUBCTR	100.	0.
OPER PRO	1294.	NET PLANT	4292.	MEN	953.	981.
OTHER EXP	955.	TOTAL DEBT	6000.	MANHOURS	477.	491.
NET PRO	339.	TOTAL EQUITY	5739.	WAGE RATE	4.00	3.00

COMPANY 3

PROFIT AND LOSS		FINANCIAL CONDITION		OTHER ITEMS	R+D	PROD
SALES	8050.	NET CASH	2506.	BACKLOG(M/H)	1216.	1999.
DIRECT EXP	6756.	RECEIVABLES	4941.	SUBCTR	100.	0.
OPER PRO	1294.	NET PLANT	4292.	MEN	953.	981.
OTHER EXP	955.	TOTAL DEBT	6000.	MANHOURS	477.	491.
NET PRO	339.	TOTAL EQUITY	5739.	WAGE RATE	4.00	3.00

COMPANY 4

PROFIT AND LOSS		FINANCIAL CONDITION		OTHER ITEMS	R+D	PROD
SALES	8050.	NET CASH	2506.	BACKLOG(M/H)	1216.	1999.
DIRECT EXP	6756.	RECEIVABLES	4941.	SUBCTR	100.	0.
OPER PRO	1294.	NET PLANT	4292.	MEN	953.	981.
OTHER EXP	955.	TOTAL DEBT	6000.	MANHOURS	477.	491.
NET PRO	339.	TOTAL EQUITY	5739.	WAGE RATE	4.00	3.00

COMPANY 5

PROFIT AND LOSS		FINANCIAL CONDITION		OTHER ITEMS	R+D	PROD
SALES	8050.	NET CASH	2506.	BACKLOG(M/H)	1216.	1999.
DIRECT EXP	6756.	RECEIVABLES	4941.	SUBCTR	100.	0.
OPER PRO	1294.	NET PLANT	4292.	MEN	953.	981.
OTHER EXP	955.	TOTAL DEBT	6000.	MANHOURS	477.	491.
NET PRO	339.	TOTAL EQUITY	5739.	WAGE RATE	4.00	3.00

Table 7-4

AEROSPACE BUSINESS ENVIRONMENT SIMULATOR

IDENTIFICATION				MANPOWER			FACILITIES	DEBT
Decision Form Code [1] [3]	Next Period [4] [6]	Company Number [7] [9]	R&D (001) Prod (002) [10] [12]	Hire (+) Fire (-) [13] (units) [22]	Ed & Training Expenditure [23] (1000's) [32]	New Hourly Wage Rate [33] (dollars) [42]	Build (+) Sell (-) [43] (1000's) [52]	Add Debt (+) Retire Debt (-) [53] (1000's) [62]
0 0 1	001	004	001		20.0		+100.0	
			002	+30.0	10.0		+ 75.0	

IDENTIFICATION				CONTRACT PERFORMANCE			CONTRACT BIDS	
Decision Form Code	Next Period	Company Number	Contract Number	Regular Time (1000's)	Overtime (1000's)	Subcontracting (1000's)	Bid ($ per hr. or total in 1000's)	Presentation (1000's)
0 0 2	001	004	004	352.5				
			014	123.0		100.0		
			024	490.6	100.0			

x Numbers within squares indicate card columns for key punching.

5-10-61-4A

Appendix C

THE HEURISTIC DECISION-MAKER PROGRAM (HDM)

The major subroutines and functions used by the HDM are first summarized, then listed. A general description of HDM appears in Chapter IV. The logic of the program can be followed by observing the comment cards (statements introduced by C). Because of their bulk and lack of general interest the dimension and common statements have been omitted from the individual subroutines; it is necessary, however, that the following arrays be defined:

X(I, J, K) – Decision generation array where I is a company number index, J is a specific decision function and K is some variable or parameter associated with function J .

Y(I, J, K) – Objective function array where I is a company number index, J is a specific objective, and K is some variable or parameter associated with function J .

Z(I, J, K) – Contract scheduling array where I is a contract characteristic variable, J is the contract number index, and K is the company index.

Within the program the subscript KN usually identifies a particular contract number, the subscript J a particular company, and the subscript K indicates one of two functions, R&D or production.

The major subroutines and functions are specified and described below.

RALOC – Calculates internal investment decisions.

RCALC – Measures and evaluates last period's performance in terms of objectives, and also calculates the productive manhour requirement next period if schedule objective is to be met.

ACALC – Forecasts available manhours next period if there are no hires or fires; determines excess or required manhours relative to productive manhour requirement from RCALC; and develops first tentative resource procurement decisions according to the mean values of the appropriate policy functions.

ASSIGN – Assigns manhours, overtime, subcontracting and schedule adjustment to specific contracts according to greatest need in terms of schedule and cost performance last period as determined in RCALC.

EVAL – Estimates the values of objective variables if plan thus far developed is implemented.

SCORE – Calculates total score of the plan considering the objective values, compares this score with the previously highest score, and saves the decision values if this plan results in a higher score.

GOL – Calculates a numerical goal score for objective functions given function specification parameters and arguments.

DBID – Generates all combinations of contracts offered, loads each combination on current backlog, selects the combination producing the least variance over the specified planning period, and calculates a bid price for each contract selected.

RSPEC – Loads selected decisions and bids into the decision area for the company under consideration.

BOTH – Produces a cash forecast and determines borrowings or debt retirement decisions for next period.

EFF – Given the percentage completion of a contract, this subroutine forecasts the efficiency to be achieved next period.

CTRL – A multipurpose function to score the deviation between an objective value and the goal value for a given objective.

RNORM – Given a sample from a uniform distribution, 0 - 1, RNORM produces a sample from a normal distribution with $\mu = 0$ and $\sigma = 1$.

INLJM – Tests whether a variable, v falls within limits a and b.

AFFM – Forecasts administrative expenses.

QTFCST – Forecasts quits or voluntary labor turnover.

RPGEN – Develops a specified number of random proportions drawn from a normal distribution with $\mu = 0$ and $\sigma = 1$ which are normalized between 0 and 1.

RANDM – Generates a uniform random distribution, 0 - 1.

```
C  HEURISTIC DECISION MAKER (HDM) PROGRAM
      DO 5 J=1,5
      IF (W(9,J+10)) 5,5,6
    6 CALL ZERJ(J)
      DO 8 K=1,2
      CALL RALOC(J,K)
      CALL RCALC(J,K)
      CALL ACALC(J,K)
      CALL ASSIGN(J,K)
      CALL EVAL(J,K)
      CALL SCORE(J,K)
    8 CONTINUE
      DO 9 K=1,2
      CALL DBID(J,K)
   26 FORMAT(5H XTRA10F12.4)
      DO 25 KRT=1,10
   25 WRITE OUTPUT TAPE 6,26,(XTRA(KRT,KR,1),KR=1,10)
    9 CALL RSPEC(J,K)
      CALL BOTH(J)
    5 CONTINUE
      CALL XYZOUT
      CALL CHAIN(3,3)
      END
      SUBROUTINE RALOC(J,K)
   10 FORMAT(1H 4I2,F10.3)
      J=J
      K=K
      KR=9
      IF(K-2) 14,13,14
   13 KR=8
   14 CONTINUE
      L=(K-1)*5
      L5=L+5
      L4=L+4
      L3=L+3
      L2=L+2
```

```
      L1=L+1
      RSUM=0.0
    8 FORMAT(1H 11HRALOC ERROR6F10.5)
      LOOP=0
      LINK=K+2
      LPT=2
      IF (MAX1F(X(J,7,L5),X(J,8,L5),X(J,9,L5))) 11,11,12
   11 LPT=1
   12 GO TO (15,1),LPT
    1 CALL RNORM(C8,R1,R2)
      LOOP=LOOP+1
      IF (LOOP-1000) 6,6,7
    7 WRITE OUTPUT TAPE6,8,C8,R1,R2,X(J,10,L2),X(J,10,L1),RADJ
    6 CONTINUE
      RADJ=R1*X(J,10,L2)+X(J,10,L1)
      IF(INLIM(0.0,RADJ,1.0)-3)5,4,5
    5 RADJ=R2*X(J,10,L2)+X(J,10,L1)
      IF(INLIM(0.0,RADJ,1.0)-3) 1,4,1
    4 X(J,10,L3)=RADJ
      CALL RPGEN(J,K,X,C8,LINK)
      GO TO 16
   15 XSUM=0.0
      DO 17 KT=7,KR
   17 XSUM=XSUM+X(J,KT,L1)
      X(J,10,L3)=X(J,10,L1)
      DO 18 KT=7,KR
   18 X(J,KT,L3)=X(J,KT,L1)/XSUM
   16 DO 3 KT=7,KR
    3 X(J,KT,L4)=X(J,KT,L3)*X(J,10,L3)
C THIS NEXT CONTAINS AMOUNT /AMH TO BE SPENT
      RETURN
      END


      SUBROUTINE RCALC(J,K)
C  THIS S/R CALCULATES PMH RQTS FOR FCTN K CTRS OF CO J ACCORDING TO
```

```
C   SCHEDULE OBJECTIVE, AND PUTS RESULTS IN Z(2,N,J).
          J=J
          K=K
          JK=J+5*(K-1)
          L=(K-1)*5
          L1=L+1
          L2=L+2
          L3=L+3
          L4=L+4
          L5=L+5
          KTP=(K-1)*5
          L1=KTP+1
          EFSUM=0.0
          PRSUM=0.0
          CSTAT=0.0
          Z(10,K+8,J)=0.0
          Z(10,K+2,J)=0.0
          Z(10,K+4,J)=0.0
          ARQT=0.0
          TRQD=0.
          SDN=0.0
          EDN=0.0
          CDN=0.0
          CSDN=0.0
          HDN=0.0
C   FIRST PUT ACTIVE CTR NRS IN Z(1,1-10,J) BY FCTN WITH N(R)IN Z(10,1,1)
C    AND N(P) IN Z(10,1,2)
          L=Z(10,1,J)
          LM=J*2-1
          LV=J*2
          DO 11 KL=1,9
       11 X(K+8,KL,LM)=0.0
          DO 555 KL=1,6
      555 X(J,KL,L4)=0.0
          R=X(8,1,K)
          TP=0.0
```

```
      IF (K-1)6,5,6
    5 L=0
   15 TP=1.0
    6 RATIO=DMEN(J,K)/(DMEN(J,1)+DMEN(J,2))
C     NOW DO INDIRECT COST/AMH LAST PERIOD
      IF(Z(1,1,J))31,31,14
   31 E1=ET(J,1)
      E2=ET(J,2)
   14 X(K+8,1,LM)=(TP*(RESH(J)+E1)     +FLFSA(J,K)+RATIO*(ADMIN(J)+ADM(J,1
     1)+ADM(J,2)+FADET(J)+FSDET(J)+WDET(J))+(TP-1.)*(TP-1.)*(XOTH(J)+E2)
     2)/(DMEN(J,K)*C20)
      DO 51 KN=1,ND
      IF(MEND(KN)) 51,50,52
   52 IF(MEND(KN)-M) 51,50,51
   50 IF(NCO(KN)-J) 51,53,51
   53 IF(NFT(KN)/2-K) 51,54,51
   54 BD=BCST(KN)/RQT(KN)
      REP=LAST(KN)-M
      RPPS=MAX1F(REP,0.0)
      RPP=RPPS
      DID=(AR(KN)+AD(KN)*C5)*PR(KN)
      ALDID=RQT(KN)-ROM(KN)
      TP=(K-2)*(K-2)
      TODO=MIN1F(ROM(KN),(ROM(KN)/MAX1F(REP,1.0))*(1.0+Y(JK,2,2)))
      DONE=RQT(KN)-CFCAP(KN)-ROM(KN)+TODO
      FIX=MIN1F((ARN(KN)+AON(KN)),1.0)
      FXC=(TP*7500.+17500.)*FIX
      XK8=PMAX(X(K+8,10,LM),WG(J,K))
      CPMH= (TCST(KN)-FXC-SBC(KN)-(AD(KN)*.5*XK8           )/(C5*PR(KN)
     1))/(APN(KN)-AS(KN)+AD(KN)*(1.0-C5)*PR(KN))
      CPMH=MAX1F(CPMH,0.0)
      CPMH=PMAX(CPMH,ASB(K))
      TCTD=CTCST(KN)/(RQT(KN)-ROM(KN))
      COMP=MIN1F((RQT(KN)-ROM(KN)+10.0)/RQT(KN),1.0)
      IF(RQT(KN)-ROM(KN)-CFCAP(KN)-10.0) 58,58,55
   55 CONTINUE
```

```
C   SCHEDULE
       XK82=(BEST(KN)*RPP-ROM(KN))/BEST(KN)
       X(K+8,2,LM)=X(K+8,2,LM)+XK82*ALDID
       SDN=SDN+ALDID
C   EFFICIENCY
       CALL EFF(0,J,K,KN,10,1.0,XK83)
       X(K+8,3,LM)=X(K+8,3,LM)+XK83*ALDID
C   COST--EST TERMINAL AVE CPMH IF BAL DONE IN HOUSE
       XK84=TCTD*COMP+
      1      (((CPMH*PR(KN))/(PR(KN)+XK83))*2.0+((TP*7500.+17500.)*RPPS)/
      2ROM(KN))*(1.0-COMP)
       X(K+8,4,LM)=X(K+8,4,LM)+XK84*ALDID
C   COST STATUS
       X(K+8,5,LM)=X(K+8,5,LM)+(XK84/BD)*ALDID
       Z(10,K+8,J)=Z(10,K+8,J)+CPMH*FIX*PR(KN)*DID
       EDN=EDN+DID*FIX
    58 IF(MEND(KN)) 51,56,51
    56 L=L+1
       XK85=TCTD/BD
       IF(L-10) 57,57,51
    57 Z(1,L,J)=KN
       Z(2,L,J)=(ROM(KN)/MAX1F(REP,1.0))*(1.0+Y(JK,2,2))
       Z(2,L,J)=MIN1F(Z(2,L,J),ROM(KN))
       TRQD=TRQD+Z(2,L,J)
       Z(4,L,J)=TCTD
       Z(5,L,J)=(BEST(KN)*RPP-ROM(KN))/BEST(KN)
       Z(6,L,J)=XK85
C   IF ONLY S/C SO FAR,WERE DONE WITH IT
       IF(RQT(KN)-ROM(KN)-CFCAP(KN)-10.0) 51,51,59
C   OTHERWISE DO EFFICIENCY
    59 CALL EFF(1,J,K,KN,L,DONE/RQT(KN),Z(3,L,J))
       ARQT=ARQT+Z(2,L,J)/Z(3,L,J)
    51 CONTINUE
       IF(K-1) 7,8,7
     8 Z(10,1,J)=L
     7 CONTINUE
```

```
      X(K+8,2,LM)=X(K+8,2,LM)/SDN
      X(K+8,3,LM)=X(K+8,3,LM)/SDN
      X(K+8,4,LM)=X(K+8,4,LM)/SDN
      X(K+8,5,LM)=X(K+8,5,LM)/SDN
      Z(10,K+8,J)=Z(10,K+8,J)/EDN
      DO 60 KT=1,10
      IF(Z(1,KT,J)) 64,64,61
   61 KN=Z(1,KT,J)
      IF(NFT(KN)/2-K) 60,62,60
   62 IF(Z(3,KT,J)) 60,63,60
   63 CALL EFF(1,J,K,KN,KT,(RQT(KN)-ROM(KN)-CFCAP(KN)+Z(2,KT,J))/RQT(KN)
     1,Z(3,KT,J))
   29 Z(4,KT,J)=(ROM(KN)*X(K+8,4,LM)+CTCST(KN))/RQT(KN)
   38 FORMAT(6H RCALC6F12.5)
      BD=BCST(KN)/RQT(KN)
      TCTD=CTCST(KN)/(RQT(KN)-ROM(KN))
      Z(6,KT,J)=PMAX(TCTD/BD,X(K+8,4,LM)/BD)
      IF(Z(3,KT,J)) 36,36,37
   36 WRITEOUTPUTTAPE6,38,CPMH,FXC,AS(KN),Z(1,L,J),ASB(K)
      CALL XZOUT(J,K)
      Z(3,KT,J)=PD(J,K)
   37 ARQT=ARQT+Z(2,KT,J)/Z(3,KT,J)
   60 CONTINUE
   64 Z(10,K+2,J)=TRQD/ARQT
      Z(10,K+6,J)=TRQD
      IF(X(8,2,2)-1.0) 39,40,39
   40 WRITEOUTPUTTAPE6,38
      CALL XZOUT(J,K)
   39 CONTINUE
      RETURN
      END

      SUBROUTINE ACALC(J,K)
C     THIS S/R DETERMINES AVAIL M/H, CONVENTS TO PMH, AND DETERIMENS DIFF.
```

```
C   BASED ON DIFF., LINK IS SET AND RPGEN SET
      J=J
      K=K
      L=(K-1)*5
      L5=L+5
      L4=L+4
      L3=L+3
      L2=L+2
      L1=L+1
      JK=J+5*(K-1)
      LM=J*2-1
      FK=(K-2)*(K-2)
      DO11 KT=1,6
   11 X(J,KT,L4)=0.0
      AVMH=DMEN(J,K)*(1.0-QTFCST(J,K))*C20
      Z(10,K+4,J)=AVMH
      RS=MAX1F((Z(10,5,J)*X(J,9,4)-20000.)/Z(10,9,J),0.0)*FK
      PVMH=AVMH*Z(10,K+2,J)
      TRQD=Z(10,K+6,J)+RS*Z(10,K+2,J)
      DIFF=ABSF(TRQD-PVMH)
      IF (TRQD-PVMH) 1,2,3
    1 LINK=1
      DO 4 KT=1,10
      IF (X(6,KT,1)) 5,5,6
    6 NGO=X(6,KT,1)
      X(J,NGO,L3) =0.0
    4 X(J,NGO,L4) =0.0
      GO TO 5
    3 LINK=2
      DO17 KT=1,10
      IF (X(6,KT,2)) 5,5,18
   18 NGO=X(6,KT,2)
      X(J,NGO,L3) =0.0
   17 X(J,NGO,L4) =0.0
      GO TO 5
    2 DO9KT=1,6
```

```
      X(J,KT,L3) =0.0
    9 X(J,KT,L4) =0.0
      LINK=1
      GO TO 10
    5 CONTINUE
      LPT=2
      IF(MAX1F(X(J,1,L5),X(J,2,L5),X(J,3,L5),X(J,4,L5),X(J,5,L5),X(J,6,L
     15))) 21,21,22
   21 LPT=1
   22 GO TO (25,7),LPT
   25 XSUM=0.0
      DO 27 KT=1,5
      IF (X(6,KT,LINK)) 27,27,13
   13 NGO=X(6,KT,LINK)
      XSUM=XSUM+X(J,NGO,L1)
   27 CONTINUE
      DO 28 KT=1,5
      IF (X(6,KT,LINK))28,28,14
   14 NGO=X(6,KT,LINK)
      X(J,NGO,L3)=X(J,NGO,L1)/XSUM
   28 CONTINUE
      GO TO 20
    7 CALL RPGEN(J,K,X,C8,LINK)
   20 CONTINUE
      X(J,1,L4) =(X(J,1,L3) *DIFF/Z(10,K+2,J))/C20
      X(J,2,L4)=(X(J,2,L3)*MIN1F(DIFF,PVMH)/Z(10,K+2,J))/C20
      X(J,3,L4) = X(J,3,L3) *DIFF
      X(J,4,L4) =(X(J,4,L3) *DIFF)/(Z(10,K+2,J)*C5)
      X(J,5,L4)=X(J,5,L3)*MIN1F(DIFF,TRQD)
      X(J,6,L4) =X(J,6,L3) *DIFF*(-1.0)
   10 CONTINUE
      X(6,1,10)=LINK
      RETURN
      END
```

```
      SUBROUTINE ASSIGN(J,K)
   99 FORMAT(1H 11HGOT TO HERE4I4,F10.3)
C   THIS S/R ASSIGNS AVMH (Z(10,K+4,J)), S/C (X(J,3,L+4)), AND OT (X(J,4,
C    L+4) TO CONTRACTS AS FOLLOWS--
C    QUANTITY IN TERMS OF SCHEDULE DEFICIENCY
C    MIX IN TERMS OF COST EFFECTIVENESS--EG. THE LESS GROSS MARGIN, THE
C    HIGHER THE PRIORITY TO GET AMH.  AMH FIRST, THEN S/C, THEN S/C
      J=J
      K=K
      JK=J+5*(K-1)
      COUNT=0.0
      L=(K-1)*5
      L5=L+5
      L4=L+4
      L3=L+3
      L2=L+2
      L1=L+1
      LM=J*2-1
      AVMH=(DMEN(J,K)+X(J,1,L4) -X(J,2,L4) )*(1.0-QTFCST(J,K))*C20
      Z(10,K+4,J)=AVMH
      X(K+8,10,LM)=(WG(J,K)*DMEN(J,K)+AWG(K)*X(J,1,L4))/(DMEN(J,K)+X(J,1
     1,L4))
      TAR=Z(10,K+4,J)
      TSC=X(J,3,L4)
      TAO=X(J,4,L4)
C   TAKE CARE OF INTERNAL RESEARCH--FIRST ASSIGNMENT OF TAR GOES TO I/R
      IF(K-1) 53,54,53
   54 RS=MAX1F((Z(10,5,J)*X(J,9,4)-20000.)/Z(10,9,J),0.0)
      Z(10,2,J)=RS
      IF (RS) 7,8,7
C    ADJUST ET IF I/R=0
    8 X(J,7,4)=X(J,7,4)+X(J,9,4)
      X(J,9,4)=0.0
      GO TO 53
    7 TAR=TAR-RS
   53 CONTINUE
```

```
C   ADJUST RQTS Z(2,L,J) BY CALCULATING SCHEDULE STATUS Z(5,L,J) TO BE--
C    0 IF LAST PD IS NEXT PD
C    AVG ROM/BEST OTHERWISE AND PUT RESULT IN Z(5,L,J)
C    NORMALIZE AND USE THIS FACTOR TO REDUCE (LINK-X(6,1,10)-=2) OR INCRE
C    ASE, LINK=1 IN PROPORTION TO X(J,4+LINK) X Z(5,L,J) BUT IN NO CASE
C    CHANGING REQT BY MORE THAN BEST
       SSS=0.0
C    FIRST CALC SCHED STATUS
       LINK=X(6,1,10)
     2 DO 30 KT=1,10
       IF(Z(1,KT,J)) 39,39,40
    40 KN=Z(1,KT,J)
       IF(NFT(KN)/2-K) 30,31,30
    31 Z(5,KT,J)=0.0
       RPDS=LAST(KN)-M
       DPDS=ABSF(RPDS-1.0)
       IF (RPDS-1.0) 1,1,4
     4 Z(5,KT,J)=BEST(KN)/(ROM(KN)/RPDS)
       IF (LINK-1) 3,6,3
     6 Z(5,KT,J)=1.0/Z(5,KT,J)
       GO TO 3
     1 Z(2,KT,J)=Z(2,KT,J)*(1.0+X(8,3,K+3)*(2.0**DPDS))
     3 SSS=SSS+Z(5,KT,J)
    30 CONTINUE
C   NOW NORMALIZE AND CHANGE Z(2,KT,J) ACCD. TO LINK ST FIN. ON TIME
    39 DO 33 KT=1,10
       IF (Z(1,KT,J)) 36,36,35
    35 KN=Z(1,KT,J)
       IF(NFT(KN)/2-K) 33,34,33
    34 Z(5,KT,J)=(Z(5,KT,J)/SSS)*X(J,LINK+4,L4)
C   CHECK THAT NOT MORE THAN 1 PERIOD CHANGE IS ATTEMPTED
       Z(5,KT,J)=MIN1F(Z(5,KT,J),BEST(KN))
     5 Z(2,KT,J)=Z(2,KT,J)+Z(5,KT,J)
       Z(2,KT,J)=MAX1F(Z(2,KT,J),0.0)
C   CALC SCHED AFTER WORKOFF
       RPDS=LAST(KN)-M-1
```

```
      COUNT=COUNT+1.0
   33 CONTINUE
   36 CONTINUE
      IERR=0
C  NOW WE HAVE NEW AV. PMH RQTS ACCD TO SCHEDULE
C  NOW DETERMINE MIX ACCORDING TO COST STATUS
C  NOW ALLOCATE RT,SC,DT, IN ORDER OF HIGHEST COS3 STATUS FACTOR
   62 FORMAT(7H ASSIGN4F10.3,4I6)
   11 IF(MAX1F((TAR-0.1),(TAD-0.1),(TSC-0.1))) 15,15,27
   27 NTOP=0
      TOP=NTOP
      IERR=IERR+1
      DO 9 KT=1,10
      IF(Z(1,KT,J)) 37,37,38
   38 KN=Z(1,KT,J)
      IF(NFT(KN)/2-K) 9,10,9
   10 IF(MAX1F(Z(7,KT,J),Z(8,KT,J),Z(9,KT,J)))9,63,9
   63 IF(Z(2,KT,J))  9,9,12
   12 IF(Z(6,KT,J)-TOP) 9,9,13
   13 TOP=Z(6,KT,J)
      NTOP=KT
    9 CONTINUE
   37 IF (TOP) 15,15,14
   14 PRQT=Z(2,NTOP,J)
      IF(IERR-50) 60,60,61
   61 WRITEOUTPUTTAPE6,62,TAR,TAD,TSC,TOP,NTOP,J,K,M
      CALL XYZOUT
      GO TO 15
   60 CONTINUE
      IF (TAR) 17,17,16
   16 IF(TAR-(PRQT/Z(3,NTOP,J))) 19,18,18
   18 Z(7,NTOP,J)=PRQT/Z(3,NTOP,J)
      TAR=TAR-PRQT/Z(3,NTOP,J)
      PRQT=0.0
      GO TO 11
   19 Z(7,NTOP,J)=TAR
```

```
      PRQT=PRQT-TAR*Z(3,NTOP,J)
      TAR = 0.0
C   NOW DO S/C ALLOCZTION
   17 IF(TSC) 21,21,20
   20 IF(TSC-PRQT) 22,23,23
   23 Z(9,NTOP,J)=PRQT
      TSC=TSC-PRQT
      PRQT=0.0
      GO TO 11
   22 Z(9,NTOP,J)=TSC
      PRQT=PRQT-TSC
      TSC=0.0
C   NOW DO OT ALLOCATION
   21 IF(TAO) 55,55,24
   24 IF (TAO*Z(3,NTOP,J)*C5-PRQT) 26,25,25
   25 Z(8,NTOP,J)=PRQT/(Z(3,NTOP,J)*C5)
      PRQT=0.0
      TAO=TAO-Z(8,NTOP,J)
      GO TO 11
   26 Z(8,NTOP,J)=TAO
      TAO=0.0
      PRQT=PRQT-Z(8,NTOP,J)/(Z(3,NTOP,J)*C5)
C   TAKE CARE OF REMAINING PRQT
   55 Z(9,NTOP,J)=Z(9,NTOP,J)+MAX1F(PRQT,0.0)
      PRQT=0.0
      GO TO 11
   15 CONTINUE
C   TAKE CARE OF ANY RESIDUAL AVMH
      IF(TAR)43,43,41
   41 CANCL=INTF(TAR/C20)
      IF(X(J,1,L4)-CANCL)44,42,42
   42 X(J,1,L4)=X(J,1,L4)-CANCL
      GO TO 47
   44 IF(X(J,1,L4)) 45,45,46
   46 CANCL=CANCL-X(J,1,L4)
      X(J,1,L4)=0.0
```

```
   45 X(J,2,L4)=X(J,2,L4)+CANCL
   47 Z(10,K+4,J)=Z(10,K+4,J)-TAR
   43 CONTINUE
C  NOW ALL AR AO SO SHOULD BE ALLOCATED AND NEXT WE TO TO EVAL
      RETURN
      END


      SUBROUTINE EVAL(J,K)
C  THIS S/R CALCJLATES PROJECTED OBJECTIVE VALUES FOR DC/PMH AND IC/AMH
C  FOR TENTATIVE DECISIONS BEFORE RSPEC-WHICH IS CALLED AFTER FINAL EVAL
      J=J
      K=K
      JK=J+5*(K-1)
      CSTAT=0.0
      NKS=0
      SAPD=0.0
      DCSUM=0.0
      EFSUM=0.0
      SCSUM=0.0
      SDN=0.0
      EDN=0.0
      CDN=0.0
      CSDN=0.0
      L=(K-1)*5
      L5=L+5
      L4=L+4
      L3=L+3
      L2=L+2
      L1=L+1
      COUNT=0.0
      TP=(K-2)*(K-2)
      LM=J*2-1
      FXC=TP*7500.+17500.
C  NOW DO EXPECTED PERFORMANCE MEASURES
      DO 19 KT=1,10
```

```
      IF(Z(1,KT,J)) 25,25,21
   21 KN=Z(1,KT,J)
   28 FORMAT(1H 10HEVAL-COUNT5I3,5F10.5)
      KTST=NFT(KN)/2-K
      IF (NFT(KN)/2-K) 19,20,19
   20 DONE=(Z(7,KT,J)+C5*Z(8,KT,J))*Z(3,KT,J)+RQT(KN)-CFCAP(KN)-ROM(KN)
      NKS=NKS+1
      RKS=NKS
      Z(9,KT,J)=MIN1F(Z(9,KT,J),BEST(KN))
      IF(Z(7,KT,J)+Z(8,KT,J)) 29,29,30
   29 FXC=0.0
      FMLT=0.0
   30 CONTINUE
      CALL EFF(1,J,K,KN,KT,DONE/RQT(KN),EFFO)
      Z(3,KT,J)=EFFO
      DONE=(Z(7,KT,J)+C5*Z(8,KT,J))*Z(3,KT,J)+RQT(KN)-CFCAP(KN)-ROM(KN)
      CALL EFF(1,J,K,KN,KT,DONE/RQT(KN),EFFO)
      Z(3,KT,J)=EFFO
      DNP=(Z(7,KT,J)+C5*Z(8,KT,J))*Z(3,KT,J)+Z(9,KT,J)
      Z(9,KT,J)=MAX1F((Z(9,KT,J)+Z(2,KT,J)-DNP),0.0)
C  CORRECT FOR S/C WHEN FIRING AND SMALL S/C AMTS.
   59 IF(X(J,2,L4)) 57,57,60
   60 IF(Z(9,KT,J)) 56,56,61
   61 Z(7,KT,J)=Z(7,KT,J)+Z(9,KT,J)/Z(3,KT,J)
      X(J,2,L4)=X(J,2,L4)-(Z(9,KT,J)/(C20*Z(3,KT,J)))
      Z(9,KT,J)=0.0
      IF(X(J,2,L4)) 63,56,56
   63 X(J,1,L4)=X(J,1,L4)+ABSF(X(J,2,L4))
      X(J,2,L4)=0.0
      GO TO 56
   57 IF(Z(9,KT,J)-1000.) 62,62,56
   62 IF(Z(7,KT,J)) 56,56,65
   65 Z(7,KT,J)=Z(7,KT,J)+Z(9,KT,J)/Z(3,KT,J)
      Z(9,KT,J)=0.0
   56 CONTINUE
   64 CONTINUE
```

```
      DID=(Z(7,KT,J)+Z(8,KT,J)*C5)*Z(3,KT,J)+Z(9,KT,J)
      DIDAL=DID+RQT(KN)-ROM(KN)
      ROM1=MAX1F((ROM(KN)-DID-15.),0.0)
      CFCA1=CFCAP(KN)+Z(9,KT,J)
      TODO=MIN1F(ROM1,BEST(KN))
      RPDS=LAST(KN)-M-1
      RPPS=MAX1F(RPDS,0.0)
      COMP=(RQT(KN)-ROM1)/RQT(KN)
      HCOMP=(RQT(KN)-ROM1-CFCA1)/RQT(KN)
       TCOMP=ROM1/RQT(KN)
      BD=BCST(KN)/RQT(KN)
      ACPH=((TCST(KN)-FXC-SBC(KN)-(AD(KN)*.5*X(K+8,10,LM))/(C5*Z(3,KT,J)
     1))/(APN(KN)-AS(KN)+AD(KN)*(1.-C5)*Z(3,KT,J)))*PR(KN)-DFAC(J,K)
     2/(DMEN(J,K)*C20)+X(J,8,L4)-WG(J,K)+X(K+8,10,LM)
      CPMH=ACPH/Z(3,KT,J)
      CPMH=MAX1F(CPMH,0.0)
      IF(ARN(KN)-.1*BEST(KN))11,11,12
   11 CPMH=Z(10,K+8,J)/PMAX(Z(3,KT,J),Z(10,K+2,J))
   12 CONTINUE
      PR1=Z(3,KT,J)
      HDID=(Z(7,KT,J)+Z(8,KT,J)*C5)*Z(3,KT,J)
      RDID=(Z(7,KT,J)*Z(3,KT,J))
      ODID=(Z(8,KT,J)*C5*Z(3,KT,J))
      SDID=Z(9,KT,J)
      TCTD=(CTCST(KN)+CPMH*RDID+(CPMH+.5*X(K+8,10,LM)/Z(3,KT,J))*ODID+
     1FXC+
     2ASB(K)*SDID)/(RQT(KN)-ROM1)
C  DO EXPECTED SCHEDULE STATUS
      YJK2=(BEST(KN)*RPPS-ROM1)/BEST(KN)
      Z(5,KT,J)=YJK2
      SCSUM=SCSUM+YJK2*RQT(KN)
      SDN=SDN+RQT(KN)
C  DO EFF ADJUSTED BO BE ULTIMATE TERMINAL
      PLUG0=CFCAP(KN)
      PLUG1=PR(KN)
      PLUG2=ROM(KN)
```

```
      PLUG3=AR(KN)
      PLUG4=AD(KN)
      CFCAP(KN)=CFCA1
      ROM(KN)=ROM1
      PR(KN)=PR1
      AR(KN)=Z(7,KT,J)
      AD(KN)=Z(8,KT,J)
      CALL EFF(0,J,K,KN,KT,1.0,EFFD)
      YJK3=EFFD
      EFSUM=EFSUM+YJK3*HDID
      EDN=EDN+HDID
      CFCAP(KN)=PLUGO
      PR(KN)=PLUG1
      ROM(KN)=PLUG2
      AR(KN)=PLUG3
      AD(KN)=PLUG4
C   DO AVE DIRECT COST/PMH IF BALANCE COMPLETED IN HOUSE
      YJK4=TCTD*COMP+
     1               (((CPMH*PR1)/(PR1+YJK3))*2.0+FXC*RPPS/ROM1)*(1.-COMP
     2)
      DCSUM=DCSUM+YJK4*DIDAL
      CDN=CDN+DIDAL
C   DO COST STATUS NEXT PERIOD
      CSTAT=CSTAT+(YJK4/BD)*DIDAL
      CSDN=CSDN+DIDAL
C   NOW DO CONTROL ESTIMATES--EFFICIENCY,COST AND  COST STATUS
      Z(4,KT,J)=(CPMH*RDID+(CPMH*Z(3,KT,J)+.5*X(K+8,10,LM))*Z(8,KT,J)
     1+SDID*ASB(K)+FXC)/DID
      YJK5=Z(4,KT,J)/BD
      Z(6,KT,J)=YJK5
   19 CONTINUE
   25 Y(JK,3,7)=EFSUM/EDN
      Y(JK,4,7)=DCSUM/CDN
      Y(JK,5,7)=CSTAT/CSDN
      Y(JK,2,7)=SCSUM/SDN
C   DO PARTIAL IND COST / AMH
```

```
      Y(JK,1,7)=X(J,7,L4)+AFFM(J,K)/Z(10,K+4,J)
      IF(K-1) 26,26,27
   26 Y(JK,1,7)=Y(JK,1,7)+X(J,9,4)
   27 RETURN
      END

      SUBROUTINE SCORE(J,K)
      J=J
      K=K
      NCYC=0
   71 CONTINUE
      L=(K-1)*5
      L5=L+5
      L4=L+4
      L3=L+3
      L2=L+2
      L1=L+1
      LM=J*2-1
      LV=J*2
      JK=J+5*(K-1)
      LMT=3
C   MLIM INDICATES THE NUMBER OF VARIABLES TO BE SCORED
      MLIM=5
      NSA=1
      CYCLE=0.0
      LR=Z(10,1,J)+1.0
      SETA=X(8,1,K+6)
      SETI=X(8,1,K+8)
      IF(K-1) 52,53,52
   53 LR=1
   52 CONTINUE
      LOP=X(8,2,K+6) +.00001
      DO 58 LOO=1,LOP
      LOOD=LOO/2
      LOGO=LOO-LOOD*2+1
```

```
      GO TO (60,61),LOGO
   60 X(8,1,K+6)=SETA
      X(8,1,K+8)=1.0
      GO TO 62
   61 X(8,1,K+8)=SETI
      X(8,1,K+6)=1.0
   62 CONTINUE
      LEA=XMAX1F(X(8,1,K+8),1.0)
      DO 2 LE5=1,LEA
      IF(LE5-1) 48,48,49
   49 CALL RALOC(J,K)
      DO 55 MJ=LR,10
      DO 55 MI=1,9
   55 Z(MI,MJ,J)=0.0
      Z(1,1,J)=MAX1F(Z(1,1,J),1.0)
      CALL RCALC(J,K)
      DO 57 KL=1,6
   57 X(J,KL,L4)=X(J,KL,L5)
      CALL ASSIGN(J,K)
      CALL EVAL(J,K)
   48 LEE=XMAX1F(X(8,1,K+6),1.0)
      DO 7 LE4=1,LEE
      IF(LE4-1) 46,46,47
   47 CONTINUE
      DO 40 MI=1,9
      DO 40 MJ=LR,10
   40 Z(MI,MJ,J)=0.0
      Z(1,1,J)=MAX1F(Z(1,1,J),1.0)
  110 FORMAT(6H SCOREI6)
      CALL RCALC(J,K)
      CALL ACALC(J,K)
      CALL ASSIGN(J,K)
      CALL EVAL(J,K)
   46 CONTINUE
      GO TO (64,7),NSA
   64 CONTINUE
```

```
      CYCLE=CYCLE+1.0
      LE2=XMINOF(LE4,10)
C  FIRST CHECK IF VALUES ARE IN LIMITS--IF NOT GO TO 22(TRY AGAIN)
    1 FORMAT(1H 10HLIMIT MISS2I5,8F10.5)
      DO 3 MI=1,MLIM
      LMT=INLIM(Y(JK,MI,5),Y(JK,MI,7),Y(JK,MI,3))
      IF(LMT-3) 4,3,4
    4 WRITE OUTPUT TAPE 6,1,JK,MI,Y(JK,MI,5),Y(JK,MI,7),Y(JK,MI,3),CYCLE
     1,Z(9,7,J),Z(9,8,J),Z(9,9,J)
      KTR=XTRA(4,3,1)+.0001
      KTR=KTR+JK
      IF(JK+MI-KTR) 76,3,76
   76 CALL XZOUT(J,K)
      XTRA(4,3,1)=MI
      GO TO 75
    3 CONTINUE
   75 CONTINUE
C  CALCULATE SCORE IF FEASIBLE SOLUTION FOUND
      DO 5 MI=1,5
    5 Y(JK,10,MI)=0.0
      Y(JK,10,3)=999.9
      DO 6 MI=1,MLIM
      CALL GOL(Y(JK,MI,1),Y(JK,MI,2),Y(JK,MI,5),Y(JK,MI,3),X(K+8,MI,LM),
     1NUT,GOAL,COG1)
      ULIM=Y(JK,MI,3)
      IF(Y(JK,MI,7)-GOAL) 26,28,28
   26 ULIM=Y(JK,MI,5)
   28 Y(JK,MI,8)=CTRL(Y(JK,MI,1),GOAL,ULIM,Y(JK,MI,4),Y(JK,MI,7))
      Y(JK,10,1)=Y(JK,10,1)+Y(JK,MI,8)
      Y(JK,10,2)=MAX1F(Y(JK,10,2),Y(JK,MI,8))
      Y(JK,10,3)=MIN1F(Y(JK,10,3),Y(JK,MI,8))
    6 CONTINUE
C  CALCULATE MEAN
      DIVID=MLIM
      Y(JK,10,4)=Y(JK,10,1)/DIVID
C  CALCULATE SIGMA
```

```
      DO 8 MI=1,MLIM
    8 Y(JK,10,5)=(Y(JK,MI,8)-Y(JK,10,4))*(Y(JK,MI,8)-Y(JK,10,4))
      DVD=MLIM
      Y(JK,10,5)=SQRTF(Y(JK,10,5)/DVD)
C  NOW WE HAVE SUM,MAX,MIN,AND AVE.SCORE FOR MLIM VARIABLES
C   SELECT 11--LEAST MAX, 12--LEAST MIN, 13--LEAST MIN+MAX, 14--LEAST AV
C   ,15--LEAST SIGMA, 16--LEAST SIGMA+MEAN
      NGO=X(8,1,K+4)+1.0
      NRPT=1
   34 CONTINUE
   35 CONTINUE
      XNGO=NGO
   38 FORMAT(1H 23HXNGO NOT IN INLIM,SCORE6I4,F10.5)
      IF(INLIM(1.0,XNGO,15.0)-3) 36,37,36
   36 NGO=1
      WRITE OUTPUT TAPE 6,38,J,K,JK,LE2,NGO,NRPT,XNGO
   37 GO TO (10,11,12,13,14,15,16,17,18,19,9,9,9,9,9),NGO
   10 NRPT=2
      GO TO 9
   11 NRPT=NFCT1(JK,Y)
      GO TO 9
   12 NRPT=NFCT2(JK,Y)
      GO TO 9
   13 NRPT=NFCT3(JK,Y)
      GO TO 9
   14 NRPT=NFCT4(JK,Y)
      GO TO 9
   15 NRPT=NFCT5(JK,Y)
      GO TO 9
   16 NRPT=NFCT6(JK,Y)
      GO TO 9
   17 NRPT=NFCT7(JK,Y)
      GO TO 9
   18 NRPT=NFCT8(JK,Y)
      GO TO 9
   19 NRPT=NFCT9(JK,Y)
```

```
    9 CONTINUE
      X(J,10,L4)=X(J,10,L3)
      NCNT=NCNT+1
   44 FORMAT(2H S2F8.3,4F6.3,1H*11F7.4,2I2,I3)
   33 FORMAT(2H S2F8.3,4F6.3,1H 11F7.4,2I2,I3)
C  NRPT=1--TRY AGAIN, NRPT=2--THIS IS A GOOD ONE
      IF(NRPT) 30,30,29
   30 NRPT=1
      GO TO 31
   29 IF(NRPT-2) 31,31,32
   32 NRPT=2
   31 GO TO (69,21),NRPT
   69 GO TO 7
   21 CONTINUE
      IF(X(8,2,3)) 65,65,66
   66 CALL XZOUT(J,K)
   65 CONTINUE
      IF(X(8,2,4)) 68,68,67
   67 CALL XZOUT(J,K)
   68 DO 24 MI=1,5
   24 Y(JK,10,MI+5)=Y(JK,10,MI)
      DO 25 MI=1,MLIM
      Y(JK,MI,9)=Y(JK,MI,7)
   25 Y(JK,MI,10)=Y(JK,MI,8)
      DO 43 MI=1,10
   43 X(J,MI,L5)=X(J,MI,L4)
    7 NSA=1
      X(J,10,L4)=0.0
    2 CONTINUE
      DO 50 MJ=LR,10
      DO 50 MI=1,9
   50 Z(MI,MJ,J)=0.0
      Z(1,1,J)=MAX1F(Z(1,1,J),1.0)
      DO 63 KL=7,10
   63 X(J,KL,L4)=X(J,KL,L5)
      CALL RCALC(J,K)
```

```
      DO 56 KL=1,10
   56 X(J,KL,L4)=X(J,KL,L5)
      CALL ASSIGN(J,K)
      CALL XZOUT(J,K)
      CALL EVAL(J,K)
      DO 51 MI=1,MLIM
   51 Y(JK,MI,8)=Y(JK,MI,10)
      NSA=2
   58 CONTINUE
      NGT=X(8,1,K+4)+5.0001
      X(8,1,K+6)=SETA
      X(8,1,K+8)=SETI
      NCYC=NCYC+1
      IF(Y(JK,10,NGT)-Y(JK,8,2)) 72,72,73
   73 NTC=Y(JK,8,1)+.0001
      IF(NCYC-NTC) 71,72,72
   72 CONTINUE
      RETURN
      END


      SUBROUTINE GOL(COG,GI,BLIM,ULIM,PREVAL,NUT,COL,COG1)
C   GI, GOAL IN, CAN TAKE ON VARIOUS CHARACTERS DEPENDING ON THE FIRST
C    DECIMAL PLACE OF COT, WHICH IS NORMALLYY(JK,MI,1),AS FOLLOWS--
C      0--GOL=GI (ABSOLUTE AMOUNT, + OR -
C      1--GOL=PCT INCREASE/DECREASE FROM PREVAL
C      2--GOL=PCT INCREASE FROM PREVAL BASED ON ULIM - PREVAL
C      3--GOL=PCT DECREASE FROM PREVAL BASED ON PREVAL - BLIM
C      4--GOL=ABS. AMT. CHANGE (PREVAL + OR - GI)
      COG1=(COG-INTF(COG))*10.0+1.0001
      NUT=COG1
      IF(NUT) 2,2,3
    2 COL=GI
      GO TO 15
    3 IF(NUT-5) 5,5,4
    4 COL=GI
```

```
      GO TO 15
    5 GO TO (10,11,12,13,14),NUT
   10 COL=GI
      GO TO 15
   11 COL=SIGNF(GI*PREVAL,GI)+PREVAL
      GO TO 15
   12 COL=ABSF(GI*(ULIM-PREVAL))+PREVAL
      GO TO 15
   13 COL=PREVAL-ABSF(GI*(PREVAL-BLIM))
      GO TO 15
   14 COL=PREVAL+GI
   15 COL=MIN1F(COL,ULIM)
      COL=MAX1F(COL,BLIM)
      RETURN
      END

      SUBROUTINE DBID(J,K)
      J=J
      K=K
      JK=J+5*(K-1)
      LM=J*2-1
      LV=J*2
      LU=0
      TBKLG=0.0
      DO 1 KR=1,10
      DO 1 KS=1,10
      DO 1 KT=1,5
    1 XTRA(KR,KS,KT)=0.0
C     LOAD IN EXISTING CTRS IN XTRA(KP,4,J) KP=1,PL HOR--X(J,6,K)
      SKMN=0.0
      OBJ=X(6,J+5,K+2)*Y(JK,7,2)
      ONHAND=(Z(10,K+2,J)*Z(10,K+4,J))/1000.
      XMEAN=X(6,J+5,K+6)*MAX1F(OBJ,ONHAND)+(1.0-X(6,J+5,K+6))*OBJ
      X(6,J+5,K+2)=X(6,J+5,K+2)*Y(JK,7,2)
      LHOR=X(6,J+5,K)
```

```
      XHOR=LHOR
      KN1=1
      DO 8 KT=1,10
      IF(Z(1,KT,J)) 22,22,21
   21 KN=Z(1,KT,J)
      IF(NFT(KN)/2-K) 8,9,8
    9 CONTINUE
      KN1=KN
      XTRA(1,4,1)=XTRA(1,4,1)+Z(2,KT,J)
      RPDS=LAST(KN)-M
      RPDS=MAX1F(RPDS-1.0,1.0)
      DO 10 NPS=2,LHOR
      IF(LAST(KN)-NPS-M) 10,11,11
   11 DELTAD=MAX1F(ROM(KN)-Z(2,KT,J),0.0)/RPDS
      XTRA(NPS,4,1)=XTRA(NPS,4,1)+DELTAD
      TBKLG=TBKLG+DELTAD
   10 CONTINUE
      IF(KT-10) 8,52,8
   52 DO 53 KN=KN1,ND
      IF(NCO(KN)-J) 53,54,53
   54 IF(NFT(KN)/2-K) 53,55,53
   55 DO 56 MPDS=1,LHOR
      IF(LAST(KN)-MPDS-M) 56,57,57
   57 XTRA(MPDS,4,1)=XTRA(MPDS,4,1)+BEST(KN)
      TBKLG=TBKLG+BEST(KN)
   56 CONTINUE
   53 CONTINUE
    8 CONTINUE
   22 CONTINUE
C  TEST FOR NO BID
      DO 32 NPS=1,LHOR
   32 SKMN=SKMN+(XMEAN-XTRA(NPS,4,1)/1000.)**2.0
      SKMN=SKMN/X(6,J+5,K)
      XTRA(2,10,1)=SKMN
C  FIRST DETERMINE CONTRACTS UPFOR BID OF TYPE K AND PLACE IN XTRA(I,1,1
C  AND CONCLUDE WITH 9898.
```

```
      DO 3 KN=1,ND
      IF(NCO(KN)-11) 3,2,3
    2 IF(NFT(KN)/2-K) 3,4,3
    4 LU=LU+1
      BID(J,KN)=0.0
      XTRA(LU,1,1)=KN
    3 CONTINUE
      TBKLG=TBKLG/1000.0
      XPPD=0.0
      IF(TBKLG/XMEAN-Y(JK,9,2)) 35,35,36
   35 LHOR=LHOR+1
      SKMN=(SKMN*X(6,J+5,K)+XMEAN*XMEAN)/(X(6,J+5,K)+1.0)
      XPPD=1.0
      XTRA(2,10,1)=SKMN
   36 CONTINUE
      LU=LU+1
      XTRA(LU,1,1)=9898.0
      NUCTR=LU-1
      JJ=(J-2)*(J-2)+1
      K1=K*2
      K2=K*2+1
      TBKJJ=(BKLG(JJ,K1)+BKLG(JJ,K2))/1000.0
      AVB=(DMEN(JJ,K)*500.0*PD( J,K))/1000.0
      SIT=(TBKJJ-AVB)/AVB
C   SET UP SUCCESSIVE COMBINATIONS TO TRY
      IF(NUCTR) 26,25,26
   26 IF(NUCTR-5)28,28,27
   27 NUCTR=5
   28 DO 5 KTRY=1,NUCTR
      CALL PERM(NUCTR,KTRY,XTRA,NX)
      NX=NX
C   NX IS THE NUMBER OF ALTERNATIVE COMBINATIONS FOR KTRY CONTRACTS
C   NOW PUT EACH ALTERNATIVE CGR NR IN X(I,3,1)
      DO 6 KT=1,NX
      INNM=XTRA(KT,9,1)
      DO 7 KU=1,KTRY
```

```
      NSET=10**(KTRY-KU)
      NTRY=INNM/NSET
      INNM=INNM-NTRY*NSET
    7 XTRA(KU,3,1)=XTRA(NTRY,1,1)
C  NOW WE HAVE KTRY CTR NRS IN X(KU,3,J) SO CALCULATE LOAD FACTRO--FIRST
C   LOAD IN EXISTING CTR DEMANDS IN X(KP,5,J) KP=1,PLNN HORIZ.,X(J,6,K)
      DO 12 KU=1,10
   12 XTRA(KU,5,1)=XTRA(KU,4,1)
      BK=MIN1F((TBKLG/XMEAN)/Y(JK,9,2),1.0)
      BD=MIN1F(Y(JK,6,10) /Y(JK,6,2),1.0)
C  NOW LOAD UP FOR NEW CONTRACTS
      DO 13 KU=1,KTRY
      KN=XTRA(KU,3,1)
      DO 14 NPS=2,LHOR
      IF(LAST(KN)-M-NPS) 13,15,15
   15 XTRA(NPS,5,1)=XTRA(NPS,5,1)+BEST(KN)
   14 CONTINUE
   13 CONTINUE
C  LOAD DEMAND IS NOW IN XTRA(NPS,5,J),NPS=1,LHOR
C  NOW CALCULATE LOAD SCORE
      SKOR=0.0
      DO 16 NPS=1,LHOR
   16 SKOR=SKOR+(XMEAN-XTRA(NPS,5,1)/1000.)**2.0
      SKOR=SKOR/(X(6,J+5,K)+XPPD)
      XTRA(1,10,1)=SKOR
      XTRA(3,10,1)=XMEAN
      SKMX=SKMN*X(6,J+5,K+4)
      LMT=INLIM(SKMN,SKOR,SKMX)
      GO TO (50,17,18),LMT
   50 SKMN=SKOR
      XTRA(2,10,1)=SKMN
      DO 51 KU=1,10
   51 XTRA(KU,6,1)=XTRA(KU,3,1)
      NBEST=KTRY
      GO TO 17
   18 CONTINUE
```

```
      IF(BK-1.0) 60,17,17
   60 NKT=0
      DO 43 KU=1,10
      IF(XTRA(KU,6,1)) 43,43,44
   44 NKT=KU
   43 CONTINUE
      DO 19 KU=1,10
      DO 42 KW=1,10
      IF(XTRA(KU,3,1)-XTRA(KW,6,1)) 42,45,42
   42 CONTINUE
      IF(SIT-2.1) 69,69,45
   69 XTRA(NKT+1,6,1)=XTRA(KU,3,1)
      NKT=NKT+1
      NKT=XMINOF(NKT,10)
   45 CONTINUE
   19 CONTINUE
      NBEST=KTRY
   17 CONTINUE
   30 FORMAT(5H XTRA 10F12.4)
      IF(X(8,2,1))6,6,34
   34 DO 31 KP=1,5
   31 WRITE OUTPUT TAPE 6,30,(XTRA(KP,KQ,1),KQ=1,10)
    6 CONTINUE
    5 CONTINUE
C  NOW ER HAVE CTR NRS IN XTRA(LU=1-NBEST,6,1)
C   NEXT DO BID PRICE--A BY BACKLOG AND B BY AWARD RATIO
C   FIRST DO BKLG FACTOR
C  INCREASING WEIGHTS--Y(JK,M,6)--LOWERS BID PRICE
      CP=MAX1F((Y(JK,5,9)-Y(JK,5,2)),0.0)
      BK=BK**Y(JK,9,6)
      BD=BD**Y(JK,6,6)
      DCST=X(K+8,4,LM)*(1.0+CP)
      IF(K-1) 23,24,23
   24 DCST=(DCST+.04*(X(K+8,10,LM)/Z(10,K+2,J)))/.97
   23 DO 20 KU=1,10
      IF(XTRA(KU,6,1)) 20,20,29
```

```
   29 KN=XTRA(KU,6,1)
      BDMX=CUT(KN)/RQT(KN)
      IF(DCST-BDMX) 33,38,38
   38 IF(BK-1.0) 39,33,33
   39 DCST=X(K+8,4,LM)
      IF (DCST-BDMX) 33,33,20
   33 CONTINUE
      XTRA(KU,7,1)=BK*(BDMX     -DCST)+DCST
      XTRA(KU,8,1)=BD*(BDMX     -DCST)+DCST
      BKA=Y(JK,9,4)/(Y(JK,9,4)+Y(JK,6,4))
      XTRA(KU,2,1)=BKA*MIN1F(XTRA(KU,7,1),BDMX)+(1.0-BKA)*MIN1F(XTRA(KU,
     18,1),BDMX)
      XTRA(4,10,1)=BK
      XTRA(5,10,1)=BD
      XTRA(6,10,1)=DCST
      XTRA(7,10,1)=BKA
      XTRA(8,10,1)=TBKLG
      XTRA(9,10,1)=BDMX
      XTRA(10,10,1)=SKMX
C     RANDOMIZE BID AMOUNT
      PART=X(6,J+5,K+8)
      XBAR=MAX1F(MIN1F(XTRA(KU,2,1),BDMX),DCST)
      XLOW=DCST
      XUP=BDMX
      CALL RNORM(C8,R1,R2)
      IF(ABSF(R1)-ABSF(R2)) 61,61,62
   61 RV=MAX1F(MIN1F(R1,1.0),-1.0)
      GO TO 63
   62 RV=MAX1F(MIN1F(R2,1.0),-1.0)
   63 IF(RV) 64,65,65
   64 BID(J,KN)=MAX1F(XLOW,(XBAR+RV*PART*(XBAR-XLOW)))*RQT(KN)
      GO TO 20
   65 BID(J,KN)=MIN1F(XUP,(XBAR+RV*PART*(XUP-XBAR)))*RQT(KN)
   20 CONTINUE
   25 RETURN
      END
```

```
      SUBROUTINE RSPEC(J,K)
      J=J
      K=K
      L=(K-1)*5
      L5=L+5
      L4=L+4
      L3=L+3
      L2=L+2
      L1=L+1
C  THIS S/R TAKES VALUES FROM X(J,K=1-2,4) AND BUILDS DECISIONS
C CLEAR CO J FCT K CTRS
      DO 7 KN=1,ND
      IF(NCO(KN)-J) 7,8,7
    8 IF(NFT(KN)/2-K) 7,9,7
    9 ASN(KN)=0.0
      AON(KN)=0.0
      ARN(KN)=0.0
    7 CONTINUE
      AMEN(J,K)=X(J,1,L4)
      SMEN(J,K)=X(J,2,L4)
      ET(J,K)=X(J,7,L5)*Z(10,K+4,J)
      AFAC(J,K)=MAX1F((X(J,8,L5)*Z(10,K+4,J)-FAC(J,K)*P(3,1))/P(3,1),0.)
      IF(DMEN(J,K)+AMEN(J,K)-SMEN(J,K)) 13,13,14
   13 X(6,J+5,K+2)=0.0
   14 CONTINUE
      KN1=1
      DO 6 KL=1,10
      IF (Z(1,KL,J)) 5,5,2
    2 KN=Z(1,KL,J)
      IF (NFT(KN)/2-K) 6,3,6
    3 ARN(KN)=Z(7,KL,J)
      AON(KN)=Z(8,KL,J)
      ASN(KN)=Z(9,KL,J)
      KN1=KN
    6 CONTINUE
    5 CONTINUE
```

```
      DO 15 KN=KN1,ND
      IF(NCO(KN)-J) 15,26,15
   26 IF(NFT(KN)/2-K) 15,16,15
   16 IF(MAX1F(ARN(KN),ADN(KN),ASN(KN)))27,27,15
   27 IF(SMEN(J,K)) 17,17,18
   17 ASN(KN)=MIN1F(BEST(KN),ROM(KN))
      GO TO 15
   18 PVMH=SMEN(J,K)*500.0*Z(10,K+2,J)
      KRT=INLIM(0.1,PVMH,BEST(KN))
      GO TO (17,20,21),KRT
   20 ARN(KN)=BEST(KN)/Z(10,K+2,J)
      SMEN(J,K)=SMEN(J,K)-ARN(KN)/500.0
      GO TO 15
   21 ARN(KN)=PVMH/Z(10,K+2,J)
      SMEN(J,K)=0.0
      ASN(KN)=BEST(KN)-PVMH
   15 CONTINUE
      RETURN
      END

      SUBROUTINE BOTH(J)
      J=J
      LM=J*2-1
      SAPD=Z(10,6,J)
      DO 21 K=1,2
C   CALCULATE IND COST/AMH EXCLUDING ADMIN
      L=(K-1)*5
      L5=L+5
      L4=L+4
      L3=L+3
      L2=L+2
      L1=L+1
      JK=J+5*(K-1)
      L9=J*2-2+K
      RT=Z(10,K+4,J)/(Z(10,5,J)+Z(10,6,J))
```

```
      TE=X(J,7,L4)*Z(10,K+4,J)
      GO TO (22,23),K
   22 VRES=Z(10,2,J)*Y(JK,4,7)*Y(JK,3,7)
      Y(JK,1,7)=(TE+VRES+MIN1F(Z(10,2,J),1.0)*20000.)/Z(10,5,J)
      GO TO 24
   23 XLAB=MAX1F((Z(10,6,J)-SAPD),0.0)*Y(JK,4,7)*Y(JK,3,7)
      Y(JK,1,7)=(TE+XLAB)/Z(10,6,J)
   24 CONTINUE
   21 CONTINUE
      TL=X(J,9,6)
      TU=X(J,9,7)
      TM=(TL+TU)/2.0
      CANT=CASH(J)-AFAC(J,1)-AFAC(J,2)
      CART=CANT/(DET(J)+SRPLS(J))
      IF(CANT) 4,4,7
    4 ADET(J)=ABSF(CANT)+TM*(DET(J)+SRPLS(J))
      GO TO 10
    7 IF(CART-TL) 8,9,9
    8 ADET(J)=TM*(DET(J)+SRPLS(J))-CANT
      GO TO 10
    9 IF(CART-TU) 10,10,11
   11 SDET(J)=CANT-TM*(DET(J)+SRPLS(J))
   10 CONTINUE
      X(J,9,8)=AFFM(J,1)+AFFM(J,2)
      X(J,9,9)=QTFCST(J,1)
      X(J,9,10)=QTFCST(J,2)
      RETURN
      END


      SUBROUTINE EFF(NPD,J,K,KN,KT,PCC,EFFO)
C  THIS S/R CALCJLATES EFFICIENCY ACCORDINT TO CONDITIONS LAST PERIOD
C   (NPD=0 OR NEXT PERIOD,(NPD=1).
      K=K
      J=J
      KN=KN
```

```
      KT=KT
      L=(K-1)*5
      L1=L+1
      L2=L+2
      L3=L+3
      L4=L+4
      L5=L+5
C  VARIABLES USED ARE--
C    V1--INV./AMH
C    V2--(DT+RT)/BEST
C     V3--AMH
C    V4--HIRES PCT. (+,-)
C     V5--PCT COMPLETE
C    EFO--EFF LAST PD OR A(Y INTERCEPT)
      PRT=PR(KN)
      ROMT=0.0
      SBCT=0.0
      LM=J*2-1
      IF(RQT(KN)-ROM(KN)-CFCAP(KN)-15.0)  5,5,6
    5 IF(X(K+8,3,LM)-1.2) 502,502,503
  502 PR(KN)=X(K+8,3,LM)
  503 PR(KN)=PMAX(PR(KN),PD(J,K)*1.10)
      PR(KN)=PMAX(PR(KN),.90)
      ROMT=ROM(KN)
      ROM(KN)=0.0
      SBCT=CFCAP(KN)
      CFCAP(KN)=0.0
    6 PM=(K-2)*(K-2)
      V30=DMEN(J,K)*C20
      V20=PMAX(((AD(KN)+AR(KN))/BEST(KN)-1.0),0.0)
      V10=(DFAC(J,K)+PM*PMAX((RESH(J)-20000.),0.0)+ET(J,K))/V30
      V40=(AMEN(J,K)-SMEN(J,K))/(DMEN(J,K)+SMEN(J,K)-AMEN(J,K)+QTS(J,K)-
     1HMEN(J,K))
      V50=(RQT(KN)-ROM(KN)-CFCAP(KN))/RQT(KN)
      EFO=PR(KN)
      NGO=NPD+1
```

```
      CFCAP(KN)=MAX1F(CFCAP(KN),SBCT)
      GO TO (1,2),NGO
    1 V11=V10
      V21=0.0
      V31=V30
      V41=V40
      V51=MIN1F(PCC,(RQT(KN)-CFCAP(KN))/RQT(KN))
      GO TO 3
    2 V31 =(DMEN(J,K)+X(J,1,L4) -X(J,2,L4) )*(1.0-QTFCST(J,K))*C20
      V11=MAX1F(X(J,8,L4),(DFAC(J,K)*(1.0-P(3,1)))/V31)+X(J,9,L4)+
     1X(J,7,L4)
      V21=MAX1F((Z(7,KT,J)+Z(8,KT,J))/BEST(KN)-1.0,0.0)
      V41=(X(J,1,L4)-X(J,2,L4))/DMEN(J,K)
      V51=MIN1F(PCC,(RQT(KN)-CFCAP(KN)-Z(9,KT,J))/RQT(KN))
      X(7,2,L2)=V10
      X(7,2,L3)=V11
    3 GCON=.4342945
      V51=PMAX(PCC,0.01)
      T1=X(7,1,L1)*GCON*LOGF(V11/V10)
      T2=X(7,1,L2)*(V21-V20)
      T3=X(7,1,L3)*GCON*LOGF(V31/V30)
      T4=X(7,1,L4)*(V41-V40)
      T5=X(7,1,L5)*GCON*LOGF(MAX1F(V51,.10)/MAX1F(V50,.1))
      EFFO=EFO+T1+T2+T3+T4+T5
      V30=V30/1000.0
      V31=V31/1000.0
    4 FORMAT(1H 4HEFF.11F6.3,2F8.3,4F6.3,F3.0,2I2)
C  SELECTIVE READOUT
      XKN=KN
      IF(X(8,2,2)-1.0) 9,8,9
    9 IF(X(8,2,2)-XKN) 7,8,7
    8 WRITE OUTPUT TAPE 6,4,EFFO,EFO,T1,T2,T3,T4,T5,V10,V11,V20,V21,V30,
     1V31,V40,V41,V50,V51,AMEN(J,K),J,K
    7 ROM(KN)=MAX1F(ROM(KN),ROMT)
      PR(KN)=PRT
      RETURN
      END
```

```
      FUNCTION CTRL(SS,GG,TT,BB,XX)
  101 FORMAT(1H1 10X,47HERROR*****N IN A STMT GO TO (A,B,C),N TOO LARGE)
      N=ABSF(SS)
      IF(6-N) 100,2,2
    2 CTRL=(ABSF((XX-GG)/(TT-GG)))**BB
      GO TO (70,20,30,40,50,60),N
   20 IF(CTRL-1.0) 70,70,21
   21 CTRL=1.0
      GO TO 70
   30 IF(GG-XX) 70,70,31
   31 CTRL=0.0
      GO TO 70
   40 IF(GG-XX) 41,70,70
   41 CTRL=0.0
      GO TO 70
   50 IF(CTRL-1.0) 52,52,51
   51 CTRL=1.0
      GO TO 70
   52 IF(GG-XX) 70,70,53
   53 CTRL=0.0
      GO TO 70
   60 IF(CTRL-1.0) 62,62,61
   61 CTRL=1.0
      GO TO 70
   62 IF(GG-XX) 63,70,70
   63 CTRL=0.0
      GO TO 70
  100 WRITE  OUTPUT TAPE 6,101
   70 RETURN
      END

      SUBROUTINE RNORM(APG,R1,R2)
C THIS S/R GENERATES TWO INDEPENDENT RANDOM VARIABLES FROM THE SAME
C   NORMAL DISTRIBUTION WITH MEAN ZERO AND UNIT VARIANCE
C   REF--G.E.P. BOX AND MERVIN E. MULLER CERCA 1958
```

```
      PI=3.1415927
      U1=RANDM(ARG)
      U2=RANDM(ARG)
      R1=SQRTF(-2.0*LOGF(U1))*COSF(2.0*PI *U2)
      R2=SQRTF(-2.0*LOGF(U1))*SINF(2.0*PI *U2)
      RETURN
      END


      FUNCTION INLIM(XL,X,XU)
C IF X LT XL F=1,XL LTE X LTE XU F=3, XU LT X F=2
      IF (X-XL) 1,11,11
   11 IF(XU-X) 3,2,2
    1 INLIM=1
      GO TO 15
    2 INLIM=3
      GO TO 15
    3 INLIM=2
   15 RETURN
      END

      FUNCTION AFFM(J,K)
      J=J
      K=K
      L=5*(K-1)
      L1=L+1
      L2=L+2
      L3=L+3
      L4=L+4
      L5=L+5
      SFC=0.0
      AFC=MAX1F((X(J,8,L4)*Z(10,K+4,J)-FAC(J,K)*P(3,1))/P(3,1),0.0)
      AFFM=(X(7,3,1)+AFC/(FAC(J,K)+AFC))*(FAC(J,K)+AFC)*P(3,1)
      RETURN
      END
```

```
      FUNCTION QTFCST(J,K)
      J=J
      K=K
      L=(K-1)*5
      L5=L+5
      L4=L+4
      L3=L+3
      L2=L+2
      L1=L+1
      QTRL=QTS(J,K)/(DMEN(J,K)+QTS(J,K)-HMEN(J,K))
      Q1=        (1.0-(X(7,2,L1)*(X(7,2,L3)-X(7,2,L2)))/(X(7,2,L3)+
     1X(7,2,L2)))*(QTRL-.02)
      QTFCST=.02+Q1
      RETURN
      END


      SUBROUTINE RPGEN(J,K,X,C8,LINK)
      DIMENSION X(10,10,10)
C S/R CALLS INLIM AND RNORM
C  WHEN CALLED THIS S/R DEVELOPS A SET OF RANDOM PROPORTIONS DETERMINED
C   BY THE ROUTINE
C   BY THE ROUTING PATH SPECIFIED BY LINK--X(6,ROUTE,LINK) WHERE ROUTE
C   CONSISTS OF DESIGNATIONS FOR K IN X(J,K,1-2) WITH PROPORTIONS PLACED
C   IN X(J,K,3).  WHEN R=0 IN X(6,R,LINK), THE END OF THE ROUTE HAS BEEN
C   REACHED
      J=J
      K=K
   10 FORMAT(1H130HCOUNTER IN RPGEN EXCEEDED 50005F10.5)
      C8=C8
      L=(K-1)*5
      L5=L+5
      L4=L+4
      L3=L+3
      L2=L+2
      L1=L+1
```

```
      LINK=LINK
      RSUM=0.0
      DO 1 KT=1,6
    1 X(J,KT,L3) =0.0
C   SELECT RANDOM PROPORTIONS BETWEEN 0-1. R.  ADJUST FOR MEAN AND SIGMA
C    (R*SIGMA)+MEAN.
C   NOW GO THROUGH ROUTE
      DO 2 KT=1,10
      NGO=X(6,KT,LINK)
      IF (NGO) 3,3,4
    4 SIGMA=X(J,NGO,L2)
      XBAR=X(J,NGO,L1)
      CTR=0.0
    7 CALL RNORM(C8,R1,R2)
      CTR=CTR+1.0
      IF(CTR-5000.0) 11,11,12
   12 WRITE OUTPUT TAPE 6,10,RADJ,R1,R2,SIGMA,XBAR
      CALL XYZOUT
      CALL EXIT
   11 RADJ=(R1*SIGMA)+XBAR
      IF (INLIM(0.0,RADJ,1.0)-3) 5,6,5
    5 RADJ=(R2*SIGMA)+XBAR
      IF (INLIM(0.0,RADJ,1.0)-3) 7,6,7
    6 X(J,NGO,L3) =RADJ
    2 RSUM=RSUM+RADJ
    3 DO 8 KT=1,10
      NGO=X(6,KT,LINK)
      IF (NGO) 9,9,8
    8 X(J,NGO,L3) =X(J,NGO,L3) /RSUM
    9 RETURN
      END
```