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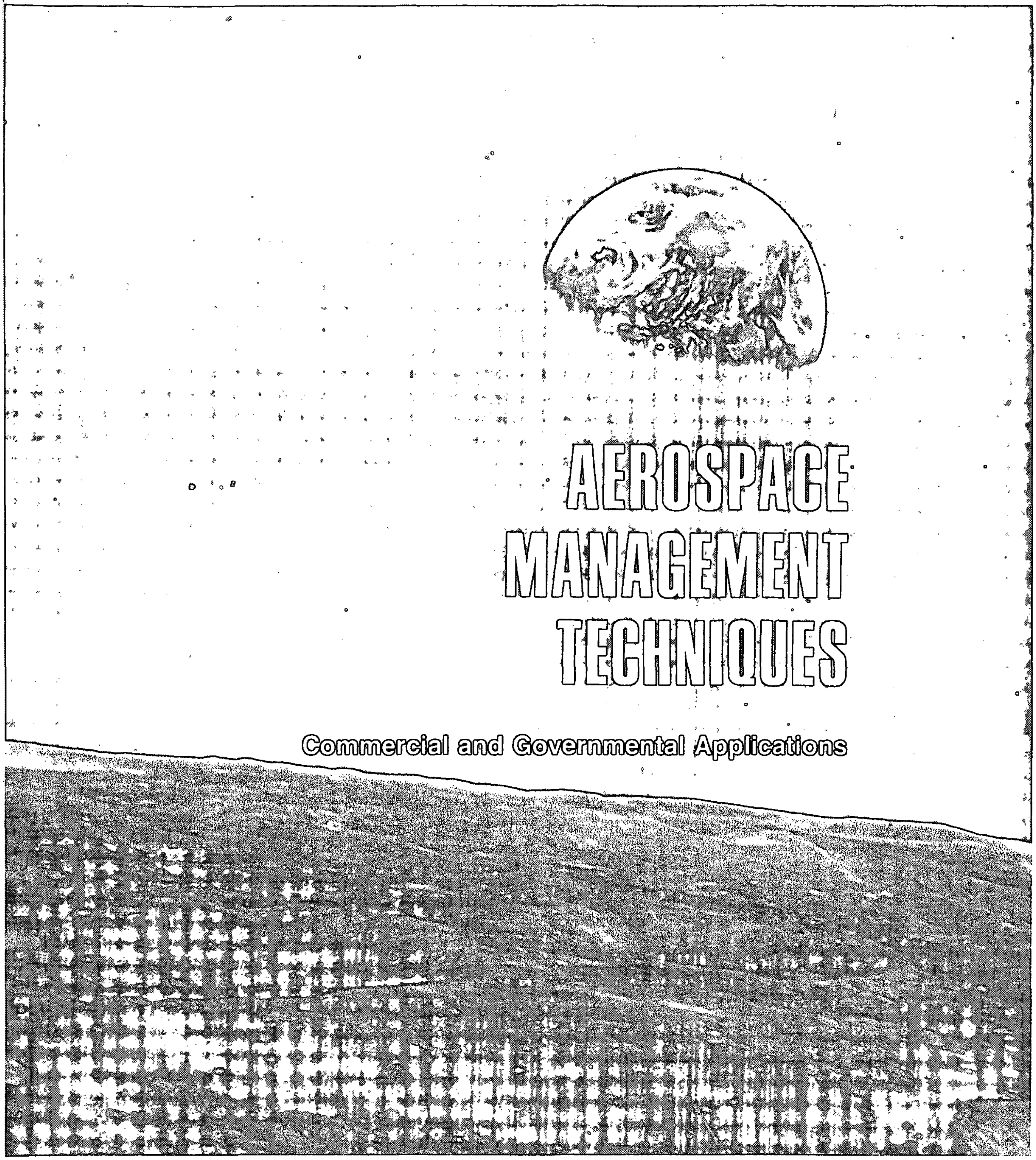

# AEROSPACE MANAGEMENT TECHNIQUES

## Commercial and Governmental Applications

UNIVERSITY OF DENVER • DENVER RESEARCH INSTITUTE

# AEROSPACE MANAGEMENT TECHNIQUES: COMMERCIAL AND GOVERNMENTAL APPLICATIONS

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## FOREWORD

This study was prepared by Dr. J. Gordon Milliken and his associates of the Denver Research Institute. Through the years of experimental programs in transferring the wide variety of technologies whose development, augmentation, and utilization was necessitated by NASA mission requirements, the Technology Utilization Office has been aware of the difficulties in dealing with management technology: as one of the most important and interesting areas in which NASA contributions appear to lie, it is one of the most difficult to synthesize, document, and transfer. To date, its transfer and application in nonaerospace sectors of the economy has taken place primarily through the movement of trained and experienced people. Accordingly, the authors' task has been a most difficult and challenging undertaking.

Experienced readers will note the absence or limited treatment of some well-known management techniques. It was agreed that certain of these, such as the Program Evaluation and Review Technique (PERT), found their origins outside the space program, and while they have been extensively used, modified, and augmented by NASA and its contractors, sufficient descriptive material already existed to make any value added by inclusion here a marginal choice. In other cases, management techniques originating outside aerospace have been sufficiently modified for space program applications that it appeared that sufficient contributions had been made to merit coverage. The conclusions are those of the authors who reached them following a period of interviews and extensive investigations of available literature.

Joseph M. Carlson
Technology Utilization Office
Office of Industry Affairs and
Technology Utilization

# PREFACE

The need for a guidebook to applications of aerospace management techniques has been expressed by numerous persons. Among these were officials of the Technology Utilization Office, National Aeronautics and Space Administration, who recognized the need as related to NASA's assigned mission to disseminate useful knowledge resulting from its aerospace activities.*

The management methods described and analyzed here have a common characteristic. All have been used rather widely within *aerospace*--the interrelated system of industrial and governmental organizations engaged in aeronautics, the space program, and related high-technology enterprises. A few of these management techniques may have originated within aerospace. In most cases, the techniques were generated elsewhere but adopted by aerospace managers and transformed or augmented to meet the critical needs of their programs. In most cases, whatever the origin of the management methods, they have evolved to a greater degree of refinement because of their use by aerospace managers.

## Scope of the Study

This study involved slightly more than one man-year of effort. Field interviews were conducted during 1969 and 1970 with 44 persons in the Federal government, 59 persons in aerospace and commercial industry, 19 persons in state and local government or related organizations, 26 persons in universities, and 11 persons in management consulting or research organizations. The field work was supplemented by an extensive literature search.

Certain study limitations should be acknowledged. The 25 aerospace management techniques described were selected from more than 50 candidate techniques as being the most widely applicable outside aerospace. The report was not intended to include all useful management methods, nor to include all examples of their successful application.

It was not our purpose, nor was it possible within the scope of this

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*NASA's Technology Utilization Office (TUO) has pioneered in developing methods for enhancing transfer of aerospace technology to other sectors of the U. S. economy. Chapter XI contains additional information on TUO's innovations in technology transfer, and discusses the technology transfer process.

effort, to attempt to authoritatively designate a point of origin for the development of the management techniques.


## Acknowledgements

The many persons listed in Appendix A contributed greatly to the study effort. We appreciate their valuable assistance, particularly those who talked at length with us in their offices, often followed by additional visits and by telephone and written communications.

We are grateful to the project monitor, Joseph M. Carlson, of the Technology Utilization Office, Office of Industry Affairs and Technology Utilization, National Aeronautics and Space Administration, who took a deep interest in the study and provided many valuable suggestions. Both Mr. Carlson and Ronald J. Philips, Director of the Technology Utilization Office, provided guidance and information which significantly enhanced the quality of the study effort.

Dr. Joseph DiSalvo and the staff of the Aerospace Research Application Center, Indiana University, assisted in our literature search.

Within the Denver Research Institute, we are indebted to the following persons: John S. Gilmore, who participated in the conceptual development, field work and writing, particularly of Chapters VI and XI; John G. Welles, Head of the Industrial Economics Division, for many creative suggestions; Terry Heller, Dean C. Coddington, Paul Bortz, Kristie Reifenberg, Sallie Sundine, Dick Johnston, Martin Robbins, and Morel Fry.



Industrial Economics Division
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## A BRIEF EXPLANATION OF THIS BOOK

This is a guidebook for managers and administrators. It is intended as a source of useful information on new management methods which show promise in solving selected problems of business, industry and government.

This guidebook has three major parts: Part 1 describes actual and potential applications of aerospace management techniques to commercial and governmental organizations (Chapters II-IV); Part 2 gives brief descriptions of 25 aerospace management techniques and discusses their use within the aerospace sector (Chapters V-IX); and Part 3 describes the aerospace sector's application of innovative management techniques.

The first part of this book has been designed as a guide to the potential usefulness of aerospace management techniques in specific organizational sectors. Chapter II is intended primarily for managers in commercial and industrial enterprises; Chapter III for administrators in nonaerospace agencies of the Federal Government; and Chapter IV for administrators of state and local public services. Each of these chapters contains a brief description of past and present use of aerospace management techniques in that organizational sector and an evaluation of the potential for future transfer of technology from aerospace to those sectors. Each of the chapters contains an illustrated grid chart indicating potential applicability of various aerospace management methods in helping to solve problems in that sector. Some examples of successful or potential transfer are also included.

The second part contains an introduction to the 25 management techniques selected for attention (Chapter V) and includes summarized descriptions of these aerospace-related techniques (Chapters VI-IX). Written for clarity of understanding and brevity rather than for completeness, the descriptions include references to other sources for detailed information. This part of the book is intended as a place of future reference, rather than as material read at a single sitting.

The last part of this book describes the process of transferring management technology from one sector to another. Chapter X describes some of the characteristics and historical development of aerospace management techniques. This chapter explains how the aerospace sector first adopted, then *adapted*, these techniques, and provides examples of how aerospace managers have responded to their needs by searching for and using new management technology. Chapter XI discusses the conditions which help promote management technology transfer, based on observations from this and other studies. Some knowledge of the barriers to transfer, and ways to overcome them, may help avoid disappointments and may improve the chances of successful application of aerospace management techniques to nonaerospace organizations.

A manager, faced with a problem that matches one of the common problems of his sector (listed in the charts in Chapters II, III, or IV) can learn which aerospace techniques (if any) are potentially useful. In some cases, illustrations of related applications are included in that chapter. In all cases, a reference to Chapters VI-IX will furnish leads to more complete information on the potentially useful technique.

# CHAPTER I

# ARE AEROSPACE MANAGEMENT TECHNIQUES USEFUL ELSEWHERE?

## If We Can Put a Man on the Moon, Why Can't We . . . ?

The U. S. space program has been widely and deservedly praised for its accomplishments. Perhaps the greatest of its achievements has been the stretching of men's minds. After the Apollo Program successes, a national--even a worldwide--reaction occurred. More men than ever began (in George Bernard Shaw's words) "to dream of things that never were and ask, why not?"

More than anything else, the spectacular moon landing missions demonstrated how skillfully U. S. managerial, scientific and engineering technology could respond to a major challenge. It was natural that men should ask why the successful efforts of the space program could not be transferred and applied to solve crucial problems here on earth.

Many candidate programs have been presented: clean-up of polluted air and water; elimination of poverty; eradication of cancer and other diseases; development of convenient mass transportation systems; in short, programs to solve almost every technological and social ill of U. S. national life. In each case it is proposed to transfer or copy the space program effort, often with a comparable commitment of funds and resources, to attack a major problem believed too massive for present attempts at solution.

Such speculation on application of our talents is healthy. A necessary step toward progress is the process of considering alternatives to what we are doing now. As a nation, it appears we are more than ever before ready to abandon tradition and consider alternative programs and alternative uses of our resources.

Once goals are defined and alternative programs to meet those goals are considered, the next step in a national planning process is more difficult: the realistic evaluation of the alternative programs to determine which are possible and which are not. This step must precede the even more difficult step of determining priorities and deciding where to commit our national resources.

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Note: References to sources appear at the end of each chapter.

There may be candidate programs which, upon analysis, will prove well-fitted for a large-scale national program effort. When these candidates appear, the precedent set by NASA on the Apollo Program (which built on earlier program experiences) will unquestionably ease the task of organizing national resources into a program structure patterned more or less after that of the space program.*

Nevertheless, we feel that most proponents of an Apollo-like response to national problems, for all their vision, overlook the subtler ways in which aerospace management techniques can be applied to business and governmental problems. They see the forest but overlook the trees.

The authors believe that duplication of the management structure and organization of an Apollo-like program does not, by any means, reflect the only method--or even the most promising method--of transforming hard-earned aerospace knowledge to the nation's problems. The real promise, the significant value of aerospace knowledge, will come in our opinion through widespread but unspectacular applications of specific technological and managerial concepts and methods to solve problems of industry and government. This diversified, fragmented use of aerospace techniques and concepts may be both a more realistic possibility and (in total) an even greater potential contribution to national goals than a new Apollo-like program.**

## Why Management Technology Transfer is Important

The quality and effectiveness of management can improve, although slowly, through experience and self-education of managers within an enterprise. A far more powerful and rapid means of improvement is through transfer of management capabilities from other enterprises. Transfer promotes technological change, and change is an essential part of progress.

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*The management of large-scale national programs is discussed in James E. Webb, *Space Age Management*, New York: McGraw-Hill, 1969.

**Past research into the nature of the technology transfer process indicates that progress normally occurs through a series of incremental advances, not usually through major scientific or technological thrusts. The same is true of progress in management techniques.

If we as a nation hope to solve the problems facing us, to shape our natural environment and our social structure, we must upgrade our management methods generally. The managerial competence of industry and government must support not only new Apollo-like programs, but the many less spectacular projects which make up our complex economy. To make the best use possible of our limited national resources, we must search for specific methods already proven successful elsewhere and gain the benefit of their use.

## Why Select Aerospace Technology for Transfer?

The system of high-technology, complex enterprises generally known as the aerospace sector has stimulated numerous innovations in science and engineering. The abundant generation of new technological concepts in aerospace programs is due largely to the heavy concentration of R & D talent required by the complexity of these programs. Besides the many scientists and engineers employed by the Federal government itself, many more are employed in industry supported by Department of Defense and NASA projects.

However, the innovations of aerospace are not limited to scientific and engineering developments. James Bright, an authority on forecasting and assessment of technology, has described the technological change resulting from the U. S. missile industry, and its chain reaction effects on management of the business environment:

> It created . . . advanced technical specialties, changed the educational background needed by engineers and designers, and required different . . . processes and new service activities . . . control systems, and . . . a basic and applied research activity . . . itself larger than most traditional industries.[1]

Complex activities and control systems present novel management challenges, as Chapter X discusses. The high-technology aerospace sector has, as a result, become a source of numerous advanced management techniques. Examples of such management innovations include the well-known PERT and critical path programming techniques originally developed simultaneously in two aerospace programs, and the scheduling/budgeting extension, PERT/Cost. They include such useful tools of management decision technique as the Simplex method for solving multidimensional linear programming problems. They include breakthroughs in planning and forecasting, mission analysis, and systems engineering. They include significant improvements in reliability analysis, a by-product of NASA's space exploration programs.

The growing concern with the management problems of other sectors of national life makes it increasingly important to search for management knowledge generated in the aerospace-related sector and to transfer this knowledge effectively to other public and private sectors where it can be usefully applied.

It is important to understand that good judgment must be used in selecting aerospace management methods for transfer, to assure they match the needs and economic capabilities of the other sector. Naturally, management techniques do not apply universally to all firms or to all situations. The key is intelligent matching of method to need and environment, because some aerospace management methods chosen uncritically for application elsewhere might do more harm than good.

Many potential benefits are to be realized from further selective transfer of management technology. In appropriate situations, the management techniques described in this book can provide a better planning function for an industrial firm, better scheduling of operating services of a city government, and other economic and social improvements. Part 1 of this book gives examples of promising applications of aerospace management techniques outside the aerospace sector.

## Reference

1. Bright, James R., *Research, Development, and Technological Innovation* (Homewood, Illinois: Richard D. Irwin, 1964), p. 10.

# CHAPTER II

# APPLICATIONS TO COMMERCIAL AND INDUSTRIAL ENTERPRISES

## Past and Present Use

Thus far, commercial and industrial firms outside aerospace appear to have adopted relatively few management techniques and concepts from aerospace. This summary opinion is based on an overview of identified direct transfers, which are comparatively few in number when viewed in the context of the total management technology of U. S. industry. This is neither surprising nor disappointing, considering the relatively recent development of aerospace management technology and the typical slowness of the technology transfer process. However, for reasons discussed in Chapter XI, the potential for future transfers appears quite promising.

Of the 25 aerospace related techniques selected for attention in this guidebook, a subjective appraisal indicates that only a few have been utilized to any significant degree by non-aerospace commercial and industrial firms. These include value engineering and cost-effectiveness analysis (indicating the cost-consciousness of the commercial sector); policy analysis (in the larger firms where a full corporate planning program exists, and particularly in analysis of marketing policies); incentive contracting (in major facility construction); and operations research (in the petroleum and other high-technology industrial sectors).

In some management areas (manufacturing management and numerous applications of operations research, for example) commercial and industrial firms use concepts and techniques similar to the management concepts of aerospace, or equally advanced. These concepts and techniques appear to have been developed largely within the commercial and industrial sector itself or adopted from nonaerospace sources.

Several other of the 25 aerospace techniques and concepts have analogous counterparts in commercial industry: project management; source evaluation; management information systems; scheduling and status reporting (often using PERT/CPM): logistics management; and quality assurance. Yet a subjective evaluation indicates that the techniques differ substantially from their aerospace counterparts in emphasis, rigor, or sophistication. In some other management areas (financial controls, for example) the stimulus of profit competition has resulted in the use of management techniques very different from those found in aerospace. These techniques are not necessarily less or more advanced. Rather, they are better fitted for their environment.

In speaking about technological transfers from the space program to nonaerospace industry, Dr. George E. Mueller, associate administrator of NASA, said in 1969:

> About 150,000 people who used to work in the space program are working elsewhere in the industry. The principal things that are going to come from the space program are the approaches that we have used toward achieving reliability . . . This rigor of looking at things will become a part of our industrial system that will--and should--lead to products that will be better.[1]

Dr. Mueller has identified a major factor contributing to technology transfer: the growing numbers of aerospace employees and managers who have moved to commercial industry. Another force promoting transfer of aerospace management methods is the growing diversification of industry which brings aerospace and commercial organizations together within industrial conglomerates.

Some diversified firms already have successfully transferred management methods from their aerospace to their conventional industrial divisions. Dr. Mac C. Adams, Group Vice President of Avco's Government Products and Services Group, said in an interview:[2]

> Avco is setting up the Economic Systems Corporation, which works on nonaerospace types of social problems, pollution, manpower training, etc., as part of the Government Products Group. By being part of the Group and having contacts there, we assume that the aerospace techniques can be transferred. The Economic Systems Corporation pulls together teams of people utilizing special talents of personnel throughout the Group who otherwise are involved in our aerospace effort. The corporate staff also arranges numerous transfers between the Government Products Group and the Commercial and Industrial Products Group. The technology transfers aren't really successful unless the people go over also.

Some further examples of successful transfer between divisions of diversified firms have been identified at TRW, North American Rockwell, and especially at Litton Industries (discussed later in this chapter), although other conglomerates have failed to achieve successful technology transfers.

## Overview of Potential Applicability

With a few exceptions (e.g., Government/Private Corporations) all of the 25 selected aerospace management techniques appear to have usefulness to the commercial industrial sector. The techniques are not, of course, uniformly applicable through the sector. Some techniques are costly to implement and are limited to the larger and richer enterprises.

A matrix chart which summarizes our evaluation of the potential applicability of aerospace management techniques to the commercial industrial sector is shown in Figure 1. The left axis lists selected management problems believed common to managers in this sector. The top axis lists the 25 aerospace management techniques described in Chapters V-IX. The boxes at each intersection are shaded to indicate the perceived degree of applicability of the technique as an aid to solving the selected management problem. To illustrate the use of this chart:

- Decision analysis (operations research) is useful for anticipating results of a management policy or decision, and for locating a new branch plant or warehouse. It is not generally applicable to problems of product planning, quality control, or controlling the performance of suppliers and subcontractors.

- Technological forecasting is an excellent tool for environmental forecasting or planning a new product line. However, the technique is not applicable in improving product reliability, developing a maintenance and repair system for products, and obtaining better operational information.

SELECTED MANAGEMENT TECHNIQUES

- ■ Extremely Useful
- ◢ Useful
- ● Possibly Helpful
- ☐ Probably Not Helpful

| SELECTED MANAGEMENT PROBLEMS OF THE COMMERCIAL INDUSTRIAL SECTOR | POLICY & PROGRAM ANALYSIS | | | | | TECHNOLOGICAL PLANNING | | | | | | ORGANIZING | | | ADMINISTRATIVE PLANNING AND CONTROL | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Systems Analysis & Policy Analysis | Cost-Effectiveness Analysis | Decision Analysis (Opns. Res.) | Heuristics | Simulation and Modeling | Technological Forecasting | Delphi Technique | Systems Engineering Management | Reliability Analysis | Maintainability Analysis | Value Engineering | Project Management | Matrix Organization Structure | Government/Private Corporations | Systems for Procurement | Source Evaluation Board Process | Incentive Contracting | Contractor Performance Evaluation | Management Information Systems | Mgmt. Reporting & Display Systems | Scheduling/Status Methods | PERT/CPM | Configuration Management | Logistics Management | Quality Assurance |
| **OVERALL MANAGEMENT PLANNING:** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Forecasting future environmental conditions (markets, costs, etc.) | | | | | ■ 1 | ■ 2 | ■ 3 | | | | | | | | | | | | | | | | | | |
| Predicting results of management policy or potential contingency | 4 | | ■ | ● | ■ | | ◢ | | | | | | | | | | | | | | | | | | |
| Making good decisions with insufficient information | | | ■ | ■ | ■ | | ◢ | | | | | | | | | | | | ◢ | ● | | | | | |
| Organizing to develop and make several products in one factory | ● | | | | ◢ | | | ● | | | | ■ | ■ | | | | | | ● | | ◢ | ● | ■ 5 | ■ | |
| **PRODUCT PLANNING AND DEVELOPMENT:** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Planning a new product line | ● | | ● | | ● | ■ 6 | ◢ | | | | ■ | | | | | ◢ | | | | | | | ● | | ● |
| Planning a product to be part of a larger system | ■ | ■ | | | | | | ■ | ■ | ■ | ■ | | | | | ● | | | | | | | ● | ● | ■ |
| Designing a product easy to repair or maintain | | | | | | | | ■ | ■ | ■ | ● | | | | | | | | | | | | | ● | ● |
| Improving product reliability in operation | ● | | | | ◢ | | | | ■ | | ● | | | | ● | | ● | ● | | | | | | | ● |
| Redesigning a product to lower costs or improve performance | | ■ | | | | | | ■ 7 | | | ■ | | | | | ● | | | | | | | | | |
| Determing product performance before production occurs | ◢ | | | | ■ | | | | ■ | ● | | | | | | | | ● | | | | | | | |
| **MANAGEMENT OF OPERATIONS:** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Managing a service operation for lower costs or improved performance | ■ 8 | ■ | ● | ● | ◢ | ● | ◢ | ◢ | ◢ | ● | ◢ | | | ● | ● | | ● | ● | ◢ | ◢ | ■ | ● | | ◢ | ◢ |
| Controlling performance of suppliers and subcontractors | | | | | | | | | | | | ■ | | ■ | ■ | ◢ | ◢ | ■ | ◢ 9 | ■ 9 | ■ | ◢ | | ● | ■ |
| Managing spare parts supplies (lower costs, reduce stockouts) | | | ● | | ■ | | | ● | | ■ | ■ | ■ | | | | | | | ◢ | ● | | ■ | | | |
| Opening a branch plant with least disruption to operations | ◢ | | ◢ | | ◢ | | | | | | | | | ◢ | ◢ 10 | | ● | | | | | ■ | ■ | | |
| Repairing products after delivery to customer | | | | | | | | ● | ■ | ■ | | ◢ | | | | | | | | | | | ■ | ■ | ◢ |
| **EVALUATION AND CONTROL:** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Getting faster and more accurate reports on operations | | | | | | | | | | | | ● | ◢ | | | | | ◢ | ■ 11 | ■ 11 | ■ | ■ | | | |
| Getting better schedule or cost control and earlier notice of problems | ◢ | | | | ◢ | | | | | | | ◢ | ◢ | ● | | ◢ | | ◢ | ■ | ■ | ■ 12 | ■ 13 | | | ● |
| Assuring a desired level of quality of products and services | ● | ■ | | | ◢ | | | ◢ | ■ | ◢ | ■ | ● | | ● | ■ | ◢ | ◢ | ■ | ● | | | | | | ■ 14 |

Note: Numbers within boxes refer to paragraphs in Chapter II.

Figure 1. Potential Applicability of Aerospace Management Techniques to Commercial and Industrial Enterprises.

Examples of Successful Application

1. *Applying simulation and modeling to forecast environmental conditions.* While the use of computer simulation is not new to industry--one recent survey showed that 35 percent of U. S. corporations used computer simulation to forecast trends in sales demand and inventory needs--some industrial firms have developed highly advanced models for simulating the operation of the firm in its total environment. The Boise Cascade Corporation's timber and wood products division uses a computerized model of some 15,000 mathematical variables to look 15 years ahead at operations, to decide on timber land use and plant location. At Du Pont, a model is used to simulate the operations of the entire dye industry and Du Pont's role in it. Commenting on such advanced applications of computer models by industry, *Business Week* refers to NASA as a prime example of a user of such new management techniques and quotes former NASA Administrator James E. Webb's caution that the computer science techniques cannot be successful if they merely are applied mechanically. Instead, Webb emphasizes that the critical factors of the changing environment must be recognized, and that the successful manager is one who adapts techniques flexibly and innovatively to that environment.[3]

2. *Applying technological forecasting to future industrial operations.* Two imaginative forecasts, both prepared by aerospace firms, are being used to assess the economic aspects of future commercial transportation in the U. S. A 1968 study, conducted by North American Rockwell for the Department of Housing and Urban Development, analyzed the managerial, economic and technological problems of urban transportation.[4] The findings are potentially valuable not only to the manufacturers of automotive and conveyor equipment but to the trucking and municipal transit industries. The second forecast, developed by Lockheed International for the Department of Transportation, projects major economic aspects of international ocean transportation. The findings are intended to help private firms

eliminate uncertainties about introducing new technology (e.g., automated containerships, advanced communications and material handling systems) into the transoceanic transportation system.

A somewhat different application of technological forecasting methods has been used to predict the effects on industrial location of the introduction of a new transportation method, super-cargo aircraft, during the 1970's. The impacts on plant location preference, industrial economics and real estate values which stem from the innovation have been explored in a program of self-sponsored research by Analytic Services, Inc., an Air Force contract research center.[5]

3. *Using Delphi technique to anticipate future markets and business conditions.* Industrial firms using the Delphi technique in 1970 to forecast business conditions included Weyerhauser Co., to learn the future of the construction business; TRW, Inc., to anticipate profitable future products and services; Smith, Kline, and French, to study the long-range future of medicine; McDonnell Douglas, to anticipate future commercial aviation conditions; and Du Pont, which retained the Institute for the Future to project future employee fringe benefits using Delphi.[6]

4. *Applying systems analysis to management control of a large commercial electric power system.* The Philadelphia Electric Company provides electric power to a region in Pennsylvania and Maryland containing about 4 million persons. The Company generates power in a variety of plants having different technologies and energy sources (fossil fuels, water power and nuclear power) and varying costs. For optimum management, the Company needs to monitor its power demand almost continuously and to direct power production to the most cost-efficient combination of generating plants. Such calculations had been done manually, using "seat of the pants" methods. The North American Rockwell Information Systems Company developed a much improved control method using aerospace systems engineering techniques. A computer system was designed to monitor power demand and compute the most economical generating source. The system also plans for contingencies (i.e., determines potential hazards in case any equipment

fails) and predicts loading demands in advance so that equipment can be activated smoothly when needed.

5. *Using configuration management to organize and control multi-project production.* The Avco Aerostructures Division in Nashville, Tennessee now uses a computerized configuration management system developed in its aerospace operations to control office equipment manufacture. This Division, which produces aerospace products (aircraft and helicopter components) on adjacent production lines, manufactures all of the steel office furniture (except desk chairs) sold by Globe-Wernicke. The computerized configuration control system controls matching of modular parts through the production operations, permitting 6,600 possible configurations (model, size, color, style) of office equipment. During a 1969 visit to the Division, it was learned that Avco management has anticipated the use of proven techniques of project engineering/systems synthesis in potential mass production of other commercial (nonaerospace) products, such as medical equipment.

6. *Using technological forecasting to direct R & D planning efforts.* Technological forecasting has been used effectively by NASA, the Navy, and some industrial firms to improve their planning of R & D. NASA's Ames Research Laboratory uses *ad hoc* groups composed of scientists of recognized stature (about 12 senior scientists representing several disciplines) to study a research field, forecast what research efforts can and should be accomplished, and whether Ames has the competence to perform them. With contributions and participation by other interested staff members, the *ad hoc* group (after 3 to 6 months of study) ranks the research projects which show promise and provides estimates of time, money and resources needed to accomplish these projects. These forecast studies give direction to the future research programs, and provide a form of quality control and method of resource allocation which are palatable to the R & D sceientists. The Navy Department, also using methodology directly applicable to industrial firms, has developed a multi-step technological forecasting technique in sequence of "optimum desirability," a measure which includes such factors as probability of

success, impact or value if successful, and even management environment (i.e., acceptability to the policy-makers).[7]

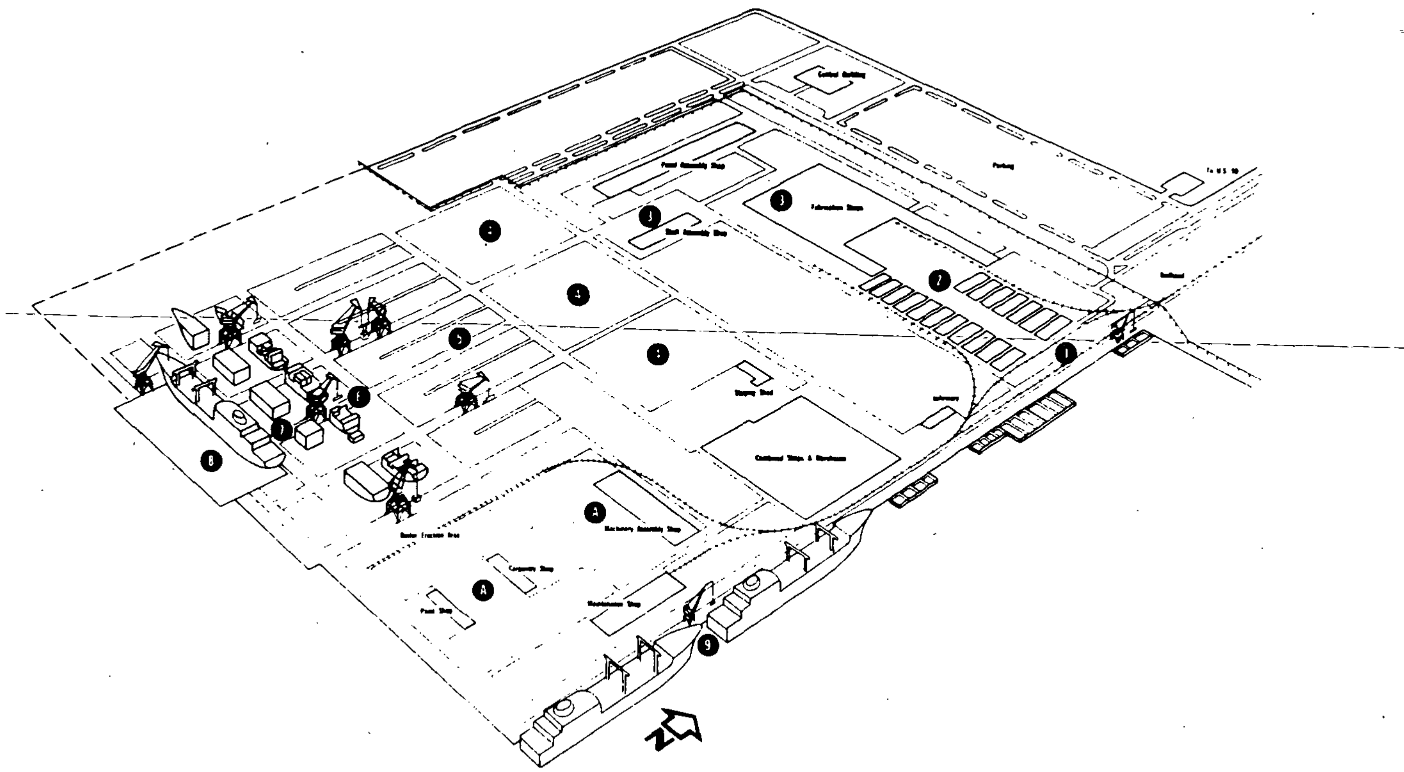
7. *Using systems engineeering to redesign products for lower cost or improved performance*. An imaginative and deliberate merger of aerospace management techniques with innovative shipbuilding technology and expertise has shown how other commercial industries might be revitalized. Litton Industries, which acquired the Ingalls Shipbuilding Corporation in 1961, has in recent years combined advanced management and systems technology with ship construction operations.

When the Department of Defense, attracted by the possibility of lowering costs through the production of a large series of identical ships at a single yard, announced their procurement plan for the Fast Deployment Logistics ship (FDL), Litton organized a team in 1965 to bid on this program.

Consequently, the company at Pascagoula, Miss., built a modern ship manufacturing facility designed for the efficient construction of a series of ships on a staged production line basis using subassemblies and modules as basic building blocks, just as airframes are produced by an aircraft manufacturer. Standardized kits are used for outfitting and modification. These methods represent a complete departure from the traditional stationary shipway method by which ships have been constructed for centuries. (See Figure 2).

The company went on to win the FDL contract, which subsequently was not funded, and every major competition the Navy has offered since, under their new series production procurement policy. These included LHA amphibious assault ships in May 1969 and Spruance-class destroyers (DD-963) in June 1970 -- the largest ship manufacturing contract in history. All these ships are to be built in the new Litton Ship Systems facility.

Before these new vessels can be manufactured, they must first be engineered and designed at the company's advanced marine technology center in Culver City, California. Through the use of computerized models, which include both engineering system design and life-cycle costs, any desired



The assembly line method of ship production is one of the unique aspects of the shipyard. Steel plate and shapes are brought to the material receiving area (1) by ship, barge, rail or truck for translation by cranes to the raw material storage area (2). Material then is transferred by crane and conveyor to the fabrication area (3) -- to the fabrication shop for processing, then to the panel shop or the shell assembly shop for further processing into structurally-complete panels and shell assemblies. These panels and shell assemblies are then transferred through the staging and kitting area (4) to the sub-assembly area (5) where sub-assemblies are completed and outfitted. Sub-assemblies then are moved to the module assembly area (6). The completed modules are translated to the ship assembly area (7) where they are joined to form the structurally-complete and outfitted ship. The ship then is transferred to the launching platform (8). After launch, the ship is moved to the final outfitting dock (9). Shop buildings and warehouses (A) are conveniently located for efficient translation of machinery and equipment, and processed and packaged material, into the ship production flow.

Figure 2. Shipyard Production, The Ingalls Shipbuilding Corp., Pascagoula, Mississippi

ship condition or characteristics can be simulated. Detailed computerized economic models are integrated with the engineering models to learn the cost effectiveness of systems, subsystems and hardware. The computer enables Litton to optimize the ship design for the most efficient performance and production.

The first of four container ships to be manufactured at the new Litton Ship Systems facility was launched in June, 1971. These vessels will be followed closely by the LHAs and the destroyers.

All the vessels will be produced using computer controlled production methods to manufacture them on an assembly line basis with modular techniques. A number of other advanced techniques (PERT and CPM Systems, use of preassembled modular units, and mathematical lofting) also have been used to improve shipbuilding efficiency. The boilers, turbines, pipes, ducts and other components are standardized for each ship series, manufactured in quantity and fitted into the modules as they move sideways on wheeled platforms along rails through the fixed work stations to the final integration area. Here the modules are fitted, welded together and made ready for launching from a specially designed pontoon system.

8. *Using systems analysis to increase efficiency of service operations*. In 1969, the New York and American Stock Exchanges retained the RAND Corporation and the North American Rockwell Corporation to analyze operational systems and methods of the securities industry. The exchanges announced that RAND, "using long-range planning methods and advanced technologies pioneered in its work for the U. S. Air Force, will develop programs aimed at restructuring the system by which the securities industry processes paperwork and transfers ownership of securities." RAND applied systems analysis to find long-term solutions to restructuring stock exchange solutions. The systems analysis studies investigated new management control systems to improve operations of brokerage firms. RAND developed a computer model to simulate actual trading and processing operations and recommended several changes which would reduce the cost of uncompleted securities transactions from $125 million to $17 million annually.[8,9]

9. *Using management information systems to control supplier operations.* The Chrysler Corporation, an aerospace/defense contractor as well as an automotive manufacturer, has developed a computerized management information system similar in scope to that used on the Apollo Program. Chrysler's system controls manufacturing operations throughout a complex network of supplier plants. Altogether, the system integrates production information for seven Chrysler assembly plants, 26 parts manufacturing plants, and 95 independent suppliers. A staff member of the Aerospace Research Applications Center, Indiana University, reports that it is the nearest thing to a total information system which has yet appeared for manufacturing. The information system, which is fully integrated into the production process, has been used for forecasting, materials management, corrective action on defective products, line balancing, manpower allocation, preventive maintenance, and other applications.[10]

10. *Using "turn-key" project performance specifications for industrial facility construction.* The "turn-key" contracting concept, which began in the construction of oil refineries and chemical plants, was widely and successfully used by the aerospace sector during the 1950's and 1960's for the rapid construction of missile and space rocket bases. Basically, the owner-operator writes a set of performance specifications (i.e., what the facility is to do, its quantity or quality of production output) but does not specify the details of construction. The engineer-contractor is responsible for feasibility studies, engineering design, procurement of equipment and materials, construction, and shakedown operation. Once the performance specifications are met the key to the gate is symbolically turned over to the owner, hence the name. The turn-key concept relieves the industrial owner of the concern for design and construction adequacy; he contracts only for the result he needs--functional performance. A paper on applications of aerospace techniques and a series of reports from the Civil Engineering Department, University of Missouri, describe how the turn-key concept can be used for large-scale construction of urban housing to help solve a major housing shortage.[11]

11. *Using management information systems to get faster and more accurate reports on operations.* Information systems specialists have successfully adapted the aerospace control room concept to commercial uses. TRW's Civil Information Systems Department has contracted with a California oil exploration consortium to create a management control center which will quickly and accurately report information needed to direct offshore oil development.

In another adaptation of management information system technology, Lockheed Aircraft Corporation's Information Systems division has designed a management information system for hospitals. The system, which has been installed at El Camino Hospital in California after preliminary experience at the Mayo Clinic, involves a computer-based patient medical record which can be retrieved and displayed either in printed copy or on a video screen. The physician, having access only to a video terminal, can use a light pen to control or select an immediate display of patient clinical data from logical groupings of information from their medical history. Lockheed information specialists stated in an interview that an estimated third of a hospital's man-hours are spent in processing information--writing, copying, verifying and recording medical orders and other data. The hospital management information system is expected to reduce the time expended and the incidence of error in information processing.

12. *Using VIS-A-PLAN to schedule development of consumer products.* After experiencing some difficulties among the R & D staff in implementing a conventional schedule control technique, the Consumer and Technical Products Division of the Owens-Illinois Corporation experimented with VIS-A-PLAN, a space program modification of PERT. The VIS-A-PLAN system was first used by Owens-Illinois in 1967 and after an orientation period has been well received by both management and the R & D staff. The stated advantages include speed in familiarizing new staff members with project status, ready identification of areas of deficient performance, and ease of updating.

13. *Using PERT to improve schedule control.* Among the many applications

of PERT/CPM techniques to commercial enterprises is an application which improves the estimating of completion time for road construction projects. Prepared at Mississippi State University, the methodology is based on PERT network calculations and regression analysis. The systematic procedures promote more objective and accurate estimates-to-complete based on the experience of 90 construction projects.[12]

14. *Adapting aerospace quality assurance techniques to commercial manufacturing.* Two firms in the Southern U. S., which helped develop semi-automated quality assurance systems for the space program under NASA contracts, have adapted these systems for use in commercial production. SCI Electronics, Inc., of Greenville, S. C., has applied its quality control systems engineering skills, together with automatic recording and display equipment similar to that manufactured for NASA, to develop an industrial monitoring system for textile manufacturing plants. Space Craft, Inc., of Houston similarly has adapted a malfunction detection system used at Goddard Space Flight Center to analyze and detect quality defects in commercial magnetic tape recorders.

## Conclusion

The 14 examples of transfer in this chapter are intended to illustrate the wide variety of potential applications. The successful transfers of aerospace management techniques to the commercial industrial sector generally occur when economic barriers are overcome (the techniques can be implemented within the budget of the adopter) and when the environment is favorable. Two factors appear essential to a favorable environment: (1) true applicability of the management technique to the need of the organization; and (2) an enterprising manager willing to try the new technique, either because he has seen it work in aerospace or because he is willing to take a calculated risk.

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## CHAPTER III

## APPLICATIONS TO NON-AEROSPACE AGENCIES OF THE FEDERAL GOVERNMENT

### Past and Present Uses of Aerospace Management Techniques

Of the 25 selected aerospace-related management techniques, only a few have been extensively or systematically applied in nonaerospace agencies of the Federal government. Among those that have been applied most often are systems analysis (particularly as used in Planning-Programming-Budgeting Systems), cost-effectiveness analysis, simulation and modeling, and management information systems. In our judgment, other techniques that might be expected to yield the greatest benefits to Federal agencies would include policy analysis, project management, and scheduling/status reporting methods. These judgments are not intended to minimize the potential returns of other possible applications which might have great impact on the management of specific agency problems.

Our research found fewer cases of *acknowledged* transfer of aerospace management techniques to nonaerospace agencies of the Federal government than were found in the commercial sector of state and local government. Based on our interviews of directors of management and organization in various departments and agencies, two indications are apparent; (1) there are some management techniques in use or under study by Federal agencies which resemble techniques used in aerospace; and (2) there is a marked reluctance to acknowledge that management practices of aerospace agencies and aerospace industry have had any great effect on the management practices of these nonaerospace agencies.

The use of an aerospace-related management technique will not necessarily have the same effect in a nonaerospace agency that was obtained in an aerospace agency. In some cases the application may be made with less emphasis in the total scheme of management of the agency. Or the application may be made with less rigor, sophistication, or pervasiveness. In some cases the impact of the technique would be diluted.

### Overview of Potential Applicability

A matrix chart that indicates the potential applicability of aerospace related management techniques to nonaerospace agencies of the Federal government is shown in Figure 3. The left axis lists some selected management problems believed to be common to many managers in Federal agencies, and the top axis lists the 25 aerospace management techniques. The boxes at each intersection are shaded to indicate the perceived degree of applicability of the technique as an aid to solving the management problem.

Most of the aerospace management techniques seem to have present or potential applicability to the Federal sector on a selective basis, even though their present use is not extensive. Most of the documented attempts to transfer these techniques have occurred among "Policy and Program Analysis" techniques, although it should be noted that even these attempts have achieved only mixed success and impact. There seems to be considerable potential for those techniques classified under "Organizing," but as yet there have not been very many reported applications in non-aerospace Federal agencies. A few applications are found among those management techniques designed for "Administrative Planning and Control," but more extensive transfers may be dependent upon different organizational arrangements or different management philosophies than now prevail.

A number of applications of aerospace management techniques in non-aerospace agencies of the Federal government are described below. These examples are keyed to the matrix chart (Figure 3) by numbers which appear in some of the intersection boxes, thus illustrating some of the types of applications that can take place. It will be noted that some keys refer to more than one block, indicating that some management techniques cluster, or that one technique may accomplish the solution of more than one problem.

## Examples of Successful Applications

1. *Applying simulation and modeling to forecast future environmental conditions*. Using simulation techniques pioneered in aerospace to predict battle conditions, the U. S. Forest Service utilizes a forest fire model to predict the combinations of events and conditions that would lead to a forest fire. This model represents, insofar as possible, all of the factors that might lead to the outbreak of a conflagration. Whenever a fire occurs within the U. S., the model is updated to include and account for the new information. The model has very functional consequences in practice.[1]

| SELECTED MANAGEMENT PROBLEMS OF NON-AEROSPACE AGENCIES OF THE FEDERAL GOVERNMENT | POLICY & PROGRAM ANALYSIS | | | | | TECHNOLOGICAL PLANNING | | | | | | ORGANIZING | | | ADMINISTRATIVE PLANNING AND CONTROL | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Systems Analysis & Policy Analysis | Cost-Effectiveness Analysis | Decision Analysis (Opns. Res.) | Heuristics | Simulation and Modeling | Technological Forecasting | Delphi Technique | Systems Engineering Management | Reliability Analysis | Maintainability Analysis | Value Engineering | Project Management | Matrix Organization Structure | Government/Private Corporations | Systems for Procurement | Source Evaluation Board Process | Incentive Contracting | Contractor Performance Evaluation | Management Information Systems | Mgmt. Reporting & Display Systems | Scheduling/Status Methods | PERT/CPM | Configuration Management | Logistics Management | Quality Assurance |
| **PLANNING** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Forecasting future environmental conditions | ○ | | | | 1 | 2 | | | | | | | | | | | | | | | | | | | |
| Planning and budgeting new and continuing programs | 3 | | | | | | / | | | | | | | | | | | | | | | 4 | ○ | | |
| Predicting the results of operating policy alternatives | | / | ○ | | 5 | | / | | | | | | | | | | | | | | | | | | |
| **MANAGEMENT OF FEDERAL OPERATIONS** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Improving and standardizing repetitive decision-making functions | | / | | | / | | | | | | | | | | | | | | | | | | | | |
| Efficiently operating decentralized government services | / | | | | | | | ○ | | | | | ○ | ○ | | | | | | / | | | | | ○ |
| Integrating one gov't service into other (Fed.,State, Local gov't) jurisdictions | | | | | | | | | | | | | | 6 | | | | | | / | | | | | / |
| Integrating public and private resources in organizations | / | | | | / | | | | | | | / | | | / | | | | / | | | | | | |
| Reorganizing government structures in response to change | | ○ | | | | / | | | | | | | | | | | | | | | | | | | |
| **EVALUATION AND CONTROL** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Getting faster, more accurate reports on programs and operations | ○ | ○ | | | | | | | | | | / | | | | | | ○ | 7 | | | / | | | / |
| Determining and measuring effectiveness of Federal agency programs | | | | | / | | | | 9 | 9 | 9 | ○ | | | | | | | | ○ | ○ | | | | |
| Controlling major procurement programs | 8 | | | | | | | 8 | | | | 8 | ○ | / | 8 | | | | | / | | / | / | | 8 |

Legend (SELECTED MANAGEMENT TECHNIQUES): Extremely Useful (shaded box); / Useful; ○ Possibly Helpful; empty box: Probably Not Helpful

Note: Numbers within boxes refer to paragraphs in Chapter III.

Figure 3. Potential Applicability of Aerospace Management Techniques to Non-Aerospace Agencies of the Federal Government.

> As a result [of the model], the Forest Service is now able to issue 'early warnings' which serve (1) to indicate the need for preventive measures . . . , (2) to alert local fire fighting authorities to an impending hazard, or (3) to minimize the risk to lives and property through prompt evacuation.

A similar kind of model has been developed by the Public Health Service to simulate the spread of contagious diseases that cause epidemics. By adjusting the variables in the model and entering the conditions that were present, the Public Health Service can chart the likely progression of the disease from one city to another and issue warnings and provide medicines that would combat the outbreak.[2]

2. *Applying technological forecasting and the Delphi technique to forecasting future conditions*. Technological forecasting techniques, which extrapolate trends and gather informed opinion in a disciplined fashion, have been used primarily within aerospace to predict the diffusion of technology and to develop as accurate a picture of the future as is possible. The use of these techniques has spread to certain national commissions and Federal government agencies outside aerospace. Five years ago, the National Commission on Technology, Automation, and Economic Progress published its seven-volume analysis of *Technology and the American Economy*[3] which forecast the likely impact of automation on manpower requirements of the future. Another national group, the American Academy of Arts and Sciences' Commission on the Year 2000 was asked to forecast what the country and the world would be like in the year 2000. The fascinating deliberations of this committee are reported in *Daedelus*, and similar work appears in other sources.[4] More recently, President Nixon's National Goals Research staff used the techniques of technological forecasting to analyze trends in national life and to set forth the key choices open to the U. S. in shaping the future of the nation. The Report of the staff includes projections of the impacts of changing technology on the environment, the economy, education, population, and consumerism.[5] A NASA executive, familiar with the environmental forecasting methods used by NASA's Mission Analysis Office to study physical impacts of the cosmic environment on space missions, commented that the National Goals Research Staff also used sophisticated environmental forecasting techniques to analyze the effects of the complex domestic and foreign environments on

economic, social and political problems of the nation.

Other agencies, such as the General Accounting Office (GAO), report that they use this technique as a tool for predicting the development rate of known but undeveloped technical inventions. One interviewee indicates that the GAO has applied technological forecasting in the areas of communication and construction.

3. *Using systems analysis to plan and budget new and existing programs*. Planning-Programming-Budgeting System (PPBS) is probably the most widespread application of systems analysis techniques in the Federal government today. Some persons say that it is nothing new, while others hail PPBS as the greatest advancement in governmental budgeting in recent years. These polar opinions reflect the differential success achieved by this technique in non-aerospace agencies of the Federal government.

The term PPBS gained visibility under Secretary of Defense Robert S. McNamara. President Johnson ordered its general application throughout all agencies of the Federal government. However, it is generally believed that the successful implantation of this technique in all agencies has not yet occurred.

The changes inherent in PPBS are significant in a number of ways.[6] Previous government budgetary systems focused either on *operational control*--emphasis on control of expenditures for specific tasks, or on *management control*--assuming that resources were already in hand and then spending them efficiently and effectively to reach a predeteremined objective. Under PPBS a new focus is added to these; *planning* is emphasized--cost-effectiveness and systems analysis are used to compare the relative outcomes and costs of each action alternative. The movement is from using the Federal budget primarily as an expenditure-oriented device to using it as a device through which it can be decided which Federal programs, at a specified cost, are worth most in terms of public objectives.

Interviews with management specialists or staff directors of most Federal departments and independent agencies during mid-1969 indicated mixed success in applying PPBS in non-aerospace agencies of the Federal government. An administrator in the Department of Agriculture indicated that its effort to apply PPBS have been largely successful. An interview with a director in the Department of Health, Education and Welfare indicated the initial impetus was on conducting analytical studies--cost-effectiveness and pilot studies, particularly in the welfare area. Later efforts in HEW have concentrated more on the planning and evaluation aspects of the technique. A number of agencies report a shortage of qualified technically trained personnel to conduct the kinds of analytical and informational activities inherent in PPBS. However, PPBS has made, and will continue to make an impression on the management of agencies in the Federal government.

4. *Using PERT to plan and schedule social action programs*. The use of PERT/CPM sometimes is mistakenly considered limited to hardware development or facility construction programs, which is its primary use in aerospace. However, the Office of Economic Opportunity has used PERT widely to plan and schedule its Community Action Program. The PERT principles are used not only by OEO staffers but are intended also to be used by community residents who receive OEO planning grants. OEO has published a two-volume PERT programmed training course to explain basic PERT principles to neighborhood residents and community leaders responsible for planning and implementing Community Action Programs.[7]

5. *Applying simulation and modeling to predict the results of operating policy alternatives*. This use of simulation is perhaps the strongest application of the technique, limited only by the ability of the model builder to approximate the conditions of the real world in his model. In many situations the duplication is almost exact. Simulators such as are used to train astronauts are in daily use in industry to train aircraft pilots, and the FAA uses them to train air traffic controllers. Another variation of simulation is used by the Department of State to train officials who will serve in foreign countries. In this model of inter-country interaction a trainee can make decisions for the country in which he is to serve and see what effect those decisions would have on neighboring countries.

A different kind of model has been developed by HEW to simulate the "product" of the U. S. school system. This model is essentially a manpower model that indicates the output mix of the nation's high schools. Such a model is of interest to industrial recruiters, as well as to the colleges and universities in the country.

TRW Systems has developed a simulator to help the National Air Pollution Control Administration predict the effects of land use patterns, transportation patterns, etc. on air quality. The model helps establish standards and boundaries for air quality control regions.

6. *Using government/private corporations to integrate one government service with other jurisdictions*. The International Telecommunication Satellite Consortium (Intelsat) is an open-end membership organization that owns and operates an international network of space satellites used for numerous types of electronic communication. Any member of the International Telecommunications Union (ITU), which includes every country in the world except for Red China, North Korea, and one or two others, may join Intelsat. The U. S. entry, the Communications Satellite Corporation (COMSAT) acts as a manager in behalf of all participants in the consortium, under the guidance of the Interim Communications Satellite Committee. It is a pay-as-you-go plan in which a participant, without a prior investment, can join at any time and pay a *pro rata* share of the costs and investment according to its use of the facilities.

The international involvement is through a treaty-type organization. The government/industry involvement in the venture makes possible commercial use of internationally owned satellites. Uses include television, telephone, teletype, facsimile, and computer data transfer from one country to another on a real-time basis. The Intelsat agreement establishes a successful pattern for integrating services for many governmental jurisdictions which vary in technological sophistication, size, and degree of economic development.

7. *Using management information systems to provide faster, more accurate reports on operations*. The Department of State has worked for several years to develop an information collection and dissemination system concerning foreign affairs. The purpose is to gather information from all over the world, sort it into meaningful categories, and then disseminate it to those persons within State who might have need for it. Considering the mass of information that might be pertinent to the operations of the Department, and considering the many sources and processors who gather the information, the job of collecting data and channeling it is immense. Even after this substantive information has arrived at the Washington headquarters

there is a large and complex job of seeing that it gets to whomever might need it for decision purposes.

Previous information systems categorized information into two categories: political and economic. By applying principles of integrated management information system design, the new system fractionalized, expanded, and reorganized these categories to give an ambassador information on all resources available to him and how they were applicable to any given problem or mission. These data can be arranged by function, country, or region. The substantive information system collects and processes both narrative and quantified data. The purpose of the system is to provide as quickly as possible all information pertinent to any crisis situation that may arise anywhere in the world, to promote timely, knowledgeable management decisions.

The Atomic Energy Commission operates a comparable management information system (AEC/MIS) encompassing all AEC laboratories and production plants.

8. *Applying the systems approach, systems for procurement, and quality assurance to meet the national housing problems*. The United States faces a gigantic housing shortage. Congress has set a goal of creating 26 million more housing units, newly built or rehabilitated, by 1978. Yet the largest builder in the country produces only about 6,800 per year. Even among prefab and mobile home producers no single company has ever turned out more than 30,000 units a year.[8] To meet the challenge, The Department of Housing and Urban Development in 1969 initiated "Operation Breakthrough" to apply innovative techniques of systems analysis and engineering to solve the housing shortage. Of HUD's Assistant Secretary for Research and Technology who directs Operation Breakthrough, *Business Week* reports:[9]

> [To this] systems expert recruited from the space program, . . . the systems approach to housing means manipulating such subsystems as management, market, land, capital, planning, design, and long-term financing to produce the best possible environment at the lowest possible cost. Several consortiums formed to bid on Breakthrough combine these disciplines in ways entirely new to U. S. housing.

Operation Breakthrough presents a great management as well as a technological challenge. Not only are new production techniques needed, but mass markets must be aggregated. Local customs and regulations of zoning boards must be contended with. So must the traditional practices of organized labor. Long-term capital must be available, and problems of aggregate economics and governmental bureaucracy must be taken into consideration and dealt with. There is mixed sentiment toward the undertaking in Congress, the housing industry, in labor, and in the Federal government. Some people are extremely hopeful, while others are pessimistic that goals can be met.

Some of the management techniques applied to Operation Breakthrough which appear new to housing programs are systems analysis and engineering, program management, systems for procurement, and quality assurance. The Department of Housing and Urban Development described some of these innovations:

- (Systems Engineering)--"The term 'housing system' describes the total mechanism employed by a business firm for the large scale production and sale of quality residential housing units. . . . Modern management techniques are employed to direct the sophisticated production, construction, and marketing operations."[10]

- (Systems for Procurement)--". . . for the first time there has been assembled a complete set of performance criteria for the testing and evaluation of housing." The National Bureau of Standards assists HUD in developing performance criteria and in monitoring performance tests.[11]

- (Quality Assurance)--"Breakthrough introduced a new emphasis on quality assurance in housing construction--step-by-step control and testing, and if necessary, redesign to meet top quality standards."[12]

If the application of certain aerospace management techniques to Operation Breakthrough's hardware-oriented problems as well as to some social problems (e.g., local zoning and labor relations) is successful, it will probably result in the realignment of a major industry and it will establish some new ground rules for government/industry relationships.

9. *Using reliability analysis, maintainability analysis, and value engineering to improve production of products, or effectiveness of standards.* The techniques of reliability and maintainability analysis and value engineering, which grew from advanced product development programs, have a special applicability to certain Federal activities. The most obvious are those programs in which the government itself controls product development rather than utilizing contractors (e.g., certain Atomic Energy Commission nuclear production). Perhaps less obvious but more widespread are Federal programs concerned with development of *standards* for products.

The National Bureau of Standards, Food and Drug Administration, General Services Administration, and other agencies are responsible for the technological planning of standards for product development and utilization; these agencies face many of the same type of management challenges as do the managers of aerospace programs.

Agencies responsible for program regulation or control, such as the Office of Management and Budget, Arms Control and Disarmament Agency, and Securities and Exchange Commission, face analogous problems requiring systems reliability and value engineering, even though they are not as concerned with products as with the operation of service programs.

## Conclusion

The management techniques which show the greatest promise of application to nonaerospace agencies of the Federal government are those which apply to programs with clearly defined goals, are more closely related to hardware or technical programs (e.g., air pollution control), and problems that are amenable to rational analysis. Because of the inherent nature of government to be sensitive to public opinion, it is difficult to progress rationally toward solution of social problems where goals are often in dispute. The institutional nature of the Federal government, which tends to resist change because administrators are more permanent than policy makers, presents another barrier to innovation in management technique. These factors indicate a need for selectivity in choosing applications for advanced management techniques adapted from aerospace.

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# CHAPTER IV

# APPLICATIONS TO STATE AND LOCAL PUBLIC SERVICES

The term "state and local public service sector" has been chosen for the third potential sector where aerospace management techniques might be applied. The sector includes administrators of state governments, city managers and other local government officials. It also includes managers of some non-governmental organizations providing essential public services; for example, public utilities, transportation services, schools and hospitals.

The use of aerospace management techniques has not yet penetrated far into the state and local public service sector, although the use is growing and certain applications are of great significance. Systems analysis is the aerospace-related management technique which has been tried most often by public service administrators, with mixed success. Some public utilities and transportation services have used operations research and modeling techniques, as have some of the larger city and state agencies. Interviews uncovered some promising and imaginative trials of aerospace management techniques by public administrators, and several of these are described later in this chapter.

## Overview of Potential Applicability

An evaluation of the applicability of aerospace management techniques to the state and local public service sector is shown in Figure 4. The potential usefulness of a particular aerospace management technique in solving the management problem is indicated by degree of shading.

Despite recognized barriers to transfer, this sector--state and local government and other public services--now appears the most likely sector to adapt and adopt aerospace management methods. Evidence for this prediction came from interviews with numerous public administrators, most of whom--not all--stated that they need management help and are willing to *try* new ideas. The public administrators typically expressed skepticism, often to

SELECTED MANAGEMENT TECHNIQUES

- ■ Extremely Useful
- ◢ Useful
- ● Possibly Helpful
- □ Probably Not Helpful

| SELECTED MANAGEMENT PROBLEMS OF THE STATE AND LOCAL PUBLIC SERVICE SECTOR | POLICY & PROGRAM ANALYSIS | | | | | TECHNOLOGICAL PLANNING | | | | | | ORGANIZING | | | ADMINISTRATIVE PLANNING AND CONTROL | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Systems Analysis & Policy Analysis | Cost-Effectiveness Analysis | Decision Analysis (Opns. Res.) | Heuristics | Simulation and Modeling | Technological Forecasting | Delphi Technique | Systems Engineering Management | Reliability Analysis | Maintainability Analysis | Value Engineering | Project Management | Matrix Organization Structure | Government/Private Corporations | Systems for Procurement | Source Evaluation Board Process | Incentive Contracting | Contractor Performance Evaluation | Management Information Systems | Mgmt. Reporting & Display Systems | Scheduling/Status Methods | PERT/CPM | Configuration Management | Logistics Management | Quality Assurance |
| **PLANNING** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Forecasting future environmental conditions | | | | | ◢ | ■ | ■ | | | | | | | | | | | | | | | | | | |
| Planning and budgeting new and continuing programs | ■ 1 | ■ 2 | ◢ 3 | | | | | | | | | | | | | | | | ◢ | | | | | | |
| Predicting the results of operating policy alternatives | ● | | | | ■ 4 | | ◢ | | | | | | | | | | | | | | | | | | |
| Planning municipal services to meet changing needs | ■ 5 | ■ | ◢ | | ■ 6 | ■ | | ● | | | | | | | | | | | | ◢ | | | | | |
| Budget development and justification | ■ | ■ | ◢ | ● | | | | | | | ◢ | | | | | | | | ■ | | | | | | |
| **MANAGEMENT OF OPERATIONS** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Managing interjurisdictional and interdepartmental programs and task forces | ● | ■ | | | ■ | | | ■ | | | | ■ | ■ | ● | ◢ 7 | | | | ■ | ● | ■ | ■ | | | ■ |
| Efficiently operating decentralized services | ◢ | | | | ■ | | | ■ 8 | | | | ■ | | | ◢ 9 | | | | ◢ | ● | | | | | |
| Operating fleets of service vehicles, mobile service groups and equipment | | ■ | ◢ | | ■ 10 | | | | ■ | ■ | | ■ | | ◢ | ● | | | | ■ | ■ | ■ | | ■ | ■ | |
| Operating and maintaining networks of utility lines and terminals | | ◢ | | | ■ | | | ■ | ■ | ● | ● | ● | | | | | | | ■ | ● | ● | | ◢ 11 | ■ | ● |
| Managing Federal or State government grants | | ■ | | | | | | | | | | ■ | | ◢ | | | | | ■ | ● | | ■ | | | |
| Integrating public and private resources in new organizations | ■ | | | | | | | ● | | | | ◢ | | ■ | | | | | ● | | | | | | |
| **EVALUATION AND CONTROL** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Getting faster, more accurate reports on municipal operations | | | ● | | ● | | | | | | | ● | ● | | | | | ● | ■ 12 | ■ | ■ | ■ | | | |
| Assuring a desired level of quality of municipal services and program results | | ◢ | | | ◢ 13 | | | ● | ● | | | ◢ | ● | ● | ◢ | | ● | ■ | ◢ | | ◢ | | | ● | ■ |
| Controlling performance of suppliers and contractors | | | | | | | | | | | | ■ | | | ■ 14 | ■ | ■ | ■ | ■ | ■ | ■ | ◢ | | ● | |

Note: Numbers within boxes refer to paragraphs in Chapter IV.

Figure 4. Potential Applicability of Aerospace Management Techniques to the State and Local Public Service Sector.

a considerable degree, but ended by saying that they need help badly enough to try something new that shows a reasonable hope of success, if that "something" can be afforded. Rational assessment shows the conventional management tools to be inadequate to solve many problems of the cities. The public administrators seem to recognize that major management innovations are necessary and seem to be willing to experiment during the search for them.

There is of course a wide range of complexity in the duties of public servants. Ninety percent of U. S. municipalities have under 5,000 people, and their mayors and city managers have vastly different problems than do administrators of the 60 or 70 largest cities. Arjay Miller of Stanford University, former Ford Motor Company president, stated that the mayor of any large city now has a much tougher job than does the president of Ford.[1] It is the administrator of the larger, more complex public service activity who most needs management innovations and may be most likely to benefit from this guidebook.

Some aerospace management techniques show rather widespread applicability to state and local public administration problems. Examples include management information systems, simulation and modeling, procurement source evaluation, and cost-effectiveness analysis. Systems analysis, particularly in its PPBS application, is frequently proposed for use in this sector and has been the subject of considerable controversy. We recognize potential useful applications of systems analysis but not an indiscriminate applicability.

The following sections contain descriptions of several innovative applications of aerospace management techniques in the state and local public service sector. As before, the examples are numbered and the numbers are keyed to the boxes in Figure 4.

## Examples of Successful Application

1. *Applying systems analysis to planning urban programs*. The deputy mayor of a large city which spends over a million dollars annually on systems analysis activities said in an interview that the systems analysis work is largely devoted to three areas. Two of these directly involve

planning, and the third area--information processing--improves planning inputs. One of the major areas where the city's systems analysis staff functions is resource allocation, involving plant and equipment deployment. Their analyses have, for example, found more effective ways to deploy fire and police stations. The analyses found that better fire and police protection would result from a redeployment even after some stations were eliminated. (The deputy mayor also noted that political barriers--neighborhood objections--hampered implementation of the analytical results.)

The second area where systems analysis was applied in this city is capital construction. Here, the systems analysts have concentrated on ways to improve construction programs by reducing the delay between authorization and completion of the construction project--a period in which costs rise, the potential beneficiaries of the construction project grow impatient, and the neighborhood is disrupted.

A 1969 doctoral dissertation[2] described several useful applications of systems analysis to urban management problems. These included analysis of unemployment problems in a model city area of Dayton, Ohio; a firehouse location analysis in East Lansing, Michigan (described later in the chapter); and the well-known "California studies" in which aerospace firms conducted systems analyses for the state of California on crime, government information, transportation, and waste management. Other interview sources mentioned successful applications of systems analysis to the problem of waste disposal in Detroit, to the planning of the Bay Area Rapid Transit system around San Francisco, and to the creation of a decision system for a model neighborhood program. A RAND Corporation staff member has suggested that systems analysis has three major uses in urban planning: to aid forecasting of impacts (e.g., of a new highway on land use); as a research tool to study the process of urban change; and as an educational or demonstration device.[3]

Systems analysis, as applied to planning and budgeting, transferred from RAND and the military services to the civilian departments of the Federal government and from there to state, county and city governments. The major impetus to local government use came from a 1966 plan (involving

The George Washington University's State-Local Finances Project, the U. S. Office of Management and Budget, and local government officials) for a pilot study. The so-called "5-5-5 Project" involved a demonstration of systems analysis for planning in five states (California, Michigan, New York, Wisconsin, Vermont), in five cities (Dayton, Denver, Detroit, New Haven, San Diego), and five counties (Dade, Florida; Nashville-Davidson, Tennessee; Los Angeles; Nassau, New York; and Wayne, Michigan). An evaluation of the 5-5-5 Project by Selma Mushkin of the Urban Institute noted that insufficient time had elapsed to measure success in terms of better decisions on program resource allocation, but she did find evidence in numerous governmental jurisdictions of better, more analytical staff work in support of policy officials. She also observed an aroused spirit of inquiry and indications of more analytical problem solving, through this demonstration of systems analysis.[4]

2. *Applying cost-effectiveness analysis to new city programs.* Cost-effectiveness analysis can readily be applied to "hard" programs (i.e., those dealing with equipment or facilities). General Electric TEMPO, however, has successfully applied the technique to a "soft" program involving effectiveness of health programs for school children. TEMPO systems analysts have developed measures of effectiveness of: (a) screening school children for disease at various age levels, trading off the advantages of early disease diagnosis with surer diagnosis at an older age; and (b) various types of testing techniques. The results of the analysis seem directly applicable to public health efforts. The technique may be adaptable by analogy to still other social service programs.

An interesting application of military cost-effectiveness analysis techniques to public investments has been proposed by an Army systems analyst.[5] He developed a methodology for analyzing a proposed public investment to determine its contribution to the welfare of some group, its harmful effects on other groups, and an evaluation of alternative investment of the same resources.

3. *Applying decision analysis to public programs.* Numerous examples can be found of using operations research/decision analysis techniques for planning technical (e.g., resource allocation) aspects of public service

programs. For example, the application of operations research to public planning has been thoroughly explored by a team of researchers whose report[6] goes beyond describing current planning applications of O. R. It portrays in simulated case studies how certain techniques (decision and value theory, simulation, cost-effectiveness analysis, sensitivity and risk analysis) can be used. Applications include land use and transportation planning, urban renewal, and development of community facilities.

The use of operations research/decision analysis techniques appears to be applicable also to the social planning aspects of public service programs. A study published by the Space Sciences Laboratory, University of California,[7] proposed a systems strategy involving a continual learning process. The strategy was proposed as having application to the solution of social problems through improved decision-making in research and development.

4. *Applying simulation and modeling techniques to predict results of policy alternatives*. At least two cities have used models to simulate future housing requirements. The City of San Francisco employed Arthur D. Little and Company to construct a computer simulation of the city's residential housing. The simulation was based on a wide diversity of specified detailed facts about housing units, the profits and investment requirements for each type of housing and each type of investor, zoning requirements in force and contemplated, and the housing preferences of various types of households in the city. The program analyzes the demand and compares it with the actual availability of space. The model then compares the two, and if excess demand is present and financial conditions warrant construction, it "invests" further funds in this type of housing. The cycle can be repeated up to nine years with the model as programmed.

General Electric TEMPO has been retained to develop a model of the Detroit housing market. A TEMPO spokesman stated that the completed portions of the model draw upon economic theory and the behavioral sciences (i.e., how people actually behave or respond to changes in housing patterns, ethnic mix, etc.). The spokesman noted that he would work with city planners to explain the interaction of the model and its internal logic, so the planners could operate the model to analyze the effects of various housing policies and other factors on the Detroit housing situation.

5. *Applying systems analysis to planning for municipal services to meet changing needs*. Some early experimental work was being done during 1969-70 in adapting systems analysis techniques to municipal services. TRW Systems, for example, was engaged with the City of Fresno, California, in jointly developing a guidance plan for operation of the city government. The project, heavily funded by the Federal government, was involved in applying systems analysis through an iterative process to adjust municipal program operations to changing citizen priorities. TRW Systems, according to an executive we interviewed, provided about 60 percent of the systems analysts in the program from its own personnel or from one of three subcontractor firms (one economic, one sociological, and one architectural planning). The remaining 40 percent of systems analysts are city employees. The TRW Systems executive stated, "The project conducts urban renewal planning and economic development planning for the city. The operation is very similar in function to an aerospace project office."

Another potential application of systems analysis to municipal services was described by Dr. William H. Mitchel, then Deputy Assistant Secretary for Management Systems of the Department of Health, Education and Welfare. Dr. Mitchel commented, "We can easily build a municipal medical clinic but can we integrate the clinic into the lives of its users? The need for integrative mechanisms is more important today than is the creation of components. A systems analysis process using computer technology is a way of doing this."

6. *Applying simulation and modeling to the planning of municipal services*. Several examples of imaginative applications of simulation to urban services are briefly noted in Chapter VI. These include Jay Forrester's theoretical work in *Urban Dynamics* and the Bay Area Simulation Study (BASS). Still another application was made by the Boston Regional Planning Project.[8] A land use model was developed to give policy makers information on the probable results of public policy decisions concerning urban development. The model, used as a predictive tool, tested alternate

development plans against a framework of community values and functional physical development.

7. *Using systems for procurement to manage interjurisdictional and interdepartmental programs and task forces*. In its management of the U. S. space program, NASA chose to develop a highly competent, but small, in-house headquarters staff and to procure goods and services by contract from other sources that already had competent technologists. This mode of operation was dependent upon rigorous systems for procurement. It is believed that other agencies or authorities could also benefit from this arrangement, especially when they need research, or the development and deployment of highly complex equipment or programs.

A number of large cities are faced with problems that require research and study far beyond the limited capabilities (resources) of their permanent staff. Contract research might prove to be valuable, especially if it is properly procured and controlled. The Boston Redevelopment Authority (BRA) reports that it has an organization similar in concept to that described above, and further that they have used contractors to conduct specialized research. Although their initial attempts to contract for the design of a Community Renewal Program were disappointing, other studies that have been contracted out have had more success. One BRA official stated that more planning and design work should be done under contract rather than with in-house staff, and that the agency would need to continue to develop more expertise in managing contract research and design studies.

8. *Applying systems engineering management to improve the efficiency of operating decentralized services*. Several universities, notably the Massachusetts Institute of Technology, have undertaken experimental urban research programs attempting to apply systems engineering techniques to problems of cities. M. I. T., which in 1969 reported involvement in 32 urban research projects, has successfully demonstrated the usefulness of systems engineering approaches to improving three decentralized services provided by local government organizations. The first of the three is a bloodbank service, in which systems engineering techniques were used to improve the nonmedical aspects (i.e., control and distribution) of regional bloodbank operations. The second service improved (in cooperation with

the Boston Police Department) is the system by which a citizen obtains police assistance. The systems engineering approach showed that minor and inexpensive changes in the dispatch system could reduce response time. A systems model was developed which also was used to evaluate new methods proposed for police dispatching, such as computer routing and automatic car locator systems. A third decentralized urban service, emergency ambulance services, also was shown to be amenable to the systems engineering technique.[9]

9. *Applying procurement systems to efficiently operate decentralized services*. A systems consulting group working with the administration of a large city has been exploring the application of certain aerospace/industrial procurement systems to simplification of city problems. One small but promising example of success involved the contracting out of a decentralized city service: towing away abandoned automobiles found on city streets. It was found that the costs of maintaining and operating a fleet of city tow trucks could be significantly reduced by contracting the work to private tow companies scattered about the city. There may be many similar examples of potential cost savings available to municipalities, which seem not to take full advantage of opportunities to profitably contract out their functional activities.

10. *Applying simulation and modeling in operating fleets of service vehicles, mobile service groups and equipment*. Cities are involved in providing many municipal services which are amenable to management technology analyses that may save money and/or improve service. The kinds of services that might be dealt with include: refuse disposal; transportation systems; fire station and other service locations; and so on. The International City Management Association (ICMA) has used small, technical assistance models to solve several municipal service problems. Using a standard model, ICMA representatives teach city employees to operate the model in a couple of weeks. Data concerning peculiar local conditions and judgments are then put into the model (often using weightings by vote of the people operating the model), and then the model is run with current data.

An experienced city manager pointed out during an interview that the East Lansing, Michigan experience (in which he participated as a consultant) was a successful example of applying simulation to municipal services. East Lansing wisely began with a small technical assistance model--locating fire stations--rather than attempting, as some cities have, to solve all of the city's major problems at once. East Lansing set up a project team including the City Manager, Assistant City Manager, Fire Chief, and building inspectors. The project team evaluated fire records and fed data on specific local conditions into the station location model. Then the team operated the model, using weighted judgments of team members, simulating coverage of fires in various parts of the city by available units that might respond to a call. The model that was used in this instance was a standard transportation model, not very complex, and easily adaptable to the local conditions to which it was applied. The result of this exercise was to save the city the cost of a proposed fire house that could be shown not to be necessary. The simulation span time was about six months from model design until the final location plan was completed.

11. *Using configuration management in operating and maintaining networks of utility lines and terminals*. One standard application of configuration control, used in the production of missiles and complex aircraft, is the charting of paths and destinations of the miles of wires necessary to the electronic equipment. Later, before launch or operation, it is possible, using a computer printout, to check each of the connections and assure its proper performance. The analogy to electric utility lines or telephone lines is exact. At present most cities are forced to use hand methods to accomplish these checks, and in practice this method is often highly unreliable and imperfect in its results.

12. *Applying automated data processing systems to improve municipal operations*. On March 30, 1970, a Federal interagency group led by the Department of Housing and Urban Development announced the signing of contracts with six cities to develop prototype automated data processing systems for municipal operations. The projects have three major purposes:

a. To improve municipal government data processing and decision-making capabilities;

b. To encourage the standardization of government data at each level of government;

c. To develop automated data processing systems which have a maximum capability to transfer from city to city.

The scope of the management information system to be developed can be seen best by the illustration in Figure 5, which was supplied by the Urban Information Systems Inter-Agency Committee.

Although results of this program had not been reported in 1970, a HUD official familiar with the program goals stated in an April 1970 interview that he hoped to have an early demonstration of a significant segment of the integrated system by the early part of the second year. Hopes for transferability are high because the system is to be relatively free from organizational relationships. Cities, which differ widely in organizational patterns, often are common enough in function to permit use of standardized data processing systems.

In addition, transfer efforts are planned. Both Washington, D.C., and Fresno, California, have sent personnel to Wichita Falls, Texas, (one of the two cities developing a total system) to work alongside Wichita Falls developers and learn details of the evolving system. Also, the State of Pennsylvania committed its own funds and personnel to assist transfer of the system from Reading (one of the four cities developing a subsystem) to other cities in the State. The projects however are long range efforts involving a minimum of two years for a subsystem and three years for the total systems. As a result final results of these efforts will not be available for several years.

13. *Using simulation to enhance the quality of educational programs*. Lockheed Education Systems has developed, for use in public school curricula, several learning programs which rely heavily on simulation and models of life experiences. One such program, called "Drug Decision," has been used extensively in California and elsewhere to teach junior high school students of the effects of drugs on a community and themselves. An important part of the program is a game called "Drug Attack" which allows the student to simulate the role of the law enforcement agent, health

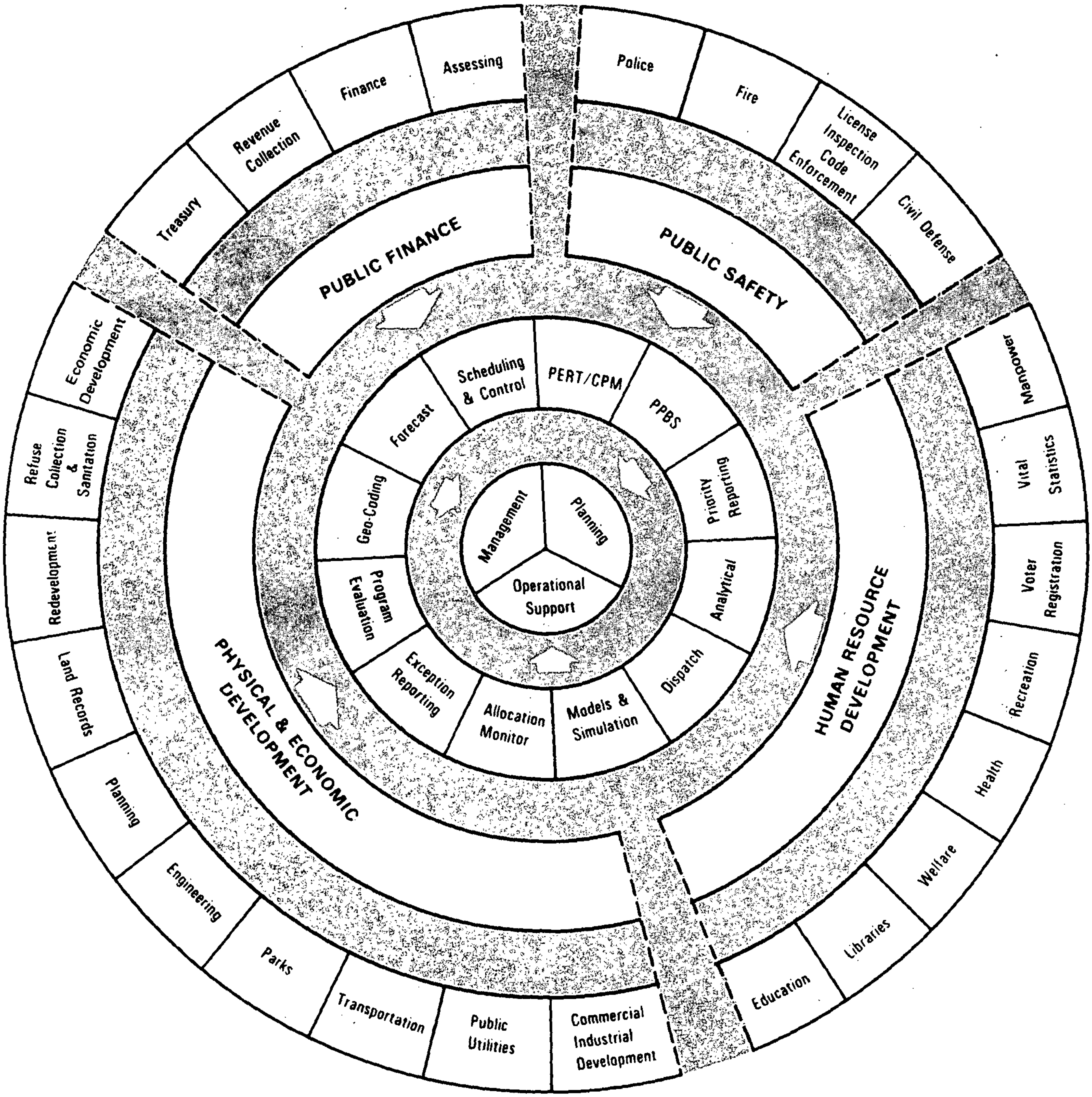


Figure 5. Scope of Activities Included in Municipal Information Systems

officer or mayor. In the assumed role the student is confronted with a simulated drug attack, and is called upon to stop the attack and treat its victims.

In another example, Lockheed also has developed an "R-3" educational program designed for underachieving junior high students from disadvantaged backgrounds. The program exposes students to a number of potential career fields through role playing and simulation, and is intended both to motivate and to broaden their career horizons. The program involves simulated participation in career activities through *Monopoly*-type board games (e.g., *Rock, Sand and Sea*, a marine biologist simulation) to reinforce knowledge of various careers. Its core content is gaming/simulation, a highly structured representation of a real world situation which can be carried out in the environment of the classroom. The "R-3" program has been implemented in a demonstration program in the San Jose, California, Unified School District. A staff evaluation found the program resulted in marked improvement in reading and mathematics skills over selected comparison groups, as well as marked improvement in student attitudes toward parents, school and society.

A third Lockheed program uses a simulated learning environment--an electronic data processing (EDP) installation--as a means of stimulating student performance in a ghetto-area school in San Francisco. Selecting underachieving students (up to 3 1/2 years underachievement) in mathematics and reading, the program provides compensatory education in these skills in a vocational environment. The program places students in a computer-oriented situation where reading and math are seen as essential tools to work effectively with EDP equipment. Each problem or lesson is modeled on an EDP application. The students not only receive compensatory training in math and reading but also acquire valuable EDP trade skills which make them employable in a computer installation even if they drop out of school, but employable in a more advanced position if they graduate.

14. *Applying aerospace procurement expertise to municipal procurement of goods and services*. John Feild of The Conference of Mayors commented during an interview that one of the biggest problems of management of large cities was the management of expenditures. He deplored the rigidity of municipal procurement practices which place traditional measures of economic efficiency (e.g., low bidding) over accomplishment of objectives. Mr. Feild speculated that cities might profitably learn from

aerospace contractors some flexible method of procurement promoting accomplishment of objectives.

An imaginative procurement technique transfer was accomplished through the cooperation of the Jet Propulsion Laboratory and the Los Angeles Police Department. JPL, from its work on NASA space programs, had considerable experience with the NASA source evaluation board process, used to select a specific contractor for a high value contract where technical capability is an important factor in the selection.

The City of Los Angeles had in 1969 planned to procure an improved command control communications system to serve the emergency service departments: Fire, Police, and Receiving Hospital. An improved system was desired which would meet the City's needs for the next ten years. Because of the lack of experience which any city faces in a highly technical once-in-a-decade procurement, Los Angeles asked JPL for technical advice and assistance. Drawing on space program expertise, JPL managers reviewed the Request for Proposal and helped the Los Angeles Police Department prepare a statement of work. Next, JPL ran a series of seminars in Source Evaluation Board techniques to increase the purchasing sophistication of the police department officials who would be directly involved in the evaluation of the equipment. While JPL took pains to avoid any direct involvement in the evaluation process itself, it did provide assistance considered most valuable by the city representatives.

The successful JPL-Los Angeles interaction is an excellent illustration of a promising solution to a widespread urban problem. American cities have no clear set of technological requirements for products. Further, city administrators do not have, and cannot reasonably be expected to have, a capability for understanding the complexities of modern technological systems. Lacking the indigenous capability to evaluate technological equipment and match it to urban needs, city officials have sought external help. To meet the need, certain specialized semi-governmental agencies have evolved--agencies with sophisticated capabilities to understand and evaluate high-technology systems--to serve as consultants to city administrators.

The Urban Institute, the International City Management Association, the RAND Corporation, the National Science Foundation, and the New York State Urban Development Corporation are among the organizations pioneering in providing specialized management techniques to strengthen state and local government capabilities. The Urban Institute, for example, is helping the city of Fort Worth analyze impacts of new police fleet plans; in Nashville, the Institute is bringing systems analysis to bear on the complex problems of dependent children. The National Science Foundation's new RANN (Research Applied to National Needs) program will sponsor research to assist and help evaluate development of solutions to long-term city problems.

Perhaps the most significant innovation in bringing technological expertise to bear on the management problems of the cities is the Technology Application Program, a joint effort of the International City Management Association and NASA. Under this program, a more technically sophisticated acquisition process is being developed for city governments. A NASA management authority, particularly concerned with urban problems, recently stated that:

> With new procurement policies and mechanisms, bolstered by a small but highly competent technical evaluative capability, cities can widen the field of competition and encourage the joining and participation of high technology firms with manufacturing firms. This will inevitably lead to a series of new options for city and state governments. The options will permit them to trade off costs, performance schedules on a technical basis, as well as on a simple cost and schedule basis.[10]

## Conclusion

The severe management problems faced by administrators of state and local public services are causing these administrators to become increasingly receptive to innovative techniques that show promise in solving their problems. Despite formidable barriers (e.g., a socio-political rather than a technological tradition of problem solving; financial constraints; a fragmented market for new technology) local governments and services are illustrating by innovative applications that some advanced management techniques can be transferred with success.

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# CHAPTER V

## THE 25 SELECTED AEROSPACE MANAGEMENT TECHNIQUES

The next four chapters contain short summarized descriptions of 25 management techniques which have been selected as (1) aerospace-related and (2) potentially valuable to other sectors of economic activity. We use the term *technique* in the sense of a method to accomplish a desired goal. However, we do not mean to limit our attention to technical procedures for solving individual problems. We include as *techniques* some major areas of management knowledge (decision analysis/operations research), broad concepts (systems analysis), and some specialized procedures or tools (the Delphi technique, one of several methods for technological forecasting).

Although they vary widely in scope and in significance, we have chosen these subject areas of management for attention because numerous managers and administrators have already found them useful and we believe others also can do so. We have left out some candidate techniques (e.g., induced creativity, or Synectics) because their connection with aerospace is relatively minor; to include them would risk expansion of this guidebook into a general management encyclopedia, which is not our intent. We have left out other techniques (e.g., evaluation of facility locations) because the aerospace contribution is too specialized or too limited in significance to make it worth the attention of a general audience of managers or administrators.

We have categorized the techniques according to the most likely way they will be used; that is, for:

- program and policy analysis
- technological planning
- organizing
- administrative planning and control.

These follow only roughly the historical *functions of management*, which include: planning, organizing, staffing, directing, and controlling. The major reason for using non-traditional categories is that aerospace is much stronger in certain management functions (e.g., planning) than in others (e.g., staffing). This emphasis results from the rapidly changing nature of the aerospace missions and the frequent need to hire new talent rather than developing personnel from within through training and motivation.

A second reason is that in the systems environment of aerospace, more and more of the management techniques span several of the traditional functions. For example, systems analysis is used conceptually for selecting among alternative programs and policies, for administrative planning, and even for providing a framework for a program control mechanism. Thus, we have retitled the categories and placed the 25 techniques into the category where they seem to fit best. The 25 techniques, arranged by category, are:

<u>Program and Policy Analysis</u> (Chapter VI)

- Systems Analysis, Policy Analysis and Related Techniques
  - Cost-Effectiveness Analysis
- Decision Analysis (Operations Research)
  - Heuristics
- Simulation and Modeling

<u>Technological Planning</u> (Chapter VII)

- Technological Forecasting
  - Delphi Technique
- Systems Engineering Management
  - Reliability Analysis
  - Maintainability Analysis
- Value Engineering

<u>Organizing</u> (Chapter VIII)

- Project Management
  - Matrix Organization Structure
- Government/Private Corporations

<u>Administrative Planning and Control</u> (Chapter IX)

- Systems for Procurement
  - Source Evaluation Board Process
  - Incentive Contracting
  - Contractor Performance Evaluation
- Management Information Systems
  - Management Reporting and Display Systems
- Scheduling/Status Methods
  - PERT/CPM
- Configuration Management
- Logistics Management
- Quality Assurance

## CHAPTER VI

## TECHNIQUES FOR PROGRAM AND POLICY ANALYSIS

### SYSTEMS ANALYSIS, POLICY ANALYSIS AND RELATED TECHNIQUES

Systems analysis came out of wartime problem solving where intuitive decisions were often too costly and often ineffective. Methods, usually quantitative, were developed for better describing an operational problem, determining what information was needed to solve it, and analyzing this for good answers.

During the World War II experience, the operations analysts in the armed services were able to help use *existing* resources to solve tactical problems: how to use radar countermeasures, how to design effective bombing patterns, how to deploy destroyers around a convoy. From this experience, systems analysis was developed to select and evaluate *proposed new* weapons systems for development. This required integration of research (on what was technically feasible) with information on defense requirements (which were sometimes not technically feasible).

Thus, systems analysis can generate information to help select a preferred set of space boosters to be developed. It can assist in determining the need for Army airlift, or the desired mix of airlift and sealift, for delivering a fighting force to an overseas point. The analysis does not include the design of the boosters or the transport aircraft; it does cover the performance requirements they should meet.

Systems analysis for management* helps in making choices among policies or among competing spending or development programs (either investment spending or operations spending). It requires systematic examination of the future *cost* and *effectiveness* of the various *alternatives*.

To do this, " . . . such an analysis requires, in the most general view, three sorts of inquiry, any of which can modify the others as the work proceeds. There is a need, first of all, for systematic investigation of the decisonmaker's objectives and of the relevant criteria for deciding among the alternatives that promise to achieve these objectives. Second, the

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*Systems analysis is a term sometimes applied to paperwork systems and procedures simplification, computerized management information system development, and engineering analysis. Systems analysis for management should not be confused with any of these.

alternatives need to be compared, usually in terms of their cost, effectiveness, timing, or risk--using a quantitative or logical model insofar as it can be made representative of the situation. Finally, there must be an attempt to design better alternatives and select other goals if those examined are found wanting."[1]

The vital words here are *objectives, criteria, alternatives, cost, effectiveness, timing and risk, model,* and *design.*

The *objectives* are what a problem solving system (or policy) must specifically accomplish to solve the problem. The *criteria* are the standards by which the alternative means of solving the problem are compared. The *alternatives* are the different means (including the present system) which might be used. *Cost* measures the resources required by each alternative. *Effectiveness* tells how well the objectives would be achieved by each alternative.

*Timing and risk* deal with what's going on outside the system under study; how the environment may change over time, and what you may lose if the system doesn't work. The *model* is some sort of simulation of reality, in a computer or on the back of an envelope; it shows the relationship of inputs and outputs, objectives, alternatives, and external or environmental forces. *Design* is the end product: some means for solving the problem, and some information helping the decision-maker to choose among them.

The key to the analytic process is iteration. As new alternatives are generated, the objectives can be made more responsive to the problem. As the objectives are better described, the cost and effectiveness measures can be improved. As timing and risk factors are better defined, the model is improved, and then more refined decision alternatives can be generated. All of these improvements lead to better information for the decision-maker; this is the purpose of systems analysis.

As the analysts grew more experienced, they began to include national policy and strategy in their analysis, and policy and strategy became topics for special study. This led to higher level systems analysis (or policy analysis): determining the role of space systems in national defense; or comparing policies of military superiority vs. military parity with the Soviet Union. The mix of forces needed, as related to their defense functions, e.g., strategic forces vs. general purpose forces vs. airlift-sealift, etc., has probably been the most intensively analyzed example of policy-oriented systems analysis.[2] Policy analysis is analysis of a complex ~~topic, dealing with risk, uncertainty, technological change, and political~~ forces.

One of the most ambitious efforts to introduce analysis into governmental decision-making is also called issue analysis. This procedure is an adaptation of systems analysis developed for New York City, with intensive treatment of the legal and political constraints usually facing local government officials.[3]

Application of these techniques outside aerospace and defense is particularly difficult. The objectives are harder to identify than in aerospace, and it may be almost impossible to get agreement on them because of different values and perceptions of social needs. Typical analysis topics like big city housing, criminal justice systems, and environmental protection, all stimulate the imagination on the harrowing arguments inevitable in sorting out the specific objectives to be achieved in solving these problems. This pushes policy analysts toward working with alternative sets of objectives in addition to alternative means to achieve each set of objectives.

A major defense-sponsored systems analysis study, published in 1971, has direct application to civilian public services at the state and local level. This is the systems analysis of a new generation of military hospitals, sponsored by the Office of Defense Research and Engineering and conducted jointly by Westinghouse Electric Corporation and Arthur D. Little. The systems analysts have investigated the complex system of health care delivery and have proposed significant innovations in facilities and services which improve the quality of health care provided.[17]

One of the best known applications of systems analysis outside aerospace is PPBS (planning-programming-budgeting systems) which will be discussed in the remainder of this section. A subsequent section briefly describes cost-effectiveness analysis--a crucial component of most systems analyses.

The aerospace/defense experience in choosing among alternative policies and allocating resources to carry out specific governmental functions or activities offers the hope of better management than the traditional organization-by-organization or unit-by-unit policy-making and budgeting. This hope is reflected in the Planning-Programming-Budgeting System (PPBS) which is being adapted and modified for Federal, state, and local government operations throughout the world.

The PPB system was first established in the Department of Defense in 1961, and the President pushed it into most other Federal executive departments in 1965. Adoption by other governmental agencies has progressed sporadically since then. The systems integrates three activities: control, management efficiency (through evaluation), and planning. The addition of the systems-oriented evaluation and planning to the traditional control function of budgeting makes a more powerful management tool--particularly in the public sector.*

As used in the non-defense Federal agencies, Jack W. Carlson[4] identifies five basic elements:

(1) Program structure--a group of agency activities (program categories) contributing to a common objective. For instance, the Department of Health, Education and Welfare categories in Fiscal 1970 are Education, Health, Social and Rehabilitation Services, Income Maintenance, and Executive Direction and Management. The efforts (subcategories) lumped under Health are: development of health resources, prevention and control of health problems, provision of health services, and general support for these efforts. The subcategories would be further broken down into detailed elements; the program category, the subcategories, and the elements are the basis for budget decisions and fund allocations.

(2) Issue letter--definition of major issue which an agency is requested to analyze. These are originated by the Budget Director, after negotiation with the agency, and are chosen to focus analytic resources on issues important to both the agency and the chief executive.

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*This is described by Hitch: "Moreover, in contrast to the private sector, where competition provides an incentive for efficiency, efficiency in government depends on the conscious and deliberate selection of techniques and policies. And wherever the relevant factors are diverse and complex, . . . unaided intuition is incapable of weighing them and reaching a sound decision." Charles J. Hitch, *Decisions for Defense*. (Berkeley: University of California Press, 1965), p. 28.

(3) Program memorandum--summarizes major decisions made by an agency on the primary issues in a program category, and justifies the decisions. It notes related analysis, identifies the alternatives considered, and explicitly states the assumptions underlying the decisions.

(4) Special analytic studies--almost any analysis. Some may be done in advance of need, many are done on questions which must be decided during current planning.

(5) Program and financial plan--these lay out for the next five years the funds committed to various program areas (including those committed by past decisions), and the outputs or accomplishments expected to result from this spending. This is the basis for implementing the planning; for using the one means, chosen from the alternatives, for reaching the objectives. The plan also translates the program budget (oriented toward achieving objectives) into the format preferred by Congress (oriented toward offices and agencies).

The annual revision of the program and financial plan faces the decision-makers with questions of "How did we do?" and "Did we get our money's worth?" It also offers incentive to raise the key planning questions: "Should we do something differently?" and "What might happen if we did?"

PPB has pushed the use of quantitative analysis, and has also encouraged more precise qualitative analysis, in parts of government. On the other hand, it has not been easily put to use; it has been hard to find analysts, and the planning activities often have been weak.

Unfortunately, little public interest is manifested in improving most governmental services. Resources are usually more readily available for increasing the level of current operations than for changing the nature and improving the quality of operations. This may change as PPB or related systems are used, as more competent analysts are trained or hired, or as sound analyses are made known to the public, if all of these potential results of PPB can acquaint the public with comparisons of what they are getting for their tax dollar vs. what they might get.

A further discussion of applications of PPBS is found in Chapters III and IV.

## COST/EFFECTIVENESS ANALYSIS

"Which is the best, among the alternatives?" is a basic question when making choices in a systems analysis context. Cost/benefit calculations have been used for several decades to compare the returns offered by different proposed investments. The costs of the resources required are related to the market value of the flow of benefits expected.

In comparing the kill-capability of alternative fighter aircraft designs, or the relative merit of alternative population control programs, however, this technique is hard to use. These investments and expenditures really don't fit the cost/benefit framework because the outcomes can't be measured in dollar terms. In such cases, *cost/effectiveness* comparisons are more useful.[5] This latter technique has been developed during the systems era, and its measurement concept may be best for comparing policies or programs furnishing many governmental or social services.

Effectiveness, then, becomes a key variable to be measured. L. D. Attaway[6] relates it to the systems analysis process in a series of definitions:

| | |
|---|---|
| Objective: | What we desire to achieve |
| Alternatives: | Competitive means for achieving the goal |
| Costs: | Expenditures to acquire each alternative |
| Effectiveness Scale: | Scale indicating degree of achievement of goal |
| Effectiveness: | Position on effectiveness scale assigned to each alternative (by measurement) |
| Criterion: | Statement about cost and effectiveness which determines choice. |

He goes on to describe several scales of effectiveness for designing an interceptor force for air defense of the United States, including the probability of a bomber kill per interceptor attempt, average number of kills per interceptor sortie, number of U. S. survivors in a complete air defense campaign, etc. Obviously, estimates of such outcomes depend on various contingencies, and the contingencies become variables, too. Therefore, cost and effectiveness must be calculated for each of a set of contingencies.

Such non-market-value measures of output or effectiveness are used in other areas of analysis besides aerospace. Seidman describes different levels of effectiveness measurement for family planning programs: percent of unwed and high risk (by age and family size) mothers enrolled; continuation rates (in the program); births averted (difference between predicted vs. actual births in target area); expected increase of educational level of mothers due to avoidance of premature pregnancy.[7]

In each case, effectiveness is measured by the extent to which the objectives can be achieved by a given system (or program). There are usually several effectiveness scales (as in the examples above), and they may be arrayed together to help choose among the competing alternatives.

Cost/effectiveness analysis techniques thus provide a useful structure for evaluation of programs which combine social and economic goals. For example, the technique has been used to evaluate government manpower training programs in New Haven. Other analysts have applied cost/effectiveness techniques to such complex topics as child health care and artificial kidney systems.

NASA and its contractors have used cost/effectiveness analysis extensively in the space program to select launch vehicles and unmanned probes for space exploration. The process involves selection among possible space missions that will gather data on the solar system, and subsequent trade-off decisions involving instrumentation parameters (weight, reliability, and accuracy vs. cost), trajectory parameters (flight time, energy requirements), and vehicle parameters (payload weight, reliability and booster cost).

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This subsection has discussed the concept of systems analysis, and the concept's antecedents in aerospace. One application outside aerospace is PPBS--a method of continuing system or policy analysis, implementation, and evaluation. One of the most important, the most difficult, and the most potentially productive techniques associated with systems analysis is cost/effectiveness study: the measurement of success in achieving objectives. These concepts and techniques are difficult to separate, and are commonly described in more detail in most of the following references.

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## DECISION ANALYSIS (OPERATIONS RESEARCH)

The terms *decision analysis, applied decision theory*, and *operations research* are used somewhat interchangeably. They describe not merely a technique but a major area of management--probably the most revolutionary advance in management practice in many years. Accordingly, some explanation seems necessary for treating a major management area as a single entry in a chapter devoted to management techniques. This is done because our purpose is to provide only a brief overview and an appreciation of the power and effectiveness of decision analysis techniques. An adequate explanation of a field so complex and growing so rapidly is far beyond the scope of this study.

*Operations research* (the original term) is generally agreed to have originated in World War II, among British scientists mobilized in interdisciplinary teams to solve military problems frequently unrelated to a single academic specialty. O. R. techniques soon spread to the U. S. The Antisubmarine Warfare Operations Research Group was formed in 1942 at Columbia University, and both the U. S. Navy and Army Air Corps became enthusiastic users of operations research. Some of the wartime O. R. organizations still function as adjuncts to the military services, and several new military O. R. groups have been formed. After the war, the techniques of O. R. were soon applied to non-military problems, and the O. R. concepts have grown steadily more sophisticated as they have spread through many sectors of the economy.

*Decision analysis* (the term chosen here) uses a variety of scientific, mathematical, or logical means in an attempt to use rationality (rather than instinct) to solve problems facing a manager. Managerial problems basically are decision problems, so decision analysis affects the full scope of managerial functions. Basically, decision analysis provides a structure, and tools, for the thinking process needed to reach a rational decision.

The problem-solving process begins with an objective, which is identified and chosen (perhaps from a group of conflicting objectives) by the manager or his superior. Once the objective is established, the various possible problem outcomes are determined and arranged according to some measure of utility.

Next, the problem is analyzed to determine all the variables which may affect the outcomes. Those variables which are beyond the control of the manager (e.g., weather conditions, competitor's actions) are termed *states of nature*. Those variables which are within the manager's control (e.g., actions he can take, including the decision to do nothing) are termed *strategies*. Next, through analysis (or perhaps by trial or simulation), the outcome which will result from all possible combinations of strategy and states of nature are determined. The manager's measure of utility (termed *payoff measure*) for each outcome is then associated with each combination of strategy and state of nature.

At this point, some technique of decision analysis is used to help the manager select the strategy most likely to result in the outcome with the most desirable payoff measure. Reference 12 describes one useful technique: the decision tree.

Decision analysis can help the manager in four distinct ways:[4]

1. When the manager does not know the important variables affecting the decision, decision analysis techniques can help him discover them;

2. When the manager knows the important variables but does not know how to relate them to each other, to the outcome, and to the payoff measure, the necessary problem-solving method can many times be provided through use of decision analysis techniques;

3. When large numbers of strategic possibilities and states of nature exist, too large for a rational search for the best solution, they can be handled through the mathematical representation used in techniques of decision analysis;

4. When the manager cannot possibly search the innumerable payoff measures in order to apply his decision criterion, mathematical methods can frequently be devised to do this for him.

## Decision Making Under Certainty

One of the three categories of decision problems a manager can face involves certainty (i.e., he knows what the state of nature will be, or what his competitor's strategy will be). The decision can be made simply in theory, though not always in practice: select the strategy which provides the largest payoff measure in terms of the manager's objective. The difficulty arises when the number of possible strategies (and thus of outcomes) is so vast as to make conventional calculation impossible. For example: determining the least-mileage routing for a salesman who must visit all 50 state capitals in a single trip; or scheduling several production jobs in a machine shop having several machines of different speeds and operating costs, to achieve a minimum total cost yet meet delivery commitments. Problems of this type can be solved satisfactorily, although not always perfectly, using techniques of decision analysis such as linear programming.

## Decision Making Under Risk

Another category of decision problems involves risk (i.e., the states of nature or competitors' strategies are not known, but can be predicted according to probability theory). Given knowledge of the probabilities, decision analysis calculations can establish a predicted outcome--one which weighs all probabilities and determines a composite "expected value" on which to base a strategy selection. Decision problems of this type occur frequently.

Typically, the probabilities are determined on the basis of past experience ("objective probability"). If records are maintained of past states of nature or of competitors' strategies selected, and if the process is considered stable (i.e., if the future experience is expected to be similar to the past), the expected future probabilities can be readily determined. However, even if no past experience is available, the decision analysis techniques can usefully be applied. Here, estimates of risks should be made based on general knowledge of the problem, and by comparison to somewhat similar problems for which experience is known. These "subjective probabilities" are nearly always a better basis for decisions than ignoring entirely the probabilities of states of nature or competitive strategies.

The concept of risk analysis is a useful adjunct to probability theory in decision analysis. This technique permits a manager to understand the *ranges* of possible gain and loss from a proposed action, and to avoid actions which may lead to disastrous outcomes even where the predicted (probable) outcome is favorable.[7]

## Decision Making Under Uncertainty

The third category of decision problems involves uncertainty (i.e., when it is not possible to estimate, even subjectively, the probabilities of states of nature or competitive strategies). That is, the range of possible outcomes is known but not the likelihood of their occurrence. In this case, the decision-maker selects a strategy based on one of several criteria he chooses as most appropriate:

- The Laplace criterion (lacking any definite knowledge, assume that one outcome is as likely as any other);
- The criterion of optimism, or maximax (expecting to be lucky enough to get the best payoff from any strategy, choose the strategy for which the best payoff is largest);
- The criterion of pessimism, or maximin (expecting to be unlucky enough to get the worst payoff from any strategy, choose the strategy for which the worst payoff is largest);
- The criterion of regret, or minimax regret (knowing that we may not choose the best strategy and will thus regret that the payoff is not as large as it might have been had we chosen the best, select the strategy that will minimize the amount of regret regardless of state of nature. That is, choose a strategy having the minimum difference between its payoff and the best possible payoff from any other strategy, for any state of nature.)

## Decision Making Involving Rational Opponents

The decision analysis process described above applies to problems in which the manager's decision has no effect on the state of nature nor on the competitors' strategy. That is, there is no interaction between the decision selected and the conditions of nature which will affect the outcome. A valuable extension of decision analysis involves situations where the manager confronts a rational opponent, perhaps a business competitor, who *consciously acts* to frustrate the manager. This interactive decision process, involving strategy and counterstrategy, is known as *game theory*.*

The major applications of game theory have been made in military analysis, either by aerospace contractors such as the RAND Corporation and Institute for Defense Analyses, or by the Department of Defense itself. However, there are notable exceptions. Ref. 1 (pp. 257-58) mentions applications of game theory "to analyze problems of bidding policy, advertising allocation, purchasing, capital budgeting, choice among alternative new products, research strategy, production scheduling (in the light of uncertain demand), and setting prices." Ref. 1 also describes the use of game theory by the Boeing Airplane Company to set prices for the first commercial jet transports, in competition with the Douglas Aircraft Company.

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## HEURISTICS

The word *heuristic* is an unfamiliar term for a familiar concept. It is used to designate techniques which simplify the effort of solving repetitive problems. We often use the term "rule of thumb" to describe heuristics used in everyday life or in business. An example is the procedural rule, "Accept customer checks under $50 but obtain managerial approval on checks of $50 or more," used to simplify credit decisions. Another example is "Use the oldest stock first," to simplify inventory management. These procedural rules are based both on intuitive judgment and on experience. They do not always provide the *best* solution to every problem--rarely would a simple rule do that--but they do provide a *satisfactory* solution to most problems. You score much higher than by chance, by using a sound rule of thumb to aid problem-solving.

In modern management thought, *heuristics* refers to the use of a combination of simplifying rules to aid in the solution of highly complex decision-making problems. Precise solutions to these problems involve the elaborate statistical techniques of operations research and decision theory, normally requiring the use of an electronic computer. Yet, certain complex decision problems cannot be solved efficiently even with these sophisticated tools if they are of two types:

1. *Problems which are too large to process.* Certain problems of resource allocation may involve millions of possible solutions. One example is the problem of scheduling production in a large "job shop" with many types of milling machines, drill presses, etc. In selecting the most efficient sequence of production, the computer would test, in turn, each of the million or more possibilities to find the production plan which minimized cost, machine "down time," operator set-up time, etc. But to do so would probably require more expensive computer time than the information is worth. Also, it could require so long to discover the best solution that the information would be obsolete.

A practical way to solve the problem is to simplify it by making some heuristic assumptions: "Put all production runs of under 50 units on the least efficient drill press;" Run the closest-tolerance items on the tape-controlled milling machine." By making these fairly logical *decisions, the otherwise cumbersome machine allocation problem is greatly* simplified. The resulting problem can be processed quickly on a computer according to an optimization goal such as "minimize machine set-up costs." Thus the use of heuristics is a trade-off. By settling for a satisfactory solution rather than insisting on the absolutely ideal solution, the problem becomes conveniently workable. And usually a much better solution can be obtained than would be true if no computer solution had been attempted.

2. *Problems which are difficult or impossible to express in mathematical terms.* Often problems of management involved qualitative values rather than quantitative values. Numerous examples occur in the area of human safety. For example, a manufacturer's decision to install safety equipment is not based on an assumed *quantitative* value of human life, but instead on a qualitative respect for human safety. In the complex interrelationship of contingent decisions which underlie aerospace program planning, certain key values override the general rule of "least time" or "least cost." Such decisions are made heuristically by applying qualitative value-oriented decision rules. The remaining decisions, however, can be made on quantitative grounds. These ill-structured problems are truly solvable only by developing computer programs that simulate the processes of the human mind. A human considering a chain of contingent decisions may decide between A and B quantitative (lowest cost) grounds. Then he may choose between A1 and A2 on grounds of other values (A2 is not ethical). Then between A1a and A1b on quantitative grounds again (greatest probability of profit).

The simulation of thought processes through use of the computer is called "artificial intelligence." It involves the combination of quantitative statistical techniques with judgment-oriented heuristics. By adapting it for computer application, the process becomes extremely useful to managers in all fields who have the organizational resources to utilize computers and management planning staffs. Even managers who do not have internal resources may find it desirable to employ outside consultants occasionally to process solutions to complex, recurring problems, to establish efficient operating patterns.

Heuristics (in its present sophisticated meaning) began to be mentioned in management literature during the late 1950's. Heuristic programming was used at least by 1958 in the RAND Corporation to solve highly complex operations research problems connected with its work for the Air Force, Department of Defense and NASA. These included research on Strategic Air Command operational effectiveness and use in designing a space rescue capability for the manned space program.

Other aerospace sector applications include the following:

a. A heuristic model (see Ref. 5 below) was used in a space vehicle development project to establish a manpower loading schedule. This schedule replaced a conventional PERT-type schedule which called for heavy manpower loading at the start of the project, then manpower reductions and layoffs. The heuristic model, designed to balance manpower allocations more evenly through the life of the space vehicle program, reduced peak manpower requirements considerably while shortening total schedule time by five months.

b. In the air transportation industry, heuristic programs have been shown suitable for simplifying the preparation of airline schedules, satisfactorily balancing passenger demand, equipment availability and service needs, CAB regulations, effects of competitors' schedules, etc.

c. A heuristic computer program developed at the University of Southern California forecasts the corrective maintenance workload for electronic equipment, based on its design configuration. The program permits aerospace managers to plan manpower needed for maintenance tasks, even before production occurs.

Heuristic programs have been applied successfully to a wide variety of complex management decision-making problems both within and outside the aerospace industry. Applications have included: job-shop production scheduling; balancing work loads at each work station of an assembly line; controlling inventories to minimize total costs; selecting warehouse locations; determining the most efficient layout for equipment in a factory; designing "custom-made" products from standard components; scheduling large construction or development projects (in connection with PERT/CPM, see pp.148-151); and even the selection of optimum stock portfolios, simulating the human judgment (decision rules) of a trained investor.

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## SIMULATION AND MODELING

Simulation--the development of and experimentation with a model which represents a real situation--is a powerful management tool used to solve problems or to improve understanding of reality. Although physical reality can be modeled, the most common application to management involves a computer model which simulates a management system. Simulation is particularly useful for the solution of problems of systems design and systems analysis, when the systems under consideration cannot be analyzed using direct or formal analytical methods.

Models can vary widely in their form and purpose, from children's toys (which visually represent a real object) to mathematical models (which abstractly portray the behavior of a system under varying conditions). Even line graphs and profit and loss statements are forms of models used by managers. Generally, models involve *simplifications* of reality which nevertheless adequately portray one or more important features of the real object or system.

### Predictive Models

The computer simulation models used in management systems analysis are *predictive* models which determine the performance of the real system when subjected to various stimuli, or when changes are made in certain aspects of the system. Typically, the predictive management model determines variations in operating performance or output corresponding to variations in resource cost or input.

The use of predictive models to simulate military operations (war gaming) is over 100 years old, and more primitive models were used in antiquity. Major advances were made in military simulation when digital computers came into use after World War II, and elaborate simulations have been used by the Department of Defense and its research contractors to establish military strategy and to efficiently manage military operations. In logistics policy research conducted for the U. S. Air Force, The RAND Corporation conducted two major simulations: one to compare the current system for procurement and distribution of all

Air Force equipment with a proposed system involving changed policies; the second to develop and evaluate alternative policies for logistics support of the intercontinental ballistic missile system, based on new operational policies.[5]

Some of the NASA applications to management simulation have included the designing and scheduling of complex space missions, probabilistic long-range planning for resource requirements, and cost estimating and control.[7]

The many publications on simulation using predictive models indicate a great variety of applications in business and government. They include applications in planning of products and services, resource allocation, operations scheduling, marketing, and many more. Simulation is particularly valuable in testing the impact of new policies to determine the possibility of undesirable results. The behavior of decision-makers in complex organizations has been simulated in predictive models, permitting experimentation with many variations of policy.[3,4,6,8,9]

## Training Models

War games have been used to train military officers for many years, and simulation devices (e.g., the Link Trainer) were used for pilot and other training during World War II. Present astronaut training relies heavily on simulation because of the obvious difficulty of providing actual experience. The use of simulation in management training, however, is relatively recent. The American Management Association's *Top Management Decision Simulation* (1957) and other games which have been developed since then have been used to give managers involvement in a decision making process which simulates the experiences of a real management environment. Such games promote a sense of emotional involvement by the manager and lead to a better understanding of the many factors which affect the outcome of a certain decision. Interactive games, in which managers compete with each other, are particularly useful in training managers in the decision-making skills faced in competitive market situations.[5,13] Games furthermore stimulate an appreciation of the need for good long-term planning, and of the need for better information on which to base decisions.

NASA's Goddard Space Flight Center has developed *GREMEX*, a computer-based management simulation game designed to provide experience in R & D project decision making from a management rather than a technological perspective. The players take the role of aerospace project managers, charged with making the management decisions which influence the cost, schedule, and performance outcomes of a hypothetical space satellite program. Each player has the opportunity to test his management judgment at small risk, thus gaining experience which can make him a better manager in real life, whether managing an aerospace program or another type of development project involving the uncertainties of contract administration. Information describing *GREMEX* is available from Goddard.[15]

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# CHAPTER VII

# TECHNIQUES FOR TECHNOLOGICAL PLANNING

## TECHNOLOGICAL FORECASTING

Technological prophecy, related to aerospace, dates back to Greek mythology where the legend of Icarus' flight too close to the sun dramatized the critical temperature problems of airframe materials. More detailed prophecies continued up to the time of manned flight, but with little improvement in scope or reliability.

Technological forecasting, as a less intuitive but more disciplined effort, was given major impetus during World War II as the U. S. Army Air Forces (later USAF) began planning for the future. In 1944, *Toward New Horizons* was published by von Karman and others, relating expected technological capabilities to future Air Force roles.

In the next two decades the Air Force (and the Army and the Navy) pursued technological forecasting programs. These were oriented toward threat analysis--what will be the enemy's technology capabilities in 19XX?--and toward R & D resource allocation.

The latter use has become important in solving the problems of gap-bridging: what gaps between present technological capabilities and future needs are most critical, and which R & D programs need support to solve the priority problems? For example, if a certain thrust-to-weight ratio in a jet engine is needed in 1980, and if achieving this ratio depends on increased combustion temperatures, can existing alloys be used for turbine blades in such temperatures? If not, research funds must be allocated to developing new blade materials (or toward alternative propulsion systems).

Most of the military forecasts are classified, but some of the methodology is openly described. These may be useful both to those interested in technological change (e.g., new product planners) and to others interested in economic, social, or environmental forecasting and planning. Two of the aerospace-augmented techniques offering such possibilities are trend extrapolation and Delphi, which are further described below.

### Trend Extrapolation

Extrapolation of indexes of productivity of materials or systems is probably the commonest form of technological forecasting. This can be a useful method where the subject technology usually advances incrementally rather than in grand breakthroughs. In these cases, accumulating progress often comes at a geometric rate; thus, fairly consistent growth in technological capability can be anticipated and extrapolated. However, natural (or social) limits to progress may interfere and should be identified. Also, there is a possibility of unexpected discontinuity which impairs confidence.

The crucial choices for effective forecasting include selection of the index of productivity and the correct units of measurement of productivity. Examples of productivity indexes may include watt-hours per pound for batteries, or watt-hours per cubic inch; for computers, capacity over add time; critical temperatures of refractory alloys; for transport aircraft, passenger miles per day; etc.

Trend extrapolation is well explained by Ayres in his book[1] and in an article in the Bright book.[2] These references also deal with other techniques such as morphological analysis and relevance trees, heuristic forecasting, and the application of forecasting methodology. All of these methodologies are useful in such planning and analytical tools as scenario writing and gaming.

Trend extrapolation and Delphi (described next) also offer tools for forecasting economic and social change, and may be useful in anticipating changes in the social and managerial environment.

# DELPHI

Forecasting of technology (and other streams of action depending on human decisions) inevitably depends on human anticipations of human actions--intuition, in a word--as well as informed judgments on what is likely.

Delphi is a method, first attempted at RAND and subsequently developed there and elsewhere, for soliciting informed judgments on such topics as what will happen and when in the stream of events it will happen.[3] As applied to technological forecasting, it is most often applied in developing consensus on major technological events and their timing.

Delphi is essentially the repeated interrogation of respondents (usually identified as "experts") on their expectations or understandings. They are queried separately, to avoid bandwagon effects or authority biases. The median or distribution of responses is then fed back to the respondents, who may alter their judgment or repeat it. In some cases, justification statements are sought for deviant opinions, and these also are fed back to the panel as further stimuli for reexamining the original judgments of the individual respondents. Finally, the estimates are stated in the form of a consensus judgment.

The use of Delphi avoids some common problems of group decision-making (as with a committee or special task force). The technique eliminates judgments based on "he who shouts the loudest," and it eliminates the inhibitions faced by group members of lesser rank or lesser reputation. Further, it allows members of the group to gracefully abandon earlier judgments without the need to reverse opinions publicly expressed during face-to-face debate.

While much of the work with Delphi has been experimental, the results of the experiments show considerable promise. Dalkey (a co-inventor of the technique) has found in experiments with college groups that the group opinion improves after Delphi iteration whereas the consensus becomes less accurate if group discussion is allowed.[8]

Delphi has been used predominantly within aerospace thus far; the U. S. Air Force funds RAND's research and has conducted experiments of its own. The Air Force Systems Command[9,11] and Office of Scientific

Research[12] have conducted pilot studies of social and technological forecasts. Dalkey has planned a series of experiments applying Delphi to value judgments.[8]

Other efforts are underway to identify impacts of future technological events.[5] TRW has used the technique for planning R & D strategies and for identifying new product opportunities.[4] Delphi also has been adapted to such business-related matters as the impact of increased leisure time on industrial product lines.[10]


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The origins of systems engineering have been traced variously to RAND's work in systems analysis for the Air Force, to RCA's work in television, and to Bell Telephone Laboratories' work on a nation-wide microwave radio system.[5] The systems engineering concept, while hard to define because of its complexity, has become the accepted way to attack major aerospace systems development programs.

As a philosophic extension of systems analysis, the *concept* of systems engineering is just as applicable as is systems analysis to the design and engineering of complex systems outside aerospace. However, the prospective adopter of systems engineering should be cautioned early that there are important practical barriers, largely economic, to the transferability of the *formal* systems engineering technique. Formal systems engineering management requires substantial technical resources and expertise.[8,9]

## Definitions

Systems engineering can be defined as:

> A cyclic and iterative process applied to integrate activities directed towards definition, design, and evaluation of a *system*.
>
> > A system is an assembly of interacting elements designed to carry out jointly a predetermined *function*.
> >
> > > The function to be performed is based on a set of objectives--with measures of performance defined related directly to these objectives.

A definition of systems engineering *management*, i.e., management of the systems engineering process, based on one given by the Department of Defense,* is:

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* Early draft of MIL-STD-499, "System Engineering Management," Department of Defense, 10 September 1965.

The integrated application of scientific, engineering and management techniques through an iterative process of analysis of requirements, synthesis of solutions, evaluation of alternatives and decision-making to:

a. Transform an operational need into a description of a complete system in terms of required performance parameters and a technical approach. This is the System Definition function. It provides the product elements of the work to be performed and the basis for technical performance measurement.

b. Construct the technical program requirements based on the system performance parameters and the technical approach. This is the Technical Program Definition function. It provides the task elements of the work to be performed and the basis for schedule and cost performance measurement.

c. Monitor and evaluate the progress of the planned technical program, adjusting system and technical program requirements as necessary. This couples technical performance measurement with system and technical program redefinition as required.

This process is illustrated in Figure 6.

## Applicability

Because of the resource investment required, the primary question for managers and administrators considering a formal systems engineering effort is: when is it applicable? The Air Force requires systems engineering on all programs for which a formal contract definition phase is applicable (i.e., programs having a cumulative R & D cost of $25 million or a total production cost of $100 million*) but notes that the systems engineering procedures can be readily adapted to benefit programs of lesser scope.[9]

Systems engineering *principles* also can be usefully applied to problem solving even where a true systems engineering effort is inappropriate. For

* DOD Directive 3200.9, 1 July 1965.

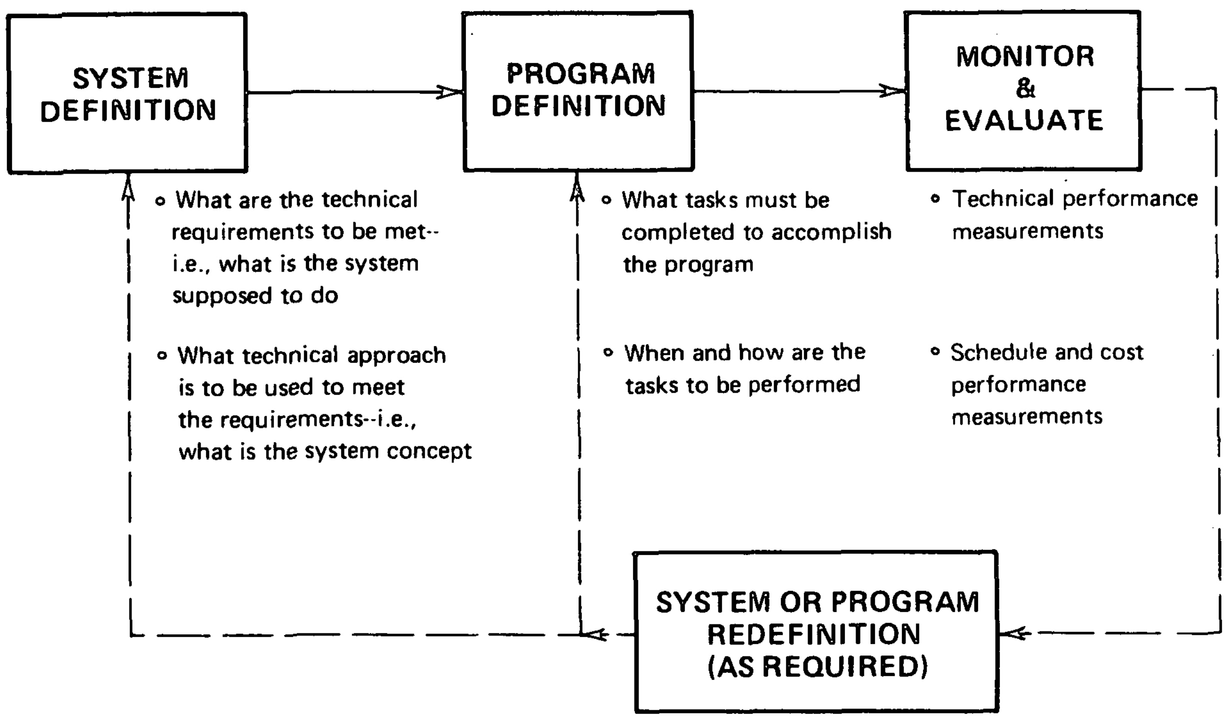


Figure 6. Systems Engineering Management Functions

example, Air Force systems engineering principles can be applied to the development of software (computer programs and related data) for electronic systems.[11]

## Steps in the Systems Engineering Process

A systems engineer in the Department of Defense[17] describes the concept of systems engineering as a methodology to solve complex problems--a methodology involving the following steps:

1. Statement of the problem to be solved.

2. Establishment of quantitative objectives in order of importance.

3. Identification and quantitative description of all significant elements (subsystems) and their interrelationships (interfaces)--e.g., the important technical, legal, contractual, organizational, social, and political parts of the system and their effects on each other and on the objectives.

4. Design of the system, including the tradeoffs among the competing characteristics of the system, subsystems and interfaces.

5. Detailed design, construction, and test of the subsystems.

6. Integration, test, and evaluation of the system.

These steps are iterative and cyclic. In other words, to carry out any single step it may be necessary to backtrack, modify the preceding steps, and then proceed forward again. Moreover, system evaluation may lead to establishment of a new set of objectives for a better over-all solution to the problem.

A systems engineer at General Electric has elaborated on the logic of the systems engineering process, as involving phases of reasoning activity: translation, analysis, trade-off, and synthesis.[1] These phases are explained in modified form below:

1. *Define the problem*--the mission; the environment; constraints (time, budget, performance standards, policy); and measures of effectiveness of the solution.

2. *Translation*--Determine the functions and the functional requirements to satisfy the mission requirements.

3. *Analysis*--Analyze candidate approaches for attaining the functional requirements within constraint limits.

4. *Trade-off*--Perform trade-off studies applying decision criteria to select the optimum approach.

5. *Synthesis*--Integrate all elements of the selected approach into a final system, program, or solution to the problem.

## Usefulness of Systems Engineering

In a world of growing complexity, systems engineering management appears to be an increasingly necessary part of development programs, to assure subsystem combinations that balance and mesh, and to accomplish physical system integration.

Some measure of the potential usefulness and scope of the systems engineering concept can be obtained by listing subjects of some recent study projects used (at Stanford-NASA Ames and at M.I.T.) to provide training in the systems engineering concept. All of these studies are based on existing technology:

- A metropolitan air transit system for commuter travel in the San Francisco bay area.[12]

- A high-speed (350 mph) ground transportation system in the Northeastern Corridor of the U. S., using air-supported, electrically propelled vehicles.[13]

- An urban transit system using fully automated moving roadways to transport vehicles, with traffic patterns controlled by a master computer.[14]

- An all-purpose orbital shuttle spacecraft capable of performing many space missions, including astronaut rescue.[15]

- Elimination of an asteroid threatening the earth, by interception with spacecraft armed with hydrogen bombs.[16]

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# RELIABILITY ANALYSIS

Reliability analysis is a technique--or more accurately a group of related techniques of management and of engineering--to promote the concept of reliability. And reliability, as a concept applied to any system or product, means the identification and correction of failure risks so that the system or product:

- Functions without failure for a specified time period.
- Operates within established performance limits.

Reliability is not limited to physical products, although nearly all books and articles on reliability concentrate on engineering and manufacturing aspects. The concept of reliability can and should be applied also to the furnishing of services, which makes the techniques of reliability analysis important to public administrators and to managers of service businesses.

As a concept, reliability is related both to quality and to maintainability, though these terms have quite distinct meanings. Some definitions are needed to clarify these terms:

Design Quality--the specifications of the product designer as to physical and performance characteristics. These include characteristics such as speed, power, and appearance.

Product Quality--the degree to which the designer's product specifications are met, or achieved, during production. Quality control (or quality assurance) is intended to achieve production quality, not design quality.

Availability--the degree to which the product exists in operating condition. Availability is dependent both on reliability (mean--i.e., average--time between failures) and on maintainability (mean time between repairs). A product is considered "available" if it has not failed, and is not undergoing repair or maintenance (scheduled or unscheduled).

The physical performance of a product is, therefore, determined by a combination of design quality and production quality--the designer's intention, as modified by the manufacturer's ability to achieve the intended characteristics of performance during the process of production.

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*Quality Assurance is described in pp. 162-167, and Maintainability Analysis in pp. 92-96.

The availability of a product (which can be thought of as the opposite of "downtime") is primarily a function of its design, for both reliability and maintainability must be considered in the early conceptual stages of the design process. Generally, the performance characteristics of the product are intimately related to the availability characteristics, and these must be balanced and conceived together.

## The Significance of Reliability

The reliability requirement is a powerful spur to technological progress. A knowledgeable aerospace reliability engineer* pointed out that two major technological achievements of the last 15 years can be traced to the impetus of reliability: the modern, transistor-based electron industry and automated electronics parts production lines.

During the development of the Minuteman, a second-generation intercontinental missile, Boeing and Autonetics engineers found that the extremely high systems reliability requirement simply could not be met because the best parts then available introduced too great a failure risk into the complex system. To correct this dilemma, the Minuteman Parts Improvement Program was begun. Suppliers (including Transitron and Texas Instruments) were asked to develop better electronics components that would perform much more reliably than any existing components would. Industry's response was the development of an array of highly reliable electronic parts, including improvements to such elemental items as capacitors and resistors. The concurrent advent of the lightweight, compact transistor led to its consideration and use as a superior replacement for the vacuum tube. In subsequent NASA- and Defense-sponsored programs, these semiconductor devices were developed to yield long lifetime reliability coupled with light weight and compact volume. Today's modern electronics industry owes its compact solid-state circuitry to these government programs.

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* Mr. Arnold A. Rothstein of Martin-Marietta, Chairman of the Reliability Division of the American Society for Quality Control, to whom we are indebted for these examples.

Aerospace reliability analysis also contributed significantly to the availability of modern-day electronic consumer products, as the following illustration shows.

Although transistors were generally reliable, there were individual differences in their performance characteristics which were incompatible with the special needs of government aerospace programs. Texas Instruments developed automatic testing equipment which screened and graded all transistors into a range of performance categories, with specially screened items reserved for Minuteman use or for NASA's Hi-Rel (High Reliability) Program. Automatic testing brought reliability to the concept of automated production lines, which have become the basis for mass-produced radio and television receivers, and other consumer electronics.

## The Nature of Reliability

Reliability is a concept based on probability, because the occurrence of failures can be determined (or assumed) to follow one of two statistical probability distributions: the normal distribution (true of failures caused by wearing out of critical components, thus primarily applied to mechanical parts) or the exponential distribution (true of failures which occur at random over operating life rather than through fatigue, thus principally applicable to electronic parts and equipment).

A major cause of low reliability is system complexity. Although designers seek simplicity whenever possible, their efforts to improve the performance of a system frequently result in an unavoidable increase in the quantity and complexity of components. If a system is 90 percent reliable, doubling its complexity will reduce reliability by the square of the simple reliability coefficient, or 81 percent. Tripling complexity reduces reliability to $(.90)^3$ or 73 percent.

## Achieving Reliability

There are three possible positive actions to increase reliability: eliminate mode of the failure and hence its effect; reduce the effect; or accept the failure effect with knowledge of its risk.

One obvious way to increase reliability is to simplify systems--

reduce the number of components. Another solution is to increase reliability of the components or subsystems at a rate greater than the growth rate of complexity. The increase in reliability can be achieved by: (1) improved quality or selection of components; (2) derating, or operating components below the maximum performance levels for which they are designed; and (3) improving their operating environment.

Special design techniques also can increase reliability. One obvious design technique is the reduction of the quantity of linked components which operate in series, since any failure of a component causes system failure. The use of redundant systems, such as parallel electronic circuits, can markedly improve reliability. If a single subsystem has a reliability of 0.9, adding a duplicate parallel subsystem increases overall system reliability to 0.99, and a third parallel system increases it to 0.999. However, redundancy of a system requires the addition of equipment to detect failure and to switch operation to the surviving system. All of this adds complexity, cost, and weight, which offset some of the advantages of the calculated reliability increase.

Another design technique is to accommodate a typical degree of component deterioration without causing failure (i.e., allow some reduction in performance before the component or system falls below its essential performance limits). This is a form of overdesign to incorporate wider safety factors in the system.

## Techniques of Reliability Analysis

Reliability analysis has reached a high level of refinement in aerospace, as was required for the successful operation of vastly complex product systems containing many thousands of physical components. In recent years, aerospace reliability analysis techniques have come to rely heavily on the use of a digital computer. Computer techniques have made practicable and efficient the use of a trial and error approach and the use of various mathematical optimization techniques. However, this summary will discuss the basic techniques of reliability analysis and will leave the explanation of sophisticated computer methods to the referenced publications.

Reliability prediction involves a number of computerized techniques for determining the expected reliability of a system or product. These techniques are applied during the early design stages, when corrective redesign can still occur. They also have proven of value when design changes are proposed on existing hardware. In such cases computerized prediction techniques are used to ensure that proposed hardware modifications will not degrade reliability. Aerospace experience has developed several predictive techniques which are described and compared in Reference 4 (e.g., comparison of similar systems, simulated operation, active element group count). Reference 4 also discusses the accuracy of each technique and the preferred application of each during program development. Reference 5 describes a Failure Effect Management System (an iterative process ranging from conceptual design through use) that uses both qualitative and quantitative approaches to reliability.

Probability design review is a basic aerospace project technique which embodies the evaluation of reliability analyses as part of the overall review of the system design. After a system is first conceived, and at planned intervals thereafter in the development process, comprehensive reviews are made of the design configuration from components through assemblies through the total system. Correspondingly, these reviews incorporate the results of reliability predictions coupled with review of the use of redundancy concepts, safety factors, and operation at derated performance levels. The design is compared, during review, with approximately similar designs for which actual failure experience exists. Human factors affecting reliability also are considered.

Failure mode and effects analysis is another major reliability activity which is a necessary part of any design review. The analysis asks: "What can go wrong? How can it go wrong? What is the significance of this kind of failure?" This requires judgment as to the potential modes of failure introduced by any new design. Critical modes of failure are, where possible, eliminated through redesign to modify or to eliminate certain components or subsystems. The true value of failure analysis is derived when it is combined with an operational or test program and a coordinated design feedback effort, to achieve a cost-effective reliability.[6] Properly coordinated test and failure analysis efforts have increased reliability by as much as ten times over a development cycle.

Worst case analysis is self-descriptive--an analysis of what will happen if everything in a subsystem behaves in the worst possible way. This analysis frequently is made with computer techniques. Usually if a subsystem passes a worst case analysis, the designer is assured of reliable performance with adequate safety margins.

Minimal-state system reliability analysis involves determining mathematically the "upper bound" and "lower bound" of a system's reliability. This rather complex concept involves tracing paths through a logic diagram of the system. The upper bound is determined by a path through a minimum number of essential components (i.e., the system functions if these components function, even if all other components fail). The lower bound is determined by a path through a "fault tree" of failure states (i.e., the system fails if these components fail, even if all other components operate perfectly). Computerized exact procedures for minimal-state analysis have been developed, based on the SCOPE (System for Computing Operational Probability Equations) computer program.[7]

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## MAINTAINABILITY ANALYSIS

The concept of *maintainability* is technically defined as the average (mean) time between repairs. The following definition may be more useful to managers: "Maintainability is the degree of facility with which equipment is capable of being retained in, or restored to, serviceable operation. It is a function of parts accessibility, internal configuration, use and repair environment, and time, tools, and training required for maintenance."[13]

Some persons become aware of maintainability--or lack of it--after a minor collision with a personal automobile. Growing recognition of the need for more maintainability has led automobile manufacturers to consider design improvements: stronger bumpers to minimize damage and wider use of throw-away parts to reduce repair costs, both improvements which would also reduce repair downtime.

Maintainability, like reliability, is determined by the designer. The design goal should be to promote cost-effective product availability. Thus reliability (reducing the frequency of failure) and maintainability (reducing the effect of failure) must be balanced by the designer to establish an optimum (least-cost) combination.

Most of the progress in maintainability has come from the aerospace sector. The military services specify it as part of the integrated logistics support system, and the space program requires a high level of maintainability for space vehicles. The concept of maintainability was formally recognized by the U. S. military services in 1954, and the first formalized program specifications (e.g., Air Force MIL-M-26512) were issued in 1959.

NASA has publicized two reports generated by contractor (Boeing Company) engineers engaged in analyzing and developing maintainability methods for space vehicles.[3] The maintainability techniques used by NASA for space vehicle logistics support systems have been studied and adapted to a much different type of operational system: a midwestern fire and casualty insurance firm has adopted the principles of maintainability analysis in the design of a complex, decentralized system of communications and data transfer.

The technique of maintainability analysis may be better understood as the early stage of a product maintainability program which encompasses:

- The specification of system-level maintainability requirements (normally established by the customer, in an aerospace program).
- Maintainability analysis (the process of translating system-level requirements into specific qualitative and quantitative equipment-design requirements, or design criteria).
- The accomplishment of maintainability production.[1,6]

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- The design review (actually a series of integrated design reviews involving reliability, human factors, etc., as well as maintainability).
- Analysis of a specific design configuration to determine maintenance support requirements.
- Formal maintainability demonstration.[5,10,11]

Within this program framework, maintainability analysis is an activity which occurs during the program definition phase, when customer maintainability requirements are converted to specific criteria, before the start of actual equipment design. The design and performance specifications resulting from maintainability analysis serve as constraints on the design engineer. The overriding design constraint is the assurance that the downtime (mean time to repair, or MTTR) of each component, when combined in a statistical mean, is no greater than the overall system requirement for MTTR. A maintainability allocation process, part of the maintainability analysis technique, accomplishes this.

Maintainability analysis involves a sequential development and review of data to establish the optimum characteristics of the product system, considering such factors as:

- Quantitative performance requirements
- Maintenance support available
- Cost
- Operating objectives
- Safety

A trade-off technique of decision-making is used to formally analyze maintainability. Although the trade-off decisions (described in detail in Chapter 7 of Ref. 1) vary with the product consideration, they may include such alternatives as:

- Man vs. machine maintenance
- Built-in vs. external test equipment
- Manual vs. semi-automatic operation
- Repair vs. throwaway parts
- Reliability vs. maintainability
- Depot-level vs. intermediate-level maintenance
- Provision of spare parts vs. provision of support (repair) equipment vs. a mix of both
- Modular vs. nonmodular packaging
- Make or buy

Recently, attention has been given to a concept of large-scale integration (LSI) which has significant implications for maintainability analysis. LSI, primarily visualized as a concept for avionics (i.e., airborne electronics systems), promises great potential advances in maintainability. Through integration of operating and corrective maintenance subsystems, LSI makes possible automatic self-testing, fault isolation, self-repair, and throwaway maintenance. LSI potentially combines high reliability with a low-cost maintainability--cheaper than conventional repair techniques.[12]

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## VALUE ENGINEERING

Value engineering, also known as value analysis, is a step-by-step method for improving product value (i.e., the ratio of its functional worth to its production cost). The method consists of quantitatively comparing the elements of product worth to their corresponding elements of product cost, and by selecting least-cost alternative means of accomplishing the required function.

Though value engineering requires technical skill in the determination of function, and in judging substitutions in product elements, it is basically a management technique for assuring orderly evaluation of alternatives. It is important to understand that value engineering involves no reduction in the quality of a product, and no reduction in safety, operating features, or in attractiveness. Value engineering does not mean "cost cutting" or "cheapening" in the customary sense of these words--reducing cost by reducing value. The cost reductions which result from value engineering occur because unnecessary costs are avoided.

The concept and techniques of value engineering are generally attributed to the innovations of Lawrence D. Miles in the General Electric Company, during and just following World War II. Miles, who has written the classic book in the field,[1] drew on certain principles of industrial engineering and scientific purchasing in establishing his principles of value engineering.

Miles first defined two kinds of "value" as a basis of value engineering studies: *use value* (the properties or qualities which accomplish a use, work, or service) and *esteem value* (the properties, features, or attractiveness which cause us to want to own it). He then outlined three basic steps in the process of obtaining lower-cost engineering and manufacturing solutions and alternatives, without lowering either kind of value:

a. Identify the function. The prime function of a useful product or service often can be described simply (e.g., provide light, support handle). Secondary functions (e.g., look attractive, resist shock) also must be considered.

b. <u>Evaluate the function by comparison</u>. All evaluation of value results from comparison of some kind: with standards; with similar or partially similar items; with alternative materials or manufacturing processes.

c. <u>Cause value alternatives to be developed</u>. Thirteen value engineering techniques have been identified as helping to identify unnecessary cost, remove obstacles, and ensure the development of good value alternatives:

- Avoid generalities which hamper inquiry.
- Get all available cost figures, including overhead and secondary costs.
- Use information from only the best source.
- "Blast" (i.e., critically analyze the basic function and focus on extremely simple alternatives to it); "create" (i.e., modify the first-chosen alternative to provide elements of increased function); and "refine" (i.e., replace all needed elements of function, at least cost, until the full function is achieved).
- Use real creativity.
- Identify and overcome roadblocks.
- Use industry specialists to extend specialized knowledge.
- Determine the true cost of key tolerances specified in the design.
- Utilize vendors' available (standard) functional products.
- Utilize and pay for vendors' skills and knowledge.
- Utilize available specialty processes (i.e., uncommon casting or shaping processes available commercially).
- Utilize applicable standard materials and components.
- Use the criterion, "Would I spend my money this way?"

The aerospace industry has been heavily involved in value engineering for many years, since the Department of Defense (DOD) has promoted its principles in its procurement of equipment from its suppliers. DOD has documented dozens of examples of new products or techniques that have benefited from value engineering.[7] An incentive system built into Armed Services Procurement Regulations provides a share of value engineering savings to the contractor.*

The impact of value engineering on product characteristics was investigated by a Department of Defense-sponsored study, partly to determine whether the financial incentives of value engineering resulted in any reduction of product quality. The study found that a sample of value engineering change proposals provided substantial improvements (and only rare reductions) in such characteristics as reliability, maintainability, producibility, quality, weight, and performance.[2]

The head of RCA's value analysis program believes the primary benefit of the program is neither cost reduction nor improved products, but the generation of earlier and better information and communication about a company's operations. He added, "Value analysis brings together the originators and the users of information so they can jointly evaluate individual project functions."[8]


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# CHAPTER VIII
# TECHNIQUES FOR ORGANIZING

## PROJECT MANAGEMENT

Although project management systems are not unique to aerospace, the aerospace environment has profoundly influenced such systems. In the process, traditional management theory has been significantly affected, with the aerospace sector's management techniques interwoven with the project management concept.

The terms *project management* and *program management* are almost interchangeable: the concept is the same, and in common usage there is considerable overlap of the terms. In precise usage, *projects* are smaller elements which make up a major *program*. However, where the concept is described in this section, the more common term *project management* is used.

The project management system as developed in aerospace permits a far greater degree of detailed control of operations than conventional management methods do. Project management also promotes rapid identification of and response to potential deviations from plan. By necessity, the system places great demands on the project manager:

> Project management, particularly in the management of major R & D projects, is undoubtedly one of the most complex and demanding management concepts in existence. . . . The project manager's task is enormously complicated and diverse; . . . He deals with technical and administrative disciplines in pulling together a project team to act as a team rather than as a fragmented group of functional experts.[1]

As a result, the selection of a competent project manager is quite important to the success of this management system.

Lt. Gen. Sam C. Phillips, NASA's Apollo Program Director who had earlier managed an Air Force ballistic missile program, states that "the Apollo management process is to *integrate people* into an organized relationship with one another, and to provide them with the assignments, the environment, the means, and the processes and disciplines that are required to insure progress at a planned *rate and cost* to attain that specific objective."[6]

As it has evolved in aerospace, the project management concept has several striking characteristics which differentiate it from the traditional concept of managing operations. This subsection will briefly describe these characteristics. However, an examination of the effectiveness and significance of the concept are beyond the scope of this subsection. (For a fuller description, see Chapter X and the references at the end of this subsection, particularly Refs. 1, 2, and 4.)

## Close-knit Organization

Normally, aerospace project assignments involve a substantial emotional commitment. The aerospace employee is not merely given a work assignment, he is placed in a new environment. There is a physical move of working location and a relatively long-term assignment to a new supervisor. The employee is made both to feel a dedication to the project goals and to recognize the close relationship between project success and his personal career advancement. The project staff is made to feel that personal sacrifices are expected. The employees often are carefully selected for homogeneity in background, education, or skills, as with the all-engineer staffing program of the Apollo Program Office. A sense of teamwork and mutual support and enhancement is stressed, although the cooperation is goal-oriented. That is, the cooperation among project workers does not extend to covering up deficiencies which threaten project success.

## Deliberate Conflict and Its Resolution

The project management system deliberately fosters conflict among organizational groups, as a means of attaining project goals. This is done through the matrix organization concept (see next subsection) which promotes tension and rivalry between groups which have different subgoals, although they share the same primary goal. Typically, the conflicting group subgoals correspond with basic philosophic conflicts in the project itself (e.g., a need for high quality vs. a need for faster production). The resolution of these conflicts involves a bargaining process and intergroup rivalry which have two results: (1) the facts of the conflict become visible very quickly, and any possibility of a harmonious settlement is quickly explored; and (2) the conflict quickly escalates through the appeal process to the project manager's level for resolution.

The results are generally favorable to the program:[4]

- Action to solve the conflict often brings desirable change to the organization and the project.
- Inherent defects in the organizational system or in resource allocation are spotlighted.
- A system of checks and balances pervades the project, so that trade-offs are achieved among project cost, schedule, and performance.
- Resolving the conflict reinforces the authority of the project manager.

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## Rapid, Thorough Communication

The reporting system used in a project management system is typified by very frequent and thorough discussions of project status. The Apollo Program had its "Breakfast Club"--daily 30-minute meetings in the Apollo Action Centers during which, "Mission status and all constraining problems are reviewed based on real-time information (telephone, travel, personal contact) . . . [and] problems are given the proper management attention as they are developing, thereby permitting timely corrective action to be initiated."[6] Most aerospace projects use weekly cycles for administrative reporting meetings, with comprehensive management reviews by higher ranking offices often scheduled monthly.

## Highly Visible Management

Aerospace project staff meetings have such names as "Black Friday" because they commonly expose managerial deficiencies in a candid manner. The free exchange of ideas on project problems is encouraged, and the discussion of problems is designed both to make managerial failure visible (the embarrassment is intended to prevent repetition) and to establish a plan and assign responsibility for corrective action. The emphasis in staff meetings is on problem identification and problem solving.

## Painstaking Attention to Detail

During the contract definition phase of program management, the amount of detailed data required has been termed "incredible."[2] The attention to detail carries over to the development of a project plan[9] and (allowing for personal variations among individual project managers) to the thoroughness of control methods employed.

When deviations from the project plan are detected, the project control system focusses detailed attention on the deviant area. A prospective delay in availability of a contractual end item is analyzed to determine the pacing work package, production item, or purchased component responsible. Rigorous corrective action is applied to comparatively tiny portions of the project activity. Such attention to detail pervades the successful project management system.

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## MATRIX ORGANIZATION STRUCTURE

The *matrix* organization structure, named for its resemblance to a rectangular grid when shown on a chart, is a product of the aerospace environment. It is quite effective as an organization pattern for aerospace R & D programs, where the emphasis is on project completion rather than on conventional production, but it also is effective in a commercial environment where product lines are varied and numerous. The matrix organization promotes flexible and adaptable use of resources to achieve project objectives.[1] The matrix structure is so frequently utilized in aerospace project management that it could be considered as a subset of project management technology.

In a typical matrix organization structure (Fig. 7) there are two lines of authority running from the chief executive: a functional line and a project line.

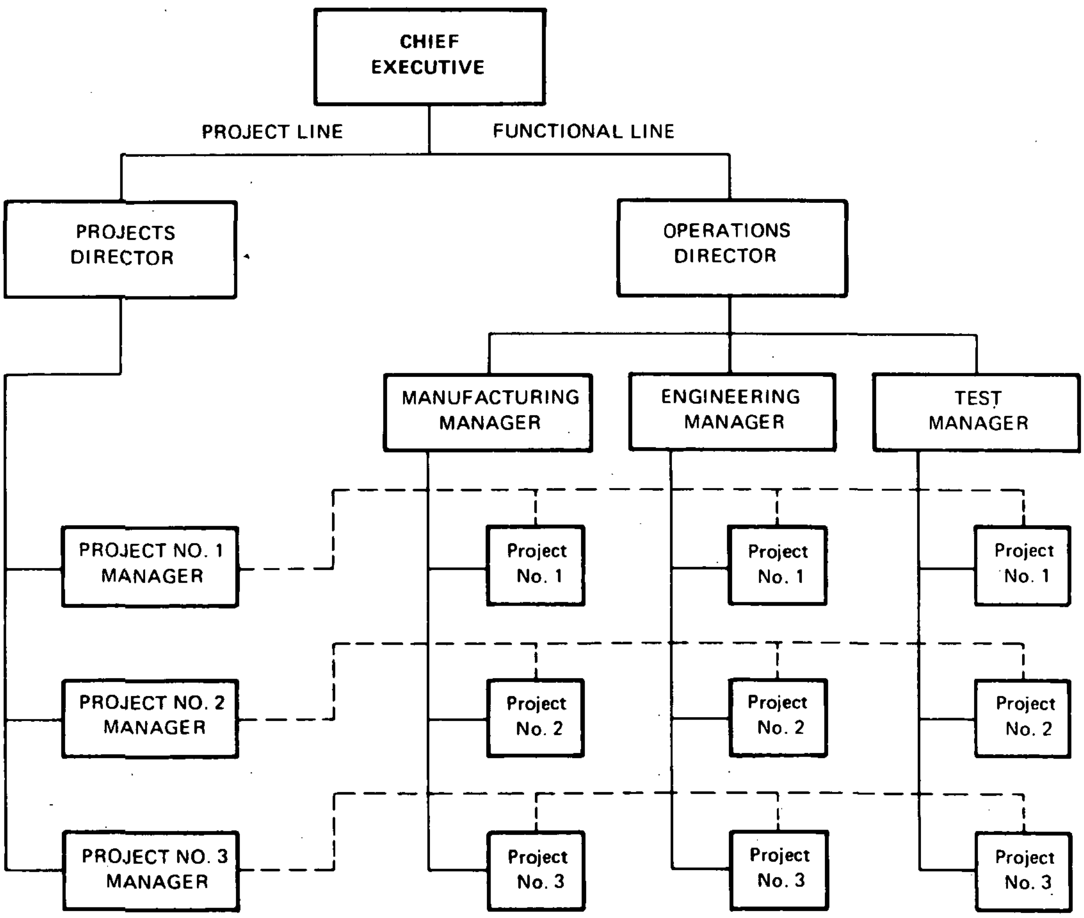


Figure 7 - Matrix Organization Structure

Each functional manager (e.g., engineering, manufacturing, finance) is responsible for supporting the project organizations of the company. He sets technical and professional standards, policies, methods and guidelines for the conduct of his function. Also, he maintains long-term responsibility for the adequacy of functional personnel assigned to projects.

Each project manager is responsible for management and control of all phases of a project from inception to completion, including contract negotiations, establishment of project requirements and criteria, identification and authorization of work performed, establishment of direct budget and schedule requirements, monitoring and reporting to management of project status and performance, and maintenance of prime customer contact on project matters.*

In effect, a matrix organization creates a continuous controlled tension throughout the organization. The inherent conflicts between functional and project responsibilities are emphasized, and each manager is constantly pushed to recognize the conflicts among design performance, cost, and time. The matrix can be viewed as a mechanism to promote decision-making, where conflicts are faced and resolved either by compromise (trade-off) or by intervention of the chief executive. In either case, the conflicts are expected to be resolved in the organization's best interests.

Advantages

The matrix shares several advantages of the project system of organization: (a) a team spirit and sense of competitive enthusiasm is established for each project; (b) the customer is able to recognize a point of contact--the project manager--who represents the company to him and his interests within the company; and (c) interfunctional rivalries (as between engineering and manufacturing) are minimized by the intervention of the project manager.

* NASA is sponsoring management research studying in depth the authority and organizational role of the aerospace project manager. The National Academy of Public Administration is analyzing the work of NASA program and project managers. A Syracuse University group is investigating the use of authority by the project manager.[4]

Still, certain advantages of the functional organization are retained: each functional manager supervises a pool of functional talent to fill the shifting needs of the various projects; he directs assignment and reassignment and arbitrates conflicting project demands; and he is in a position (because of the employee's long-term career dependence on his functional manager) to promote adherence to desired technical standards.

A matrix organization is designed less around power and more around possession of useful information,[6] so it encourages innovative ideas throughout the organization.

NASA has found, in using the matrix structure, that good organizational communications are essential to the success of the system.[5] The space program also has learned that the matrix system of organization is not a comfortable place for the man who insists he can be responsive only to one boss. Also, the matrix organization can be a jungle of frustration to people who think that ease of administration is the same thing as effective management.[5]

## Applications

John F. Mee, in an early description of the matrix structure, stated that "although the matrix organization emerged to improve work performance in the aerospace industry, other alert industrial managers can adapt the concept for uses in new product or market developments in a marketing dominated economy."[1] The matrix is used also in the Office of Emergency Planning, in the Executive Office of the President,* and has clear relevance to governmental as well as commercial projects.

Recently, it was suggested that the matrix organizational form is an on-going characteristic of colleges and universities.[8] With the growth of interdisciplinary academic programs, this seems increasingly true. The authors have successfully implemented an aerospace-derived matrix organization structure for an interdisciplinary research program involving five colleges of the University of Denver and Denver Research Institute.[9]

When the matrix structure is applied to commercial firms,

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*Prof. George A. Steiner, co-author of Ref. 2, pointed out this application during an interview with us.

the checks and balances which are created to assure tradeoffs of cost, schedule, and performance supersede the conventional functions of the organization. Thus the traditionally strong cost controls of a commercial firm tend to be balanced by an equal emphasis on quality, reliability, and performance. For conventional commercial firms this may mean a major change in competitive effectiveness.

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## GOVERNMENT/PRIVATE CORPORATIONS

When new enterprises are created they tend to follow traditional patterns of legal form. Typically, the public sector problems are handled by an executive agency or a task force; private sector problems are handled by a corporation. There is little experience in combining the responsibilities of the two sectors. Yet some novel problems of aerospace have stimulated a search for new organizational patterns to better coordinate governmental and private sector work efforts.

Two innovative organizational forms have evolved from the aerospace experience, both government-private corporations in structure. One is the treaty-type organization, by which several governmental jurisdictions join in a consortium to sponsor a corporation which provides a technological service to all of the jurisdictions. The other is the Federal contract research center, which marshals private-sector technological skill to serve as an adjunct to a governmental agency. Both organizational forms show promise for solving difficult problems faced by public administrators at local and regional as well as Federal levels.

### Treaty Consortium (INTELSAT)

*International Telecommunications Satellite Consortium* (INTELSAT) is a unique international joint venture. Through the INTELSAT agreement, most of the world's governments (62 as of 1968) have combined to finance and manage a space satellite system utilized by earth stations owned either by private corporations or by government agencies. INTELSAT is a technological, financial, and above all a political success. It has brought together in common purpose a great number of governmental organizations, varying widely in size, technology, and wealth, and it is flexible enough to accommodate changes in membership. It is financed on a "pay as you go" basis which minimizes both initial investment and investment risk.

INTELSAT was formed in 1964 by two international agreements, one an intergovernmental treaty and the other a "Special Agreement" among the public or private telecommunications organizations designated by their respective countries.[1] The Special Agreement provides specific guidance on contracts, payments and cost allocations, and the use of patent rights and technical data. In principle, the INTELSAT agreements allowed the organization to be created with only a few participants, and for others to be added later. The growth of membership brought in new investments and allowed operations to expand. In this way, INTELSAT resembles an open-ended mutual investment fund.

There were several innovative features in the INTELSAT agreements which contributed to its success:

- There was recognition that the technological resource could be developed most efficiently through international cooperation, rather than through a proliferation of competitive systems. (This would appear to be true also for most metropolitan utility services: communications, transportation, water, sanitation, pollution control, etc.) Thus INTELSAT encouraged broad membership.

- The form of organization accommodates a diversity of public and private membership, corresponding to the diversity of economic systems of the members.

- Economic considerations (i.e., operating efficiency) are emphasized more than political considerations; thus rationality rather than emotion underlies operating policy.

- The organization provides for wide variances in degree of investment and ownership; investment quotas are determined for each member based on its degree of utilization of the total system (i.e., by each nation's percentage of international communications traffic).

- Each member's vote in the policy making of INTELSAT is weighted according to its investment quota.

- The pay-as-you-go plan lets new participants enter without a prior investment (which would tend to serve as a barrier to entry at the local government level, if a bond issue authorization were needed to obtain investment funds). Collections from telecommunications operations help offset costs each accounting period. In this sense, INTELSAT functions like a non-profit cooperative. It avoids the problems which might arise if a few countries owned the system and sold services to other countries.

- A professional management organization is hired for a fee to operate the consortium. In the case of INTELSAT, the management is provided by a well-known firm in the U. S., the Communications Satellite *(COMSAT)* Corporation.*

The INTELSAT concept would appear to set a useful pattern for obtaining needed cooperation from groups that are quasi-sovereign in authority yet interdependent in actuality. For example, an INTELSAT form of agreement seems well suited for such regional applications as management of a river basin to supply municipal and industrial water and waste disposal services to both public and private jurisdictions. The local governments surrounding San Francisco Bay (now associated in ABAG, the Association of Bay Area Governments) might find an INTELSAT-like compact useful in maintaining the desired environment of the bay. Local water districts in a metropolitan area dependent on a single water source, and metropolitan Councils of Governments, also may find the INTELSAT pattern useful.

Dealing with environmental problems, particularly air and water pollution, may call for the creation of new governmental or quasi-governmental organizations. The Tri-State Compact, being considered by New Jersey, Pennsylvania and Delaware, may create an interstate air pollution control agency covering parts of the three states. To be effective, the agency also must maintain sufficient flexibility to expand its membership to cover new areas where air pollution problems arise.

The INTELSAT concept appears to have the greatest promise when applied to activities requiring technical expertise; there is some question whether the INTELSAT concept would work as well on the local government scene where the direct interest group is the general public rather than an expert group of technical specialists.

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*COMSAT, itself an interesting government/private administrative mechanism, also may serve as a model for application elsewhere. COMSAT is funded entirely from private sources (half from individuals, half from communications carrier firms) yet operates under U. S. Government controls and has 3 of its 15 directors appointed by the Government. COMSAT functions somewhat in the manner of a regulated, privately owned, public utility.

## Federal Contract Research Centers

Many of the 40 *Federal Contract Research Centers (FCRC's)* (such as the AEC's Oak Ridge and Los Alamos, the Air Force's RAND, and NASA's Jet Propulsion Laboratory and Bellcomm) were formed in response to an urgent national need.[3] The FCRC provides a fast start-up device when government has limited internal talent and must quickly meet a pressing requirement.

FCRC's are nonfederal in the sense that their employees are not part of the Civil Service system, yet each of the FCRC's has a special, continuing relationship with a single Federal agency that supplies all (or nearly all) of its funding. Typically, the Federal agency also owns most of the facilities used by the FCRC. The work done by FCRC's includes basic research, applied R & D, systems analysis and planning (e.g., RAND), and systems engineering and technical direction (e.g., MITRE).

NASA, for example, has used the Jet Propulsion Laboratory (JPL) to direct development of automated space vehicles and operation of worldwide tracking and data acquisition networks. Bellcomm, managed by AT&T and Western Electric, performs studies, technical fact-finding and evaluation, analytical investigations, and related activities in support of manned space flight and related NASA programs.

Examples of the extension of the FCRC concept to new sponsors, Federal and local, are:

- The Urban Institute, sponsored by HUD to do R & D in urban problems.
- The New York City-RAND Institute, formed by RAND to conduct policy research studies in such areas as public safety, housing, health, and welfare.
- The Los Angeles Technical Service Corporation, funded more by private foundations than by the City of Los Angeles, which contracts with industrial firms for performance of R & D on city problems.
- The regional education laboratories formed by the U. S. Office of Education to conduct educational R & D.

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3. Welles, John G., *et al.*, *Contract Research and Development Adjuncts of Federal Agencies*, Denver: University of Denver Research Institute, 1969, 400 pp. [An exploratory study of the institutional role of 40 FCRC's.]


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# CHAPTER IX

# TECHNIQUES FOR ADMINISTRATIVE PLANNING AND CONTROL

## SYSTEMS FOR PROCUREMENT

This subsection introduces a family of aerospace-related management techniques and concepts for performing a common management function--the procurement of goods and services. While all organizations engage in purchasing, and a considerable amount of expertise has been developed in the craft of purchasing agents, the aerospace sector has pioneered new and highly complex concepts. It is one thing to evaluate products, prices, and delivery promises of conventional suppliers. It is quite another thing to procure a unique weapons and space system, involving billions of dollars and several years development time, on which depends the success of a major national program.

To a great degree, the space program has demonstrated the feasibility of contracting for goods and services for a large-scale enterprise. Even though under its legislative charter and presidential encouragement, NASA could have built up a large and highly centralized department, it chose instead to keep a relatively small headquarters staff and to procure goods and services from others. James Webb commented on this:

> A major NASA policy has been to rely on contracts with non-governmental establishments and institutions for the work they were qualified to do. Over ninety percent of all funds invested in the NASA program have been spent outside the government. In some years this has reached 95 percent. . . . The NASA program has involved about 20,000 industrial prime and sub-contractors and suppliers, 200 universities, and almost 400,000 non-governmental workers. . . . [This] has forced us to extend into new dimensions the art and practice of administration and management.*

Quite possibly the highly developed procurement systems of the Department of Defense and NASA may be usable in other large-scale enterprises,

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* James Webb, "NASA As an Adaptive Organization," address at Harvard Graduate School of Business Administration, September 30, 1968, p. 42.

particularly those dependent on research, development and deployment of highly complex equipment.

Cities, for example, are both large in scale and increasingly in need of R & D efforts and high-technology systems. One observer, experienced in application of technology to urban needs, recently wrote:

> Practically every American City has had under way for some time one or more special programs involving the procurement and utilization of technological intensive products or services. These programs, largely funded by the federal government, relate to housing, health services, transportation, education, environmental quality, welfare, labor, police effectiveness, and general community development and well being.
>
> These programs are mostly conducted and managed by the same people who manage other city affairs . . . and they are generally handled like other city programs requiring outside products and services--by a simple contracting process usually accepting the lowest bid.
>
> Cities have not made a particular effort to develop an in-house scientific-technical capability to determine what is actually needed in the way of technological products or services, and how they can be most effectively acquired, or to evaluate the results achieved by industry and university contractors, or to ensure that the technological products or services being supplied are utilized in a way to secure optimum results and benefits both in the solution of specific problems and from a systems standpoint.*

The need for innovation in city management and in the procurement of technology is great. The author of the article calls for "new approaches, new ways of doing things, new and different skills and competences." The aerospace management experience may provide some of the needed ideas.

The aerospace innovations in procurement include the following concepts and techniques:

- Source Evaluation Board Process
- Incentive Contracting
- Contractor Performance Evaluation.

Each of these innovations will be described in a following subsection.

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*Ronald J. Philips, "Technology Utilization: Supplying the Blueprints," *Public Management*, February 1971, pp. 18-19.

# SOURCE EVALUATION BOARD PROCESS

In aerospace procurement, a formal *Source Evaluation Board (SEB)* process is used whenever the total cost (including prospective follow-on items) is high--NASA specifies SEB's when the total estimated cost is $1 million or more. The purpose of the SEB process is to provide a sound basis for judging the selection of the contractor having the highest probability of best performing the contract tasks within the specified price.

The Source Evaluation Board does not select the contractor, but decides on the particularly important criteria that affect the selection and determines the most appropriate way of applying these criteria. The Board determines what expert knowledge is required and assures that it is available and used. Finally, the SEB sees that all competitive proposals are judged fairly to the same significant criteria, and ranks the proposals in order of preference.

The value of a Source Evaluation Board process is not limited to the selection of the most competent contractor, although that goal (if attained) should be sufficient justification for its cost. A study which has evaluated the SEB process found it to be an effective measuring device used by the chief executive to determine how well contractors are developing their capabilities and to gauge the quality of the thinking of top officials in his own organization.[2] Another evaluator, although pointing out evidence that major procurement decisions frequently are not made in accordance with formal source evaluation recommendations, nevertheless writes:

> These data do not suggest that the formal evaluation systems are without value. Indeed these methods seem to stimulate a more thoughtful and more orderly planning process that enhances management effectiveness.[3]

## Organization

In a typical aerospace program, the SEB is composed of members appointed by top management. Their service takes priority over their regular jobs. Besides a chairman and secretary, the Board includes representatives of the procurement and contracts functions and (importantly) of the technical divisions who must later supervise operation of the procured system. The Board usually operates with three committees, each taking leadership in evaluation of a major aspect of the procurement decision: technical expertise of the contractor; management ability; and cost. A typical organization of an SEB is shown in Figure 8, below.

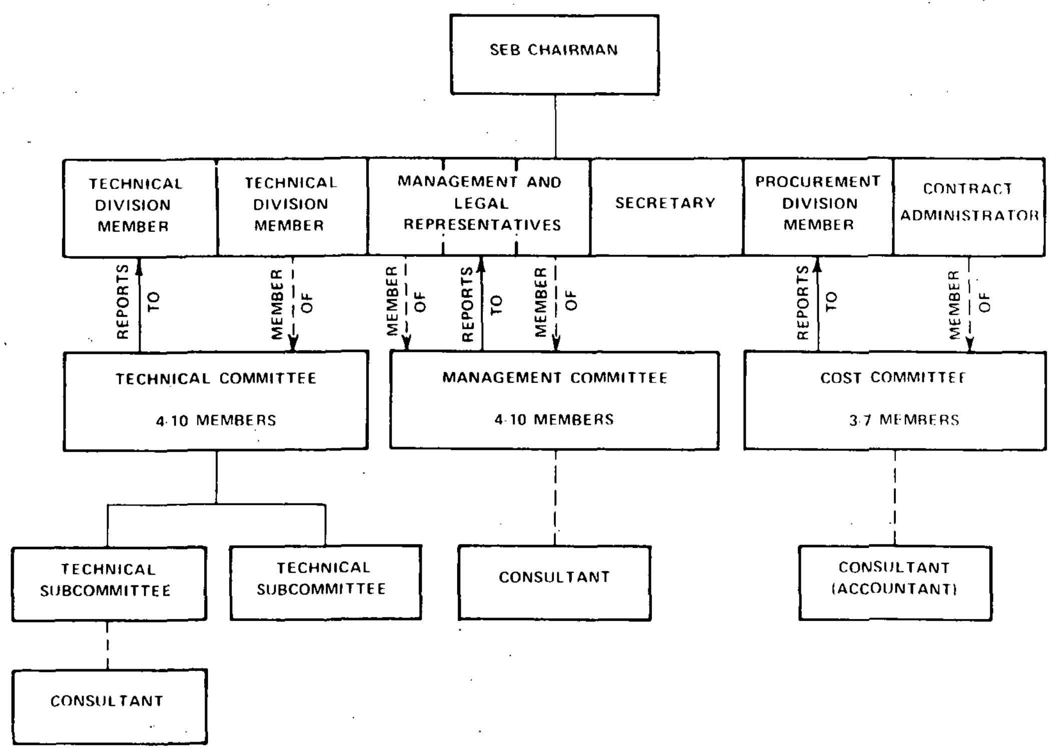


Figure 8. Source Evaluation Board Organization

## Procedure

A typical SEB procedure involves the following steps:

- The SEB is organized, isolated from personal contact with potential contractors, and a board work schedule is established.
- Qualification criteria, defining the minimum capability of potential contractors, are established to eliminate unnecessary effort in writing and evaluating proposals.
- The SEB reviews the Request for Proposal and determines the major subject areas on which proposals will be evaluated.
- Committees are appointed to study in depth the evaluation areas (e.g., technical ability, management ability, and cost). Each committee recommends specific evaluation criteria that will indicate significant differences between proposals.
- The SEB reviews and approves committee recommendations on evaluation criteria, and establishes a system for weighting and scoring proposals according to these criteria. This occurs *before* receipt of proposals.
- Proposals are received, screened and scored by the respective committees, and weights applied to determine total score.
- The proposals are ranked in order of score, and the proposers in the top competitive range are contacted by the SEB for discussions and surveys of their facilities and capabilities, to identify other strengths and weaknesses.
- The SEB, judging all factors, makes a final ranking of the proposers and prepares a report of findings.
- The SEB report is given to the official responsible for making the final selection of the contractor.

An evaluation of the SEB process as used by NASA finds that the use of SEB ensures the selection of the best contractors in terms of NASA objectives, stimulates competition, provides for fair and impartial review, insures review flexibility, and maintains a desirable balance between top management authority and decentralized operational responsibility.[2]

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## INCENTIVE CONTRACTING

Incentive contracts are designed to provide a special financial motivation to the contractor, so that he (or his product) will perform more efficiently, or that he will control costs more carefully. The contracts can involve performance incentives or cost incentives or some combination of both.

The use of incentive contracts has grown rapidly throughout aerospace in the last few years, primarily as a result of the policies of the Secretary of Defense. During the 1961-68 period, the use of incentive contracting doubled (from 14 to 28 percent of total contract dollars) in the Department of Defense. However, the concept of incentives in military procurement contracts is not new. Performance incentives were used by the Navy in the Civil War (the *Monitor* had to float, attain a specified minimum speed, and win its first battle against the *Merrimac*, or the contractor would not be paid) and by the Army Signal Corps when purchasing a flying machine from the Wright Brothers (with a reward/penalty of $2,500 for each one mile per hour over or under the target of 40 m.p.h.). Cost incentives (50-50 cost sharing of cost reductions) also were offered shipbuilders during World War I.[2]

How well do incentives work? It is difficult to say, because the completed studies of incentive contracting are based on early experience believed unrepresentative of current incentive contracts. The findings of six major studies compared in Ref. 1, confirmed by Ref. 2, conclude that incentives *do not* appear to accomplish their intended goal of motivating contractors to lower costs or better product performance. This is not to say that incentives are harmful (except in added administrative cost) but merely that they are ineffective. However, the negative findings of comparative studies are admittedly based on an analysis of early and poorly-structured contracts which would not show incentives to be effective motivators even if they actually could be effective.[1]

A manufacturing executive with space program experience who reviewed the draft of this report made an enthusiastic defense of incentive contracting as a performance motivator. Mr. J. Thomas Markley, Vice President and Assistant General Manager of the Raytheon Company's Equipment Division, commented that the incentive contract worked on Apollo and continues to motivate him in his present role in industry. He added that Raytheon has experimented successfully with cost award fee incentives in commercial contracts with software firms. Mr. Markley also commented that the subtle financial incentive of relating progress payments to technical performance milestones under a contract also successfully motivates contractors to improve schedule performance.

While none of the major studies of incentive contracting[1,2,3] could find satisfactory evidence of the effectiveness of incentives as motivators, still none of them suggested that incentive contracting should be eliminated. They suggested changes in emphasis and more selectivity in using them, but not abandonment of incentive contracts.

Even if incentive contracts do not consistently serve to motivate contractors, such contracts have several other important advantages:

- Incentives provide a planning discipline for the buyer's employees. When an incentive contract is to be negotiated, the analysis of requirements is more thorough and the work statement is more precise. Thus, incentive contracts provide the buyer with better program cost information than do cost-reimbursable contracts. Because target costs are more realistic, they permit better financial planning and budgetary control, and reduce the likelihood of large cost overruns.

- Incentive contracts tend to make both the buyer and the contractor more cost-conscious, which probably results in indirect cost savings.

- Incentive contracts clearly communicate the buyer's objectives to the contractor. They attract special management attention to the objectives and explicitly show their relative importance. Of course, this can be accomplished without a variable fee.

- When it is possible to associate activities of individuals with specific contracts, incentives (regardless of their amount) provide a useful tool for motivating contractor employees.

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# CONTRACTOR PERFORMANCE EVALUATION

The complex procurement tasks of aerospace have prompted the buying agencies to develop detailed systems for evaluating contractor performance. Intuitively, it would seem to be part of every purchasing agent's responsibility to keep performance records on vendors and contractors from which to base judgments on the award of new contracts. Yet an American Management Association survey found that such records were relatively rare. The AMA survey report commented:

> The pressures of defense and space-age projects, together with the increasing complexities of industry, are highlighting the need for knowledge of vendors' capabilities and performance.[1]

The survey goes on to describe several methods for contractor performance evaluation and points out that they serve a dual purpose: (1) to evaluate the potential ability of prospective vendors to meet the company's requirements; and (2) to evaluate the actual performance of the vendor after the purchase has been made. The more complex performance evaluation methods used by aerospace also have both purposes, plus an extension of the second--to recognize the need for corrective action by the buyer who may need to rescue the contractor to avoid a failure of the program.

## Evaluation of Prospective Contractors

The Department of Defense *Contractor Performance Evaluation (CPE)* program is a continuous, systematic method for collecting centralized information on prospective DOD contractors. Data on total past performance by contractors, for any of the military services, are correlated and made available to procurement officers. The Assistant Secretary for Defense (Procurement) indicates that CPE is integrated both with source selection and with contract financial incentives: "It is the intent to see that buyers utilize CPE information in determining which sources are good and which are marginal and that they reward good performances with higher profits."[3]

## Evaluation During Performance of the Contract

The Department of Defense has pioneered a formal system designed to integrate the information necessary for management decision-making on procurement contracts. This system (which NASA is helping to develop and adapting for use) is called *Selected Acquisitions Information and Management System (SAIMS)*. SAIMS, whose component systems are briefly described below, consolidates the following information elements:

- An integrated financial management reporting system.
- A specification defining essential criteria for the contractor's planning and control system.
- An integrated work breakdown structure, used jointly by DOD and the contractor to identify contractual work elements.

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SAIMS [AF Regulation 375-6] itself is subdivided into four subsystems, which will be described only briefly. (Ref. 2 contains a more complete discussion.)

- *Program Performance Measurement System (PPMS)* [DOD Instruction 7000.2] specifies that contractors' internal management control systems must provide data which (a) indicate work progress; (b) closely relate cost, schedule and technical performance; (c) are timely, accurate and possible to audit; and (d) supply DOD managers with summarized reports appropriate to various review levels.

- *Cost Information Reports (CIR)* [DOD Instruction 7041.2] provide data on actual or estimated future costs to complete programs through their entire acquisition cycles.

- *Economic Information Systems (EIS)* collect data for analysis of the economic impact of defense spending by industry and by region.

- *Contract Funds Status Report* [DOD Instruction 7800.7] provides data to defense managers to help plan funding requirements by program, by year.

In total, SAIMS is a management tool that provides early visibility to potential problems of cost, schedule, and technical performance. By doing so in a rapid and consistent manner, SAIMS promotes clearer communication between Government and the contractor, more accurate analysis of corrective actions, and a more comprehensive evaluation of program status.

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## MANAGEMENT INFORMATION SYSTEMS

Presumably every organization has some form of management information system to observe or measure the results of operations and to provide a basis for managerial control. In many organizations, the information system is quite simple: the manager requires periodic written reports from his subordinates, the branch heads or chiefs of sales or production. On a regular basis he reviews profit and loss statements and sales records. The manager tours the organization's facilities occasionally and holds staff meetings to learn of operating problems.

Some organizations, however, have developed far more detailed systems, using computer techniques, which rapidly and accurately tap sources of data that are meaningful to management decision making. The term *Integrated Management Information System* (IMIS) is used to describe a system which is highly flexible, able to accommodate many diverse kinds of data, and to serve various levels of managers having differing needs.

The modern concept of integrated management information systems grew from the World War II efforts of the U. S. Army Air Corps in developing statistical control models for logistics systems.* After the war, The RAND Corporation further developed these concepts for the U. S. Air Force. A RAND executive commented: "The task of simulating a management system is strikingly analogous to the task of building a management information system. . . . The data which are needed to make a simulated system behave realistically in essential respects are identical to the data which the manager needs to determine how his system is performing."[8] The Air Force and Department of Defense have developed some of the more advanced generalized management information systems.[1]

An *integrated* management information system first collects useful data, generally as a by-product of operations, then stores the data in such a way that they can be retrieved automatically in a form usable by

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* The origin of IMIS was described during a conversation by Dr. William H. Mitchel, then of the Department of HEW. Dr. Mitchel, a pioneer in development of management information systems for municipalities, served with the U. S. Bureau of the Budget and was assigned to the Pentagon during WW II when the Air Corps logistics systems were being developed.

other systems (i.e., integrated with related data generated from other sources). In military or aerospace logistics systems, IMIS provides integration of system effectiveness data, system cost data, and information concerning the management and adaptability of the system.[8]

Perhaps because aerospace firms are involved in and thus familiar with the management information systems of the Pentagon, and perhaps also because numerous aerospace firms themselves are involved in the development of such systems (e.g., G. E. TEMPO, TRW Systems, Lockheed, MITRE, SDC) the use of IMIS appears more common within the aerospace sector than in other sectors of the economy.[14,15] A *Fortune* article mentions IMIS applications at General Electric, Litton Industries, and North American Rockwell, and comments:

> A substantial boost in the state of the art of management control was one by-product of Project Apollo. The staggering requirements and liberal government funding led to a number of management control systems in some aerospace companies and in government organizations.[9]

The extension of the IMIS concept to other sectors has been spotty. A few industrial firms have instituted systems which quickly and accurately provide top management with key information needed for the decision process. In evaluating the success of the General Motors management system, a prominent management consultant remarked on "the development of the elaborate central office, with its responsibility for feeding into the general decision-making process all of the information necessary for corporate-wide major policy and strategic decisions."* A more recently implemented (1968) system was designed to consolidate United Air Lines operations in 116 cities into the world's biggest commercial IMIS.[13]**

In the municipal government sector, information systems progress has been slow. The U. S. Department of Housing and Urban Development commented in 1969 on the need for improvements:

> Approaches to the design and implementation of

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*Harold Wolff, "The Great GM Mystery," *Harvard Business Review, 42* (September-October 1964), p. 195.

**This integrated management information system should not be confused with the airlines' automated systems for making passenger reservations, such as American Airlines' SABRE, which are mentioned in the next section (p. 139). However, a "data bank"-type management information system can be constructed from an existing reporting/display system by deciding what management needs to know and developing a simple program to retrieve such data.

> urban information systems to date have been diffused and fragmentary, and have yielded a level of benefits well below that which was anticipated. The potential benefits are widely understood to include a superior foundation of social, environmental, and governmental information from which a broad spectrum of users could make better decisions in their respective fields of interest. For example, municipalities would be better able to identify problems, conduct planning, administer the routine affairs of government, monitor the progress of their programs, and evaluate their effectiveness.*

However, the HUD document also criticized other sectors:

> Other levels of government would similarly benefit from the availability of more consistently structured, aggregatable data for the evaluation of their program activities which operate in municipal environments. Private enterprise would be able to function more efficiently were its planning and operating decisions based upon a more complete and accurate description of its environment. However, these benefits are not likely to be realized for many years, if ever, given a continuation of past methods and low resource investment.**

In the Spring of 1970, HUD announced it had signed contracts with six municipalities to develop prototype integrated municipal information systems. The systems will be computer-based and they will be designed, documented, and programmed in COmmon Business-Oriented Language (COBOL).***

One example of a statewide information system is that of the State of Hawaii, developed with the help of General Electric TEMPO.[12] Hawaii's system calls for a single master data bank, centrally located, that provides broad-based support for operational and managerial control of the State's resources. The system is integrated so that:

- ° Data files are standardized and compatible so that data from various subsystems are readily interchangeable.

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* U. S. Department of Housing and Urban Development, "Request for Proposals No. 11-2-70 for Municipal Information Systems," July 31, 1969, p. C-10.

** *Ibid.*, pp. C-10, 11.

*** U. S. Department of Housing and Urban Development, *HUD News*, March 30, 1970.

- Data files are analyzed and structured to facilitate access for decision-making.

- Total system cost-effectiveness criteria have been developed and applied.

- Data collection, editing, and updating have been facilitated.

A management information and control system developed by NASA for use in the Apollo Program Office, called *Forecasts and Appraisals for Management Evaluation (FAME)* uses statistical techniques to develop trend forecasts from masses of data flowing from many contractor sources.[16] As a NASA report points out, FAME is a data handling and analysis system which has a wide potential for application to urban government problems: air pollution control, public transportation, health, and municipal budget control.[17]

## Barriers to IMIS

If integrated management information systems are as valuable as indicated, why have they not spread more widely? There are three major reasons: the software gap, a lack of widespread managerial understanding, and input data inaccuracy.

The gap in software ("the array of languages, programs, data, and special internal operating procedures") is clearly described by a *Fortune* writer who said in part:

> Four years ago, Burroughs Corp. and U. S. Steel announced that they were going to develop a centralized data-processing project that would perform a variety of tasks . . . This ambitious project ran into trouble and has now been curtailed. . . . according to computer industry sources the trouble was that while the hardware for so complex an endeavor could be designed, the software could not.
>
> To compound industry's problems, the engineers of software--programmers, systems analysts, and management scientists--are a scarce and highly paid breed. . . . A textile manufacturer . . . reluctantly abandoned ambitious plans to establish a management information system because the salaries required by the senior systems analysts would have exceeded the salaries of vice presidents in charge of the entire plants.[10]

The managerial problem is even more difficult to overcome. An article by Melvin Anshen in the *Harvard Business Review* states:[7]

> [Recent management thinking] has been marked by a superficial popularization of the concept of the integrated information system which calls on the storage, retrieval, and manipulative capabilities of large computers to bring the total information requirements of a business within an integrated decision network. (This does not imply a computerized decision system, but simply an organized information system, computer-based, to assist comprehensive human decision making.)
>
> While the notion of the integrated information system has been widely described and explored in technical and management journals, several probes of management practice suggest that few companies have made a sustained attempt to operate in this way, and few managers have any real grasp of what the concept means in either theoretical or operating terms. . . .
>
> It would be a gross misconception to view this gap as the familiar one between software and hardware. The primary task ahead is not to develop programs that will utilize the capabilities of the machines. Rather it is to develop management concepts that define integrated systems. . . .
>
> At present, most top managers have yet to approach even the initial stage of developing basic concepts.

In summary, IMIS is a concept of great promise, yet one requiring considerable management skill and vision. Also essential to success are the systems design and software skills which normally must be purchased at substantial cost from specialized organizations.

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# MANAGEMENT REPORTING AND DISPLAY SYSTEMS

Management information systems result ultimately in some form of reporting to managers. The report form may be a written document or one of many techniques of audiovisual display. While reporting and display techniques are not management methods in the usual sense, still they affect significantly the effectiveness of communication to managers. In turn, this affects the speed and accuracy of management decisions. For these reasons, this section discusses some aerospace-related advances in reporting and display--advances which may be of value to other sectors.

The reporting and display systems having the greatest potential management usefulness elsewhere are in one of three categories: (1) the *management control center* which uses a variety of audiovisual components to provide management meetings with significant data; (2) the *computer-driven display system* which links human intellect with electronic data computation capacity. (One form of this system, the *interactive display system*, provides a two-way man-machine interchange.); and (3) the *on-line display system* which permits instant access to stored information. A fourth type, the simulation display, is extremely useful as a training device but as such is not part of the management decision-making process. NASA has prepared a comprehensive survey of visual information display systems, including discussions of each category of system.[1]

Many of the advances in reporting and display have been stimulated by military (and later space) requirements, first for military command and control and later for management of program operations. The first applications of computer-driven displays were made about 20 years ago by Massachusetts Institute of Technology researchers, in work which led to the development (by The MITRE Corporation) of SAGE, the first military command and control display system. SAGE, an air defense system, transmits remote radar signals to a central command location for processing and display on computer-linked consoles.[2] In a highly developed form, it now is used by the North American Air Defense Command, Colorado Springs, Colorado.

As the NASA survey points out, "although it may be thought that most display technology is a spinoff from the television industry, it should be remembered that much of that industry has stemmed from military radar developments. Almost all of the hardware display developments in use today have descended from a military predecessor."[1]

## Management Control Center

Perhaps the most dramatic example of management reporting and display technique is NASA's Apollo TIE (*technical integration and evaluation*) system. TIE is a communications network which links Apollo Program managers and engineers at six locations throughout the U. S.* Each location has an identical management control center containing communications equipment, backlighted charts showing current program status, and screens for rear projection. In a daily status meeting, and on an unscheduled basis when program crises occur, the Apollo Program Director can confer simultaneously with program managers located elsewhere. Communication links allow spoken comments in any location to be heard in all other locations. Because the status charts are maintained in identical fashion, they are projected and viewed simultaneously in all locations. Furthermore, charts and sketches which are drawn in one location can be transmitted over a long distance xerography system in about two minutes, then projected on screens in the other locations. The result is a real-time system of management communication, permitting broad participation by specialists while eliminating much of the need for time-consuming personal travel.[3]

The management control center concept has several advantages for industrial managers and public administrators: it provides a focal point for management communication, where managerial attention is drawn to problem identification and resolution; it promotes *management by exception*, so that status data which deviate from a predetermined norm are spotlighted; and it permits tracing a deviating or suspicious signal through related operational status information to determine its potential effects.

The adaptation of management control centers from the Apollo Program to nonaerospace activities has been successfully demonstrated by Midwest Research Institute (MRI). As part of a NASA-sponsored technology utilization

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*The use of management reporting systems as a control technique is closely interrelated with the project management organization technique (see pp. 101-102).

program at MRI, effective application of management control centers to local government has been achieved.

A management information center modeled directly on the NASA control room at Kennedy Space Center has been installed in Kansas City International Airport. (See Figures 9 and 10.) The Kansas City center is being used to control a $200 million airport development program.

Another, similar management center has been installed in the Jackson County (Missouri) Courthouse to assist local officials to control a major capital improvements program: hospitals, juvenile facilities, parks, a sports complex, and roads. The capital worth of the improvements being developed is $102 million. (See Figures 11 and 12.)

In the Fall of 1971, MRI completed plans for still another management control center for local government, this for an Alcohol Safety Action Project within the city hall of Kansas City, Missouri. The center is to serve as the planning and control headquarters for the project, which is designed to implement countermeasures to reduce the threat caused by the problem drinker who drives. The project is sponsored by the U. S. Department of Transportation.

John E. Stacy, Jr., Midwest Research Institute's Manager of Technology Utilization pointed out the following benefits which a management information center provides to local government users:

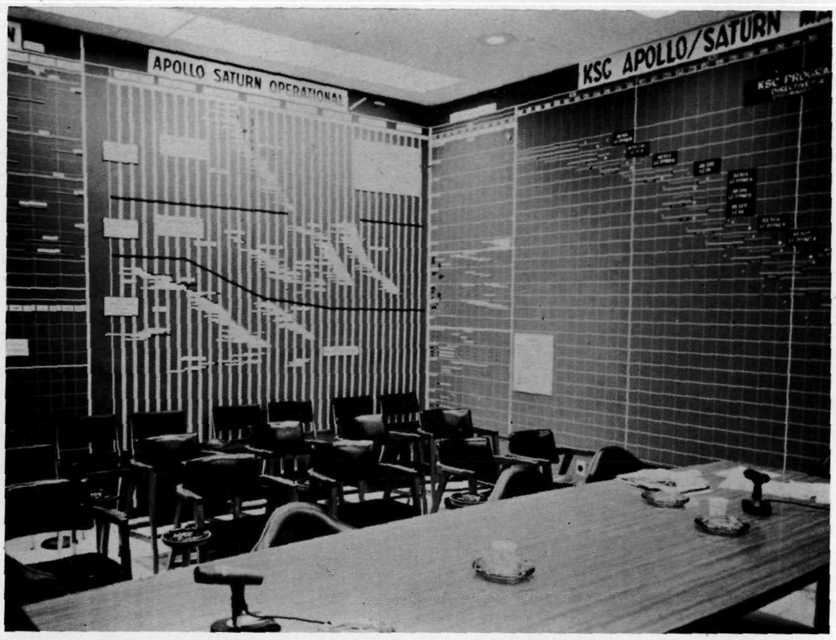
- It is the catalyst for a total project management approach which includes organization, management systems, and reporting methods.

- It is a convenient repository for easily referenced data on the project--goals, responsibility for tasks, and progress.

- It stimulates a real team management spirit with free exchange of data about plans, status and problems.

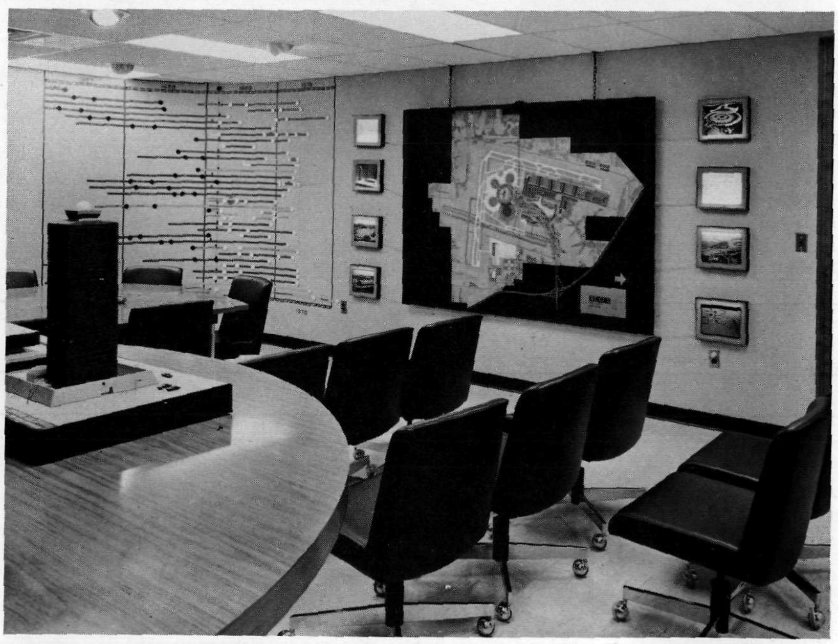
- It is a "programmed" conference room that makes periodic project review meetings both productive and well attended.

- It allows decisions to be based on consistent and current information.



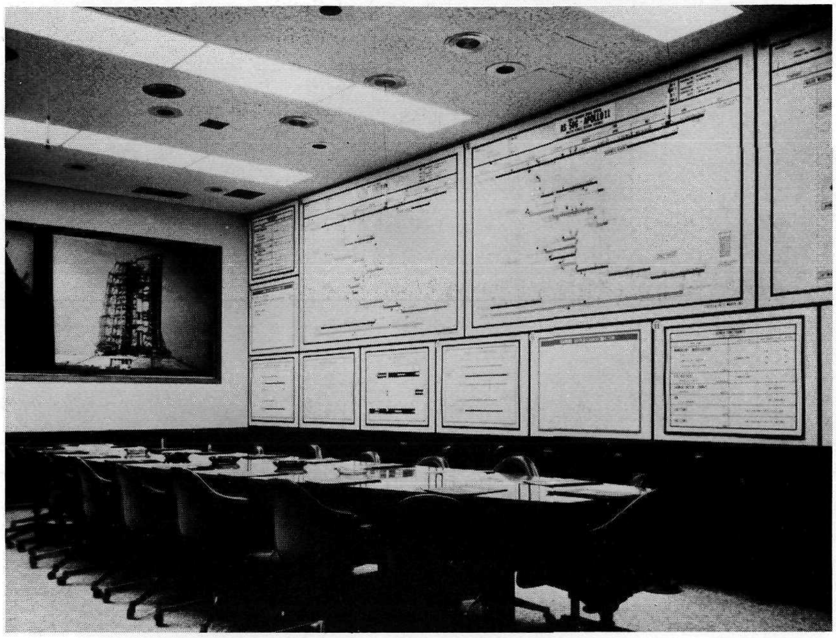

*NASA Kennedy Space Center photograph*

Fig. 9 - Apollo Spacecraft Manager's Control Room at Kennedy Space Center



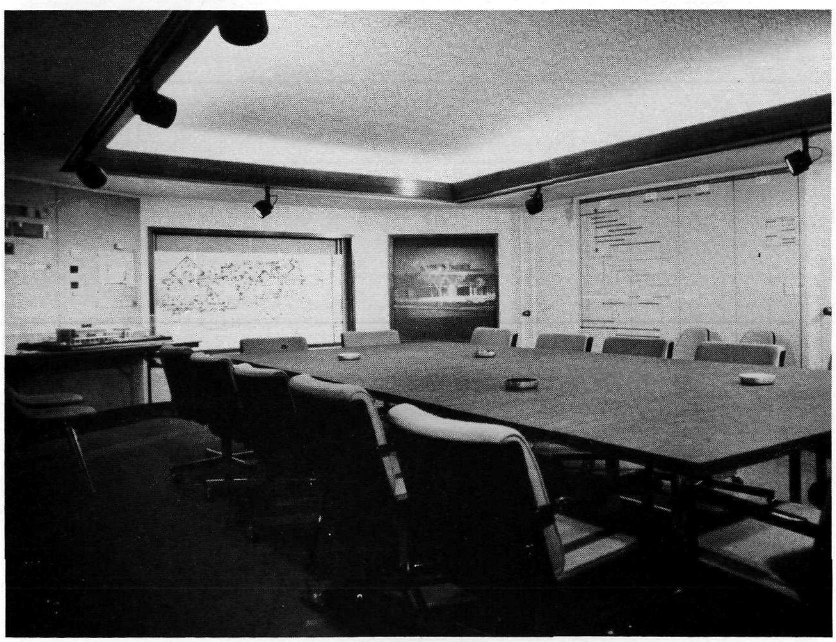
*Midwest Research Institute photograph*

Fig. 10 - Kansas City International Airport Management Information Center



*NASA Kennedy Space Center photograph*

Fig. 11 - Apollo Program Manager's Control Room at Kennedy Space Center



*Midwest Research Institute photograph*

Fig. 12 - Capital Improvements Management Center, Jackson County (Missouri) Courthouse

### Computer-Driven and Interactive Display Systems

> The modern data display field is fundamentally concerned with the assembly, transformation, and presentation of information that provides meaningful communication between man and machine. In computer-based systems, the display provides effective coupling between man and machine combining the creative and adaptive qualities of the man with the storage and high-speed computational characteristics of the machine.[2]

The power given to management planners by computer-driven display systems reaches its highest potential through interactive systems, which: "extend the capabilities of a man to perform complex and time-consuming tasks by giving him a direct view of computer outputs and allowing him, in turn, to provide inputs to the computer."[1]

One of the data display concepts of potential value to management planners is the "sketchpad" or computer-linked graphic input device now used in computer-aided design. Although computer graphics (Ref. 1, pp. 57-71) are primarily aids to design engineers, they have been explored also as an aid to planning.[5,6] Basically, the computer graphic device is a television-like screen linked to a computer. Drawings appear on the screen, corresponding to a design formula stored in mathematical form in the computer's memory. The planner or designer, using a tiny flashlight "pencil," can draw or erase lines on the screen, and thus automatically modify the design formula.

The interactive display technique also can be extended to management analysis, through display of management data in graphical form on a screen. A manager can change scales on the graph, enlarge a section of it, or otherwise manipulate the display through a keyboard or other input device.

### On-Line Display System

In a rapidly changing, dynamic enterprise, management is handicapped when it must rely on static information on operational status. When management reports are prepared remotely and sent through editing channels, the decision-making levels of management find themselves relying on obsolete information. Sometimes the task resembles steering a car while looking out the rear-window at the traffic which has passed.

Faced with an analogous problem of reservation control, the U. S. airlines have pioneered systems for on-line information storage and retrieval. These systems allow data updating to occur continually, with access from many points. Also, they permit a console operator to query the system and obtain instantaneous status data without interrupting the updating process.[1]

Applications of on-line display systems have been used by stockbrokers (permitting instant access to the latest price of any stock) and by police departments for instant review of wanted criminal files and stolen car reports. Further applications have been proposed for automatic dispatching of urban transit vehicles or police cars and for determining machine loading in factory "job shops."

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## SCHEDULING/STATUS METHODS

The art of scheduling is known to have been substantially influenced by military needs for logistics planning and troop movements. The extremely comprehensive *Scheduling Handbook*[1] related the development of scheduling methods by the Roman Legions and the development of the Gantt chart for production scheduling during World War I. The most significant scheduling advance in many years, PERT/Critical Path Method (described later), was developed concurrently about 1957 by DuPont engineers (CPM) and by a task force directed by the Navy special projects office for the Polaris program (PERT).

This subsection describes three aerospace-related methods for scheduling and status recording: the Line of Balance method developed by the Office of Naval Material; the program trend chart used by NASA; and a job-shop scheduling technique evolved at Hughes Aircraft Company.

### Line of Balance

The Line of Balance (LOB) method is a technique for graphically showing the essential components of a production process from raw materials and parts through assembly to end product completion, against a time schedule. It is a management-by-exception tool, showing only the critical facts (lagging items) which require corrective action. LOB can be used to establish the initial schedule of production operations, then to monitor progress and predict whether or not deliveries will be made on time.

LOB is a simple, non-mathematical method which can be done manually, yet is readily adaptable to a computer. The method involves the following steps:

1. A time-scaled network plan of production operations is prepared, working backward from final assembly.

2. An *objective chart*, or cumulative calendar schedule of end item deliveries, is prepared.

3. A *progress chart* showing program progress in terms of program milestones is prepared, to the vertical scale of the objective chart. A stepped line (the *line of balance*) is drawn, showing the required level of components at any point in time. The height of bars above and below the line readily illustrates ahead--and behind--schedule conditions.

## Program Trend Chart

In managing a complex R & D program containing a large number of unknowns and a substantial (multi-year) time span for accomplishment, there is a high degree of uncertainty with respect to scheduled completion and to the cost overruns involved in a program delay. Yet top management must have a realistic evaluation of the completion date, one which allows for certain slippages in the program working schedules.

One technique used by NASA is the program trend line analysis by which successive changes in completion schedule are plotted and analyzed to determine the trend of slippage, or *schedule/trend factor*, of the program.

For example, the status report of the October 1960 Mercury program predicted that the first manned orbital flight (MA-6) would occur in June 1961. However, during the previous 22 months, the predicted flight date had slipped a full year. When the sequential predictions were plotted on a time/time chart (Fig. 13) and the program trend line projected, an ultimate flight date of April 1962 was forecast. The actual Mercury program history (Fig. 14) shows that status report schedule dates continued to slip and that the MA-6 flight ultimately took place much nearer the predicted trend line than the October 1960 status report's predicted date.

Exhibit I describes the construction of program trend charts.

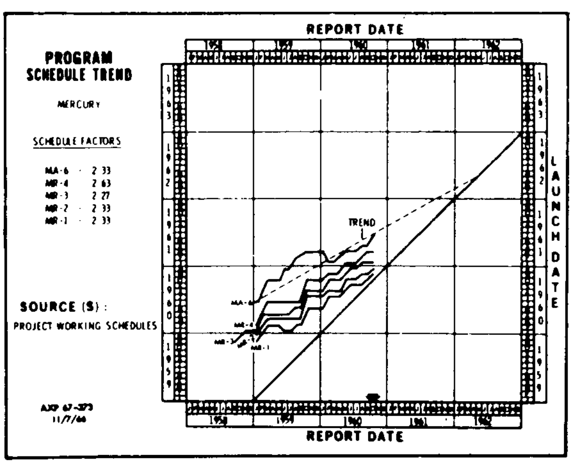


Fig. 13 - Mercury Plot (Partial)

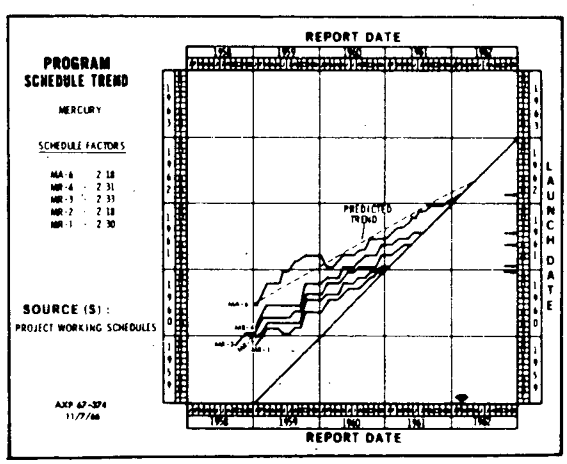


Fig. 14 - Mercury Plot (Complete)

## EXHIBIT I

### CONSTRUCTION OF PROGRAM TREND CHARTS*

By T. E. Jenkins

As used by NASA, the Program Trend Chart used for trend line analysis is simply a "time-time" plot of periodically reported scheduled completion (or launch) dates (see Figure 15). The date on which the plotted data is "as of" is indicated on the horizontal axis. The scheduled completion date for the event(s) being monitored is plotted along the vertical axis. Chronological sequence progresses to the right along the report date (horizontal) date axis and vertically for projected completion dates. Both of these factors are plotted on scales of the same dimension.

After the proper dates have been selected for the report date and schedule date axes (for optimum display and appearance of the trend line being plotted) an "Equal-Time" line is added to the chart. This is done by connecting all points on the chart that represent the same dates (or "equal time") on both axes. For example, if January 1, 1965, appears on both axes, plot that point on the chart (see point "A"). Then plot another "equal time" point "B" which represents December 31, 1968. Then connect the two points, extending the line, if necessary, to its longest possible length. This line will always have a slope of 45° since the axes are equal in scale. The "Equal-Time" line is a graphic technique which helps to visualize the progress of the trend toward completion of the event being trended.

The trend is then plotted starting with the first "firmly" reported schedule, although prior "under study" or tentative dates may be shown for historical purposes (usually depicted by a dashed line). In the sample chart, the first firm schedule (point "C") was found in a report dated August 21, 1965, and the event completion date in that report was scheduled for February 19, 1966.

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* Reprinted by permission of the American Astronautical Society from Vol. 12, *The Management of Aerospace Programs*, AAS Science and Technology Series, Tarzana, California, 1967, pp. 257-260.

SCHEDULE FACTOR

$$\left( S.F. = \frac{\text{Project Length}}{\text{Project Length minus schedule change}} \right)$$

S.F. to date = 1.59

**SOURCE (S) :**

OFFICIAL SCHEDULES,
WORKING SCHEDULES,
OR PERT DATA

NASA AXP 67-384
11/7/66

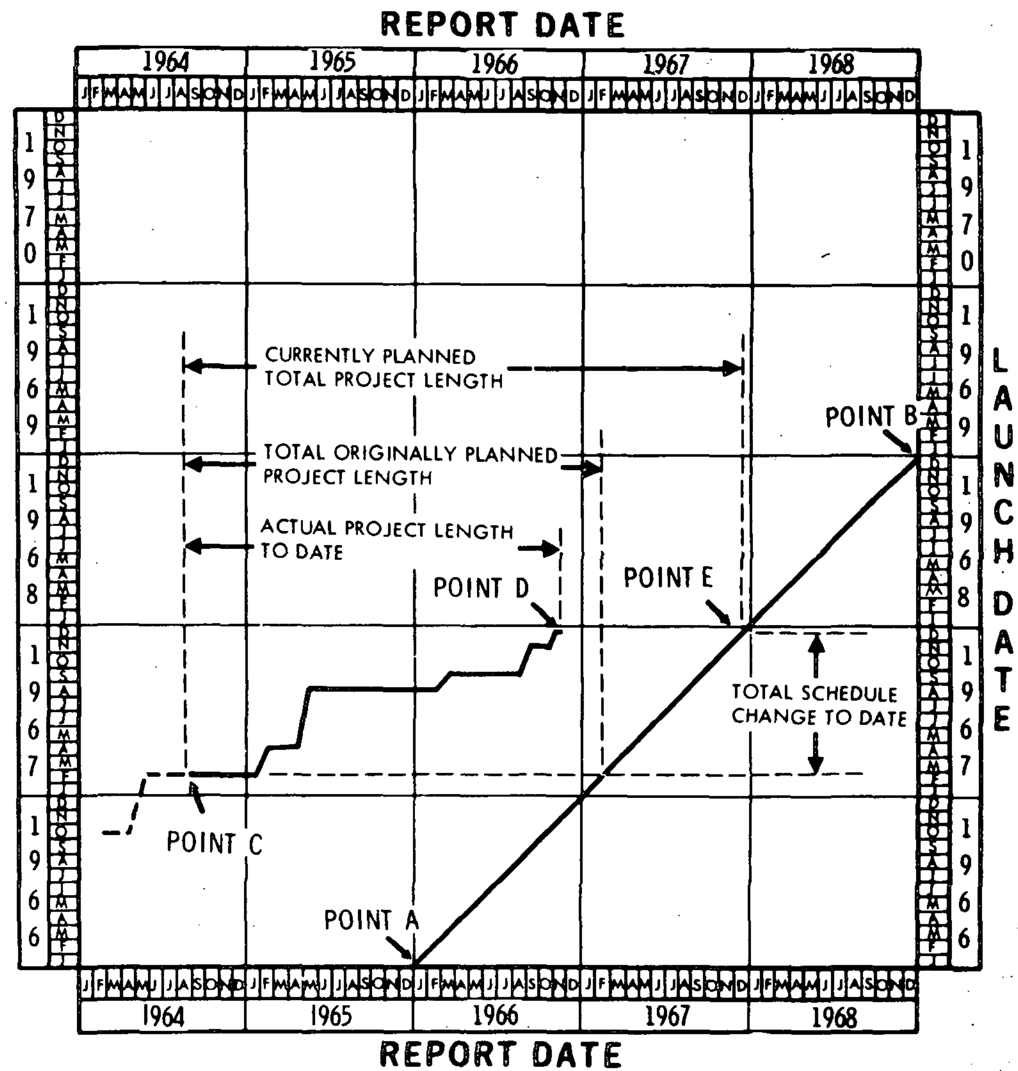


Figure 15 - Sample Program Trend Chart

## Job Shop Scheduling

A job shop scheduling system based on simulation has been developed at Hughes Aircraft Company.[7,8] Here is how such a system works: following studies of the operating pattern of the specific job shop and its past history of orders, a computer simulation is developed. Beginning with current status information on all jobs in the shop, a short-run, one-shift computer simulation is run, integrating current orders (with associated processing times and work priorities) with expected orders that will arrive during the shift. The computer analyzes this work load according to established decision rules and priority strategies. It then provides a computer printout at the start of the next shift, containing instructions for foremen on job priorities.

## Major References--Line of Balance


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Perhaps the most widely used and best known of the advances in management science in recent years is a system of scheduling known as *Program Evaluation and Review Technique (PERT)*. An important constituent of PERT is its use of networks to analyze interrelationships of activities and events and to determine the critical path (i.e., time-controlling series of activities) through a network. This constituent of PERT is shared with, and evolves from, a closely related system: *Critical Path Method (CPM)*. While PERT is the most common method used in aerospace, and the method preferred by NASA and the Department of Defense, the similarities of the two methods are much greater than the differences. This section will treat PERT/CPM as a single concept.

The advantages of PERT/CPM as a management system for program planning and control include the following:

- Planning of the program is made orderly by the use of a logic network diagram which shows both the sequence and dependence of activities and events (that is, which activities must be complete before others can start).

- The network provides a framework for establishing time estimates for the completion of each activity. The time estimates are based on multiple forecasts which consider the probability of chance occurrences, and are therefore generally believed more accurate than a single estimate of the most likely time. (In practice, the "estimated time" calculated by a statistical formula is a few percent larger than the "most likely time.")

- By tracing paths through the network, the *critical path* which controls completion of the program can be determined. This permits concentration of corrective action on the activities which lie along this path, with a consequent greater effectiveness of the resources expended.

- An extension of the time-oriented PERT ("PERT/Time") system allows cost estimates associated with each activity to be superimposed. This PERT/Cost system integrates financial and schedule data so the program manager can readily learn their interrelationships.

- While the PERT/CPM system is simple enough to be calculated manually, it is well-fitted for programming on a computer. In aerospace applications, computer programs are used to trace paths and prepare printouts of financial and schedule status.

- Actual or proposed changes anywhere in the program can be traced to determine the ultimate effects on the cost and time of program completion.

- The tasks which must be started immediately are identified and the key decision points in the program are determined.

PERT/CPM is applicable to a wide variety of activities. It is used throughout aerospace to schedule and control major development programs. The technique has been extended to multi-project and functional management by the U. S. Army Electronics Command to provide management data in varying degrees of detail and in specially-tailored format to meet the needs of headquarters policy makers as well as local field offices. PERT/CPM now is widely used in construction projects to control the interrelated activities of subcontractors and materials suppliers. The more complex the project, the more useful PERT/CPM appears to become. PERT, when used in R & D organizations, has a significant effect in improving cost and schedule performance, according to a NASA-sponsored study at M.I.T.[7]

As PERT and CPM have been adapted to many industries and areas of activity, there have grown up many variations with their own nomenclature. As early as 1964, about 50 variations of PERT were known to exist. Some of the modifications relate to the method of visual display, to make the schedule status easier for managers to understand, or to emphasize the impact of critical items. Three such modified systems are PERTREE,[9] VIS-A-PLAN,[10] and GERT (Graphical Evaluation and Review Technique).

VIS-A-PLAN, developed by a NASA contractor, is a bar-charting technique for representing and evaluating project activities on a performance-time basis. This technique may be used in development planning without need for sophisticated machine programming and computer analysis. The technique has been applied by Owens-Illinois in new product development, by an eastern aviation firm, and by several other organizations.

Despite its general applicability, PERT/CPM still is not well known or widely used in small manufacturing firms. For example, a survey of South Dakota industrial firms in 1969 found that less than 10 percent were utilizing PERT and that only 14 percent of South Dakota production managers were familiar with its techniques and objectives.*

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## CONFIGURATION MANAGEMENT

Configuration management can be thought of as the disciplined management of engineering changes. In a complex program which advances the state-of-the-art, change is both inevitable and desirable. Yet the program manager is challenged by the evident need to systematically control change so that its impact on other program elements is foreseen and that the changes are smoothly implemented and fully documented. (See Chapter X, p. 176.

As configuration management is practiced in aerospace, a rigorous system discipline is established.[2,3,4] This includes creating a configuration management organization to monitor the status of prospective and actual changes, and a change review board which approves or disapproves proposed changes. The change review board's actions include analysis of changes proposed by any part of the organization (e.g., engineering, quality control, manufacturing) or by the customer, subcontractors, or suppliers. The board categorizes changes as follows:

- *Mandatory changes*: those changes which affect mission success (e.g., flight safety), correct errors in design or mismatches in assembly, or otherwise are considered essential by the customer. These changes must be implemented immediately on items being produced, and implemented by retrofit on items already delivered.

- *Improvement changes*: those changes which increase the effectiveness or lower the cost of the product.

A further categorization separates prospective changes into Class I (which affect the product performance, interchangeability, safety, contractual requirements, etc.) and Class II (all other changes).

The change review board determines: (a) whether or not the change is to be made; (b) the effectivity (i.e., the point of introduction) of the change, depending on whether it is mandatory or an improvement, and its ease of incorporation; and (c) the impacts of a change on other elements of the product.

The following characteristics are considered necessary to a successful configuration management program:[1]

- A formal configuration management system relying on total top-management support and on clear, enforced procedures.

- An independent central organization responsible for all aspects of engineering change, including authorization and accountability.

- Well-defined configuration baselines (i.e., complete specifications documenting the design or configuration of each product end item as of a particular time) from which changes can be measured and compared.

- A quick reaction capability for processing mandatory changes.

- A single control and status system (normally maintained by computer) which accounts for all changes in process, specifies the schedule of their accomplishment, and documents precisely the actual configuration of each product.

Configuration management appears appropriate for use on major construction or development programs where changes can significantly affect cost or schedule, or cause a potentially serious impact to other parts of the program which is not recognized by the person initiating the change. It may also have application to small manufacturing firms producing new and improved products.[10] It is particularly important in a systems acquisition program characterized by concurrent development, production, and site deployment, where changes among subsystems are critical and errors expensive.

Can configuration management techniques be applied to program policies and administrative decisions, as well as to a program's physical equipment and facilities? This interesting analogy was suggested during an interview by William Davis, a former NASA executive and currently Deputy Assistant Secretary for Administration for the Department of Transportation. Davis commented that he wished the Department of Transporation had a configuration management or similar system to monitor the status and interrelationships of its programs. He noted that, because of the complex relationships of the programs and the inevitable quantity of changes in program decisions, it is not possible to trace or predict the sequential effects of that changed decision on the total system. Although the creation of a program policy configuration management system may seem visionary, it would be a tremendously powerful management tool for any large and complex organization.


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## LOGISTICS MANAGEMENT

*Logistics* sometimes conveys a different meaning to managers in commercial industry than in aerospace. The aerospace sector and the military services use logistics to mean the science of planning and carrying out:*

- Design, development, acquisition, storage, movement, distribution, maintenance, and disposition of materiel;

- Acquisition or construction, maintenance, operation and disposition of facilities;

- Acquisition or furnishing of services.

Military and aerospace programs have made substantial advances in the science of logistics. The construction and activation of remote bases (e.g., arctic radar bases for the DEW Line, and intercontinental ballistic missile sites in unpopulated areas) have presented difficult challenges in facility construction and field support. Field operation of sophisticated equipment still under development has required new techniques of modification, spare parts provisioning, maintenance, and repair. Several logistics advances having potential applicability in other fields are described in the following paragraphs.

*Logistics Planning*--Through application of systems engineering principles to logistics, an *integrated logistic system* can be designed.[1] Such a system coordinates several aspects of logistics (supply support, transportation, support and test equipment and facilities, spares and repair parts, maintenance planning, data control, etc.) so that equipment availability is maximized and support costs are optimized. Proper logistics planning requires a realistic consideration of the total life cycle for systems and system hardware, planning for contingencies, and a reassessment of logistics support concepts based on the new needs of advanced programs.[1,2]

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* Adapted from *Dictionary of United States Military Terms for Joint Usage*, Publication 1, Joint Chiefs of Staff.

*Logistics Forecasting*--The needs of the military services to maintain an adequate yet not wasteful quantity of resources for maintenance and replacement of equipment has led to considerable research in forecasting demands for logistics support. Methods have been formulated at RAND for the U. S. Air Force to forecast work volumes of repair depots serving several operational weapons systems, and thus to improve forecasts of maintenance manpower requirements at these depots.[3] Statistical research conducted by the U. S. Army Inventory Research Office and by the University of Michigan under Army contract have resulted in methods of detecting trends and forecasting shifts in demand for spare parts, based on analysis of past orders received at National Inventory Control Points.[4]

*Inventory Control*--Several inventory control and management techniques which recently have been reported by aerospace agencies appear to have applicability elsewhere. An inventory control computer program has been designed for a small electronic system development group which is suitable for on-line, multiple access operation.[5] A computerized parts list system which coordinates engineering releases, parts control, and manufacturing planning has been developed as part of an AEC/NASA program.[6] Decision rules are given for an inventory control manager on whether to retain or dispose of stock in excess of normal stock quantities.[7] An Army Logistics Center report discusses policies for stocking *insurance items*--items which rarely if ever need replacement but require a few spares because of their critical nature and long lead time for reorder.[15] Ref. 8 and the nine papers of Vol. II-4 of Ref. 2 discuss other advanced aspects of mathematical theories of inventory control.

*Maintenance and Repair Concepts*--In aerospace operations, as elsewhere, the decision as to whether to repair an item of equipment or to discard it is normally based on economic criteria. There are exceptional cases where non-economic factors govern (as when a sufficient quantity of replacement equipment is not available). However, a policy on repair vs. discard can be rationally established based on several cost/use factors: replacement cost, repair cost, support costs, disposal value, remaining life expectancy, obsolescence, and maintenance downtime. A complete decision logic network for repair/discard decisions has been developed, using repair expenditure limits based on economic rationality.[9] Other papers on maintenance and repair concepts are found in Ref. 2, Vol. II-5. (See also the sections on Reliability Analysis and Maintainability Analysis in Chapter VII, above.)

*Retrofit Concept*--The military services and their suppliers appear to have led in the development of the retrofit concept of equipment modification. That is, as design improvements to equipment are developed during an R & D program, it is generally thought desirable (and even essential in cases where mission success is threatened) that the improvements be made on all equipment items, not only those in production but also completed items which have been placed in operation. One way to do this is to return the completed equipment to the manufacturer for refitting. But this is undesirable in the case of operationally deployed aircraft and missiles whose effectiveness is lost during the refitting. Another solution is to prepare a *retrofit kit* of replacement parts and modification instructions for shipment to the operational site, permitting the modification to be completed there or in a convenient field depot with minimum loss of operational status. An aerospace contractor has described a system for retrofit accountability and configuration control designed to assure accurate records of retrofit operations.[16]

*Logistics Information Systems*--The earlier section on Management Information Systems stated (p. 127) that modern integrated management information systems grew from early statistical control models for logistics systems. Logistics information systems themselves have advanced to more sophisticated networks which integrate forecasting systems and decision-making systems which involve marketing and customer service with distribution and storage operations. Reference 13 gives a good summary of these systems.

*Logistics Evaluation*--Techniques for the evaluation of effectiveness of a logistics system are basically the same as other techniques for cost-effectiveness analysis (see p. 53). However, those interested in applying cost-effectiveness analysis to logistics operations may profit by reviewing four papers in Ref. 1 (pp. 71-79), vols. II-7 and II-8 of Ref. 2, and Ref. 17, all of which discuss evaluation of military/aerospace logistics systems.

*Logistics Simulation and Modeling*--Simulation and modeling techniques described earlier (p. 68) are widely applied to logistics systems. Vol. II-9 of Ref. 2 contains eleven papers on the application of computer simulations to logistics operations (including food service facilities, spare parts depots, wholesale distributors, etc.). Analytic models and techniques developed at RAND appear general enough to be used by medium-sized companies engaged in manufacturing and distribution.[10] The models relate broadly to the management of a firm's assets, analyzing such questions as when to buy supplies, where to stock them and where and when to repair equipment. The U. S. Navy has designed a computer program analyzer to supply the inventory manager with pertinent statistics for comparing alternative management policies (e.g., on stock levels, reorder points), replacing the risks of policies based on intuition.[18]

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## QUALITY ASSURANCE

*Quality assurance*, as the term is used in aerospace, is a far more pervasive program than typical inspection, quality control and quality assurance programs which exist to some degree in almost every production or service operation. This is particularly true in the space program because:

- The cost of failures in space missions is measured in tens and hundreds of millions of dollars.

- More important, the loss of even one astronaut in manned space flight is unacceptable.

The formal, intensive, and rigorous quality programs used so widely within aerospace may provide useful information to managers in any enterprise who wish to upgrade the quality of their services or products. For this reason, quality assurance appears among the aerospace-related management techniques and concepts.

NASA's quality assurance program is a comprehensive and permeative discipline, encompassing a combination of management, engineering, inspection and test techniques which ensure that aeronautical and space flight hardware will perform successfully as planned. Dr. Thomas O. Paine, former NASA Administrator, has stated:

> A key element in the realization of this objective is comprehensive, detailed knowledge about the hardware and its operational and performance characteristics. As a result, NASA places strong emphasis on hardware inspection and testing, including comprehensive analysis of anomalies, defects and failures and the development of corrective and preventive techniques. The knowledge gained from these activities has been documented and distributed to other government agencies and industry for use in improving the reliability and quality of other products.*

A number of principles underlie the space program's quality assurance program which pervades the organizations of NASA and its suppliers:[6]

- Encourage industry initiative in achieving quality and in developing objective evidence of quality.

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*Appendix 7 to statement before the Committee on Aeronautical and Space Sciences, U. S. Senate, April 6, 1970.

- Permit use of those existing industry procedures found suitable for space quality, either as is, or with modifications.

- Require deliberate management effort in many quality functions, including but not limited to traditional quality control and inspection.

- Permit variations in detailed effort to be tailored to the circumstances of individual procurements.

- Provide for a firm understanding of quality requirements prior to NASA purchase and definition of quality requirements in subsequent subcontracts.

- Require control from initiation of design through to operational use.

- Provide for early problem recognition and solution to avoid the cost and schedule impact of problem solutions delayed to the end-item test or launch site.

- Provide for personnel accountability and responsibility through identification of the worker with his work, training and certification.

Although these principles are intended primarily to help ensure mission success and flight crew safety, they also offer identifiable opportunities for cost control.

In the complexity of an aerospace environment, quality assurance invades the management policies of the organization as well as its technical operations. To reach top effectiveness, the quality assurance activities require coordinated central management from the program office. Problems of significance, especially those which threaten product performance, must be quickly brought to the attention of a proper level of management for corrective action, along with analysis of cost and schedule impact.[7] In General Electric's Aerospace Group, a quality assurance program was formulated using a systems approach to develop policy, procedures, and an organization structure under time and cost constraints.[8]

Both NASA and the U. S. Air Force have published numerous manuals and documents on aspects of aerospace quality assurance. NASA has prepared over 60 publications on the subject, many available through the

U. S. Government Printing Office. Three of the most generally applicable documents are listed as References 2, 3, and 4.

When adapted outside the aerospace industry, *quality assurance* has a broader meaning than *inspection* (a checking and measuring against standards) or *quality control* (a disciplinary system responding to inspection results). Quality assurance implies a comprehensive system which assures managers that products have been designed, manufactured, and deployed to meet an established level of excellence. An effective quality assurance program requires integration for planning and control purposes of information from the environment as well as the functional divisions of the organization. While *inspection* can be described as a simple process of sensing and comparison, *quality assurance* implies a more complex cyclic process ("feedback loop") in which the comparison results are used automatically to alter the production mechanism and to directly cause a desired change in the characteristics of the product.

An example of the far-reaching benefits of an active quality assurance program occurred in 1969 at Kennedy Space Center, where a flash fire occurred in a commercial resuscitator during a space flight checkout. When investigation showed that a regulator component was made of a highly inflammable material, the NASA quality assurance organization not only corrected this design hazard but also alerted the U. S. Bureau of Mines which took corrective action among all U. S. manufacturers of commercial resuscitators.

## Quality Motivation

The aerospace industry has originated and expanded some techniques of quality motivation which are now widespread in U. S. industry. In 1966, the American Society for Quality Control established a National Committee on Quality Motivation, a step which formally recognized its importance.

*Zero Defects* programs are perhaps the best known of the aerospace innovations in the area of quality motivation. Zero Defects is neither a quality assurance program nor a replacement for one, but wholly a motivational program to make employees conscious of quality and to develop in them a personal commitment to eliminate errors. Rather elaborate promotional and record-keeping methods are used in the aerospace firms with Zero Defects programs. (There are well over 1,000 such firms, for the Zero Defects programs are commonly extended to the subcontractors and suppliers involved in the aerospace programs.)

The concept of Zero Defects is claimed to have originated in the Martin Company's Orlando Division about 1961, in its work on the Pershing missile system.* Martin Orlando has perhaps the best-known Zero Defects program, with reported savings of $1,650,000 in one year alone.[15]

Other firms have coined their own names for a Zero Defects-like program (e.g., North American's PRIDE; Douglas' VIP; Raytheon's PAL; Westinghouse's EFP).

The basic elements of a Zero Defects program involve:

- Top management commitment
- Organization selection (committee and departmental representatives)
- Establishment of program goals
- Indoctrination and motivation of employees
- Quality awareness campaign ("error cause identification and removal")
- Continual program promotion
- Measurement and reporting of performance
- Recognition and reward for achievement.

Zero Defects programs are applicable to a wide range of manufacturing, service, and governmental organizations.[15,16] In fact, the Hartford Insurance group announced, in late 1970, that it was establishing a Zero Defects program.

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*See Ref. 14, p. 11 ff. As is true in several other cases of attributing origin of management concepts, some dispute exists. An executive of Bell Laboratories stated during an interview that the concept began there in 1952 during manufacture of transatlantic cable.

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# CHAPTER X

# CHARACTERISTICS OF AEROSPACE MANAGEMENT

To better understand the significance of aerospace management techniques and their usefulness outside aerospace, it is helpful to review briefly the social, political, and technological environment in which they developed. Those management and organizational arrangements that characterize aerospace today represent a response of men to awesome challenges which faced them in an earlier time. Managers faced with comparable challenges today may find the aerospace experience a useful guide.

## Historical Development

Throughout its history, the aerospace sector has been characterized by the need to respond quickly to emergency needs, to grow rapidly (and sometimes to cut back rapidly) in size, and to constantly accommodate a greater complexity of technology, equipment, and organizational relationships. It is precisely this sense of urgency in dealing with advanced technology and immensely large and complex programs that has characterized the aerospace industry and that has shaped its organization and management techniques.

It is difficult to go back in time and visualize the environment in which the aerospace industry grew. In its early beginnings in 1914, a work force of 222 men produced 49 aircraft that sold for approximately $790,000. During the next 30 years the aircraft industry grew from a fledgling to a sizable industrial force. In 1944 the industry employed 1,296,000 workers, producing 96,318 aircraft, worth about $16 billion.[1]* Most of the growth of the aerospace industry occurred during World War II. After 1945, growth occurred during other periods of national emergency as well as in response to commercial air transportation requirements and the advent of the space age. Aircraft changed in complexity and cost with the introduction of complex electronic components, turbine engines, and the continuing quest for more speed and greater size.

During the closing years of World War II the science of rocketry showed its vast potential. International political considerations, often

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*References appear at the end of the chapter.

dubbed the "cold war" and the "missile race," intensified the nation's concern with space age technology. The aerospace industry turned to this new challenge which required development of vastly more complicated electronics, guidance and control systems, launch vehicles, and telemetry. Aerospace industry marshalled many of the best technological minds to develop these new systems, spurred on by the twin incentives of national security and national prestige.

It is important to note that the development of aircraft had been primarily associated with wartime needs and only secondarily related to transportation needs. Technological innovation and production requirements therefore have been managed in an environment of intense pressure, resulting from a need for rapid program development coupled with the large scale of programs and an insistence on reliable performance of equipment. In response to international political considerations, e.g., the missile race and national prestige, space programs also faced those same requirements. Thus the industry was created and managed by techniques suited to respond to these urgent requirements and pressure conditions.

After World War II the nation expanded its national security objectives by assuming the role of a primary world power. It accepted a policy that the United States would remain militarily strong as a deterrent to potential enemies. This position required keeping up with, and staying ahead of, technological development of weapons systems created elsewhere in the world.

The national policymakers could have chosen to build a large central capability within the U. S. Government--a continuation of the traditional "arsenal concept"--to accomplish the objectives of providing for the defense, and later of achieving preeminence in space, with which it was charged. Instead, the policymakers chose to operate in a decentralized manner, by contract with existing organizations. Thus the government looked to private industry for productive capability and to the industrial scientific community for research and development support. In this way the aerospace industry was created. The situation was one of interdependence. The government, as a buyer, needed industry as much as industry needed the government.

The commitment to national objectives was strong. During this period defense budgets won almost unanimous approval in Congress, often in amounts above those requested. After the Russians orbited Sputnik I, and again after Yuri Gagarin's successful orbital flight, the nation supported plans to "catch up" in the space race. On May 25, 1961, President John F. Kennedy solidified the general feeling when he stated the " . . . goal, before the decade is out, of landing a man on the moon and returning him safely to the earth." The aerospace industry expanded to carry out this objective.

In summary, in the years after World War II, the aerospace industry was faced with problems of developing and building large, very complex, high unit cost systems that required, in some instances, several years to complete. Time pressures were intense. The programs were large-scale, requiring complex interfaces among many interdependent parts. Attention to minute detail was essential. Reliability was a key factor since failure would be painfully obvious and damaging to national policy. Managers were asked to marshal the resources of the nation and manage those resources to complete a task to which the electorate of the nation, and their leaders, were firmly committed. The challenge was primarily concerned with technology and management, for which this country is renowned. Much of the program was performed behind the scenes in offices and laboratories, with periodic glimpses at results. Of course these results had to be near-perfect because of their great impact on the nation and the world.

## A Distinctive Aerospace Management Technology?

Stimulated first by the military, and later by the National Aeronautics and Space Administration (NASA), the aerospace industry developed a characteristic method of operation and organization suited to managing the tasks to be accomplished. Management techniques were created, adopted, adapted and developed. These techniques included operations research, systems analysis, systems engineering, Program Evaluation and Review Technique (PERT), configuration control, reliability engineering, program management, project management, and many others.

Professor Robert Fetter of Yale University believes there is no set of uniquely *aerospace* management techniques. He views management techniques as being universal, arising from many industrial and academic sources. As ideas are generated and are perfected they tend to gravitate to those organizations and industries that need them.[2] A modified form of this view is expressed by Professor Leonard Sayles of Columbia University who says:[3]

> There is no unique NASA management technology. In managing their programs there is a need for terribly precise coordination, yet room for flexibility for highly qualified professionals. This coordination is extremely difficult to achieve. Project management was used by NASA, but project management is certainly not a uniquely aerospace skill.

One NASA administrator concurred during an interview, "I am concerned about some of the claims made about our great management skills. Much of our success is due to the selection of elite people." Another NASA executive commented, "We have done a great deal, but I don't know what we have done that is unique. Perhaps the organizational mix is unique."

James E. Webb, Administrator of NASA from 1961-1968, describes many aspects of the management of NASA during his tenure as Administrator in the book, *Space Age Management*. He states that NASA utilized conventional forms of organization as well as many conventional management techniques. But, says Webb, the agency developed a highly flexible organization based on proven management principles, and at the same time permitted innovation and the adaptation of a variety of appropriate management techniques.[4]

A distinction between management techniques and management skills is made by Professor George Steiner of the University of California at Los Angeles:[5]

> Skills include techniques as well as the practice of good management principles, plus knowledge of how and under what circumstances to use innovative techniques. In specific problem-solving situations, much depends on the manager's skill in knowing what the circumstances are that make the choice of a particular technique appropriate.

Regarding the possibility of a new aerospace management technology, the issue was summarized by a management consultant to NASA, who stated in an interview that, "They [NASA officials] have combined existing management practices and principles in innovative ways." It seems that the *critical* question is not what new management techniques the aerospace programs have created. Rather the question is what have NASA and the aerospace industry done that may benefit managers of other organizations facing new challenges in the private or public sectors of our nation in the years ahead?

What are the business arrangements, organizational relationships, and management practices that are characteristic of the aerospace sector? These subjects are examined under two broad headings: (1) program management and government/industry relationships; and (2) project management and contractor management practices. The details of specific aerospace management techniques are covered in Chapters VI-IX.

Program Management and Government/Industry Relationships

In the management of programs the importance of well established objectives cannot be overstressed. It also is essential that fixed objectives have the continuing support of decision makers who provide resources for their accomplishment. Also required is a "critical mass" of support through resource allocation. Webb has pointed out that just as an airplane must achieve a certain velocity to take off, or a missile must achieve a certain thrust in order to escape the earth's atmosphere, programs require a critical mass of support before they can be expected to achieve even minimally successful results.[6]

After national space objectives were established and their support was assured, there was a need to determine appropriate programs and action priorities necessary to their accomplishment. This program planning function, a traditional function of management, was carried out by government administrators aided by recommendations and analyses from the aerospace industry. Program administrators relied heavily on systems analysis techniques in relating planning and budgeting activities to requirements for accomplishing a mission.

Next, program management established the subgoals of the program, determined the activities necessary to achieve each of these subgoals, established the responsibility for their accomplishment, and scheduled the sequence of the events to take place. In a complex program, this planning process is necessarily systematic and detailed. Systems analysis is an invaluable tool in this process. Early experience in the space program revealed " . . . that a successful space program would have to be built on a foundation of well-formulated basic policy, and planning be effectively organized, be firmly supported with resources, and given high priorities."[7]

It might be said that program management is an organized method of defining problems blocking the accomplishment of an objective and then defining in detail what has to be done, and why, where and when actions should take place, and by whom. How the task should be done is then specified in great detail, and a project-oriented organization established to do it. Thus program management is an attempt to rationalize the entire complex process of accomplishing objectives.

In managing the development and purchase of defense and space systems, the Federal government defined and translated program objectives and priorities at the policy level, and then managed programs through their life cycle. Industry provided the technological and productive skills. Facilities were provided by both. Since the government was supervising the technical performance of industry, it was necessary for NASA and Defense program management offices to have sufficient technical expertise to determine whether all was going well in the program.

Two approaches were employed to provide technical expertise. The military often hired nonprofit technical organizations to supervise the technical progress of its programs. NASA, for the most part, developed in-house capabilities to handle this supervision. In some of its larger programs, NASA found it desirable to use nonprofits (e.g., Jet Propulsion Laboratory) and to hire outside technical assistance to help oversee technical progress. Steckler comments on this arrangement:[8]

> The government does not have the facilities or skilled manpower to produce aerospace items and often finds it difficult even to supervise the day-to-day operations of its prime contractors. In fact, these government agencies have often assigned the task of direction and coordination to private companies, known as management companies.
>
> Management companies perform the government's function of supervision and coordination and often suggest to the contractors, through the appropriate government agency, an alternative approach to a technical problem.

To oversimplify, the task of government was to determine what needed to be done and then go out and buy it in the market. When there were no existing suppliers of the necessary service, the government made imaginative use of the contract mechanism to induce potential sellers to develop the capability desired. Once a contractor was engaged to provide the service, the government, sometimes through management companies, would supervise the accomplishment of the task and approve the results.

For scientific and production services, the government has made extensive use of prime contractors and successive layers of subcontractors. A prime contractor would be responsible for developing, coordinating and integrating an entire weapons system or program. The prime contractor, which might retain some product development responsibility as well as the integrating role, would then subcontract with other firms to provide portions of the major system. This tier of subcontractors might further subcontract for development or production of smaller portions of the work to be done, and so on through several layers of subcontractors and suppliers. The contractual policy is standardized by Federal Procurement Regulations (FPR) and procedural requirements have been codified extensively in the Armed Services Procurement Regulations (ASPR), dating from before 1947. NASA has established similar (NASAPR) requirements. Thus the aerospace industry has a fairly uniform, if complex, set of business practices to which it can respond. These business regulations have been augmented by the evolution of specialized government organizations which oversee the complexities of contract negotiations, administration and auditing.

The importance of standardization of the government procurement structure and regulations is evident to those aerospace companies that have tried to sell their technological wares to other potential users. As the corporate director for advanced product planning of one aerospace firm says:

> Aerospace companies are credited with systems expertise, but little is said about buyer systems or organization or orientation. Within the environment established by our government customers we can discern needs, specify and give priority to those needs, and we can examine the feasibility of a system and begin pricing. But the degree of organization is very important, especially when it is absent, as in the case of selling a transportation system to a multiplicity of local governments.[9]

He also made another simplified, but important, observation--"Business is the mechanism that links technology to people." The complex relationships between government and the aerospace industry constitute business practices through which the objectives of national security and achievements in space are accomplished.

As a result of the dispersion of work among many prime contractors and subcontractors, and because of the complexity of the systems being acquired, two requirements arose that complicated, but at the same time made possible, the management of these large scale programs: (1) the development of baselines; and (2) detailed documentation requirements.

A baseline is a "snapshot" of what a system looks like at a specific stage of its development. The purpose of establishing baselines is to record and control changes in the design configuration. Baselines are established at each critical stage in the design and development of a system and form the base against which all changes in the system are made. Each of these baselines is described and controlled through a technique called configuration management (described in more detail in Chapter IX). This technique makes possible the analysis of effects of changes in any part of a system on all other parts of the system. Complex weapons or space systems that are developed cooperatively by many companies during many months of concurrent work require a technique for tracking these interrelationships to assure that the entire system will work after all necessary changes have been made.

Detailed documentation is necessary to identify what each firm has contributed during the development of a system. Moreover, since technical management of the entire program is coordinated in the program office of the buyer or through a management company, the necessary information must be provided for that function. This documentation might come from literally tens or scores of companies.

A further complication arises in the purchase of defense systems that will be operated and maintained by members of the armed forces. While the owner's manual for an automobile is fairly simple, the same document for the operation of a missile system is immense. Also necessary are manuals for the repair of the system and documents for training the servicemen who will operate it. Thus the flow of technical and logistical information often constitutes a major portion of the "product" produced by aerospace firms.

Finally, one characteristic of the relationship between government and the aerospace industry that is generally not true of the free commercial market concerns the financing of high-risk research. In NASA and the armed services, most of the required research and development are undertaken on a contract basis, in universities, federal contract research centers, or industrial firms. Some R & D work is done in government laboratories. Business firms traditionally have not supported massive research programs that do not have a high probability of economic return through the sale of a product in the marketplace. However, government programs in defense and space systems often have required research by many firms that had the research capability but not the production facilities to produce the system. Frequently, the government wishes to have several firms research an idea competitively, to maximize the likelihood of a research advance, even though it was known that only one of the firms would get the engineering and production contract. Therefore, in order to induce firms to bid on research projects, the government offered R & D contracts to companies which paid for the cost of the research, plus a profit for the use of the firm's resources. The government used this mechanism to "buy management" of research projects. Thus it became profitable for an aerospace firm to conduct necessary research even though it might not "cash in" on an engineering or production contract related to the system. The importance of this contract research arrangement is easily seen when an aerospace company considers conducting an expensive research program related to mass transporation systems that may never find a customer. The risk is prohibitive.

## Project Management and Contractor Management Practices

Large aerospace programs are subdivided into *projects* that represent major portions of the program. In government agencies a project monitor manages all aspects of the development of an assigned project. The project monitor has a counterpart in the prime contractor's firm, a project manager, who is responsible to the customer for all aspects of the project, including schedule, cost, and technical performance.

As an extension of program management, project management makes possible better planning and control of complex, interfacing activities. In project management, the statement of objectives is critical, and day-to-day management of projects tends to focus on problems that stand in the way of accomplishing objectives. Organizational arrangements and management techniques reflect this problem orientation. One aerospace company manager stated, "In the aerospace industry we have insisted upon specific, measurable statements of our objectives and goals. These are done in qualitative terms and in specified, quantifiable, measurable terms." This statement reflects one of the advantages of working on projects that are primarily hardware-oriented; problems can be identified and pursued in a systematic manner. As another aerospace executive puts it:[10]

> One of the most important things that comes from aerospace management is the identification of the most critical problems. The key element is to lay out a complete plan for everything you are going to do, then to identify the pacing elements. All of these follow a PERT-type logic to establish criticality and sequence of actions.

More will be said about sequencing and scheduling later in this chapter.

As one might expect in the management of technical programs that are pushing the limit of the state of the engineering arts, many problems arise which require intensive study. The mechanisms for "working" (seeking solutions to) these problems exist, and both government and industry managers work them vigorously. For example, an executive in the Apollo program noted:[11]

> NASA has been able to make the design review cycle really work in the Apollo program. There is an openness, a free exchange of ideas. For example, after encountering a vibration problem on Apollo 6, over 250 people, including Mr. James Webb, assembled at Marshall Space Flight Center on a Sunday in April to discuss it. There was nothing sophisticated--the problem was just worked intently.

He observed further:

> NASA has the in-house capability to supervise major programs. Everybody in the Apollo Office is an engineer or a technical scientist. It is a personnel hiring requirement. Yet they have the job of managing. None of them seems to like discussions of management philosophy--they just want to get on with the job. Many managers couldn't sit still and worry a valve problem for three days, but engineers seem to enjoy it. Engineers are trained to be technical problem solvers.

Also, since all of the managers in that office were engineers, they spoke a common language and had similar ways of approaching situations. This commonality very likely facilitated successful interaction.

This intense problem-orientation also was present at the contractor level. As one aerospace executive described it:

> There is a willingness of management to get into problems while they are still in the embryo stage. People very high in the organization will work intently on a problem until it is solved. Management controls are designed to make problems obvious early in their life, and when a problem becomes visible it is worked until a solution is found.[12]

Another aerospace executive states that:

> Our management, within major programs, is organized like the problem itself: (a) top management rides herd on end results; (b) middle management works the interfaces where subproblems join together; and (c) management of the functional disciplines works at the subproblem level--i.e., at the first line supervisory level of management.[13]

Control systems are based on planning in detail to specify results as well as technical cost and schedule considerations. When a project falls behind in the results that should be achieved by a certain time, it is reviewed at a high level in the organization and the resources that are necessary to bring it back on schedule are allocated. A detailed "catch up" plan is established. This detailed planning makes it possible to identify weaknesses in the technical abilities of the organization.

Critics of the aerospace industry have charged that, because of the great need in aerospace programs for reliable end items and systems performance, "gold plating" occurred--engineering standards were higher than they needed to be.[14] In general business practice, manufacturers sometimes put less emphasis on safety and high performance in order to minimize the cost of products such as consumer appliances. Because of the high reliability requirements for military and space items, the tendency in the aerospace industry has been to emphasize safety and high performance at considerable expense to engineering and development budgets. Failure of programs or equipment in the open glare of the international political arena is hardly tolerable.*

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*A parallel exists in public management: a failure cannot be tolerated in a bridge, a health system, etc. Public administrators may find aerospace systems reliability techniques particularly appropriate for some programs.

Internal visibility was a key factor in program management, according to Apollo managers. For example, NASA's Apollo program made use of what were called Apollo Action Centers--identical briefing rooms located at each of the Manned Space Flight centers and at the Washington, D. C., headquarters. Management briefing and project review meetings were held daily concerning the progress of the Apollo program. Each of the centers had the capability for facsimile transmission of documents within two minutes. A telephone hookup made possible on-line communication. As one observer noted, "These were no-nonsense meetings. Pressure for results was tremendous; there was management by embarassment, and responsibility was public and very visible." However, this observer also noted that corrective disciplinary action was administered in private. Another Apollo executive stated that the Action Center was not just a discussion room but rather a place for a decision meeting. "We never leave a meeting without a specific idea of exactly what we are going to do. Action is specified." He further added that the Apollo organization was effective because the leader *could* lead and give strong direction. Obviously these devices and techniques were not unique to the aerospace programs described, but the successful management of these programs was partly due to their rigorous application.

The need for reliability resulted in redundant systems both in hardware and in management organization. Failures were not acceptable in space systems. Thus technological systems often were duplicated so that if one should fail its function would be performed by a backup system. Wherever possible, electronic systems were backed up by mechanical or manual systems. The same was true in the engineering development and production of these complex systems. Aerospace companies could not afford costly failures in producing portions of a total system. Therefore they also built redundancy into their management organizations in order to back up any failures that might occur.

Redundancy was built into management organizations in several ways. In some cases, responsibility for task completion was assigned both to project and functional organizations to reduce the likelihood of failure even at the cost of disputes over jurisdiction. In other instances, jobs were assigned in such a way that, if one executive did not get his part done, those other executives whose jobs were interdependent upon his performance would have to bring the effect to the attention of their superiors. In this way, problems came to the attention of higher management much sooner than they otherwise would. The benefits of redundancy are noted by an aerospace executive who stated, "As a result of this philosophy, our management organization is about thirty percent larger than it otherwise would be, but results in the longer range are impressive." Benefits of this deliberate policy of redundancy also have been noted by administrators of public service organizations.[15]

NASA management took great pride in developing a flexible organization that could respond to problems and meet contingencies as they arose. Webb has written about the critical necessity for flexibility.[16] He observed that the situation and the job to be done required it. Other administrators who are interested in selecting and adapting aerospace management techniques to their particular situations and tasks might agree with Thomas Jenkins, Assistant Director (Management) for the Apollo program, who remarked in an interview:[17]

> NASA was set up to do *its* kind of job. There is nothing magic about a particular *kind* of organization--only that it fits the job to be done. We needed an organization that was flexible rather than static. In NASA we had authority under the President to establish the appropriate organization, and that authority was used to set up a flexible organization.

## Conclusion

Aerospace management techniques and skills were a response to the conditions and problems that faced the aerospace sector as it worked to meet the objectives of national security and space program requirements. Technological innovation, time pressures, large scale, large impact, complex systems, and large expenditures in multi-billion dollar programs characterized the environment. Traditional management practices were not adequate to accomplish the tasks to be done, and innovative ways of allocating and managing resources were required.

For those who would choose to learn from aerospace managment skills, it will be necessary to examine carefully what was done by aerospace managers, select those techniques that seem most appropriate to a specific situation, and apply them with the same skill that characterized successful managers of aerospace programs.

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## CHAPTER XI

## MAKING USE OF MANAGEMENT TECHNOLOGY

To an industrial manager or a public administrator, the important question concerning aerospace management techniques is: Can I use them to help me solve my problems? Our findings on this question are summarized here.

This chapter describes the process of transferring aerospace management technology to other sectors, and points out the necessary conditions for achieving transfer. It concludes with several suggestions on how aerospace management techniques can be adopted.

The next section contains, in concentrated form, findings from research into the process of technology transfer. This material will be of interest only to some readers of this guidebook; others may prefer to skip to the next section, "Transferring Management Technology," on page 189.

### The Technology Transfer Process

In recent years, numerous research studies have explored the process by which technology* is transferred. The process is a complex one, involving not only the generation of technical knowledge but also its effective communication to another who accepts and applies it.

A direct communication link between a disseminating source and a consuming receiver is probably the most effective way to transfer technology, because it transfers both the technical knowledge and the experience-based recommendation of the existing user. A less effective approach is to use impersonal and indirect channels to communicate information about the technology. Such information is usually diffused through a network of many different channels, many different receptions and redisseminations, and among many sources and receivers. When no direct communication link exists, even if the information

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**Technology* is considered to be technical knowledge (scientific, engineering or managerial) which makes possible the conception, development, design, production, and distribution of goods and services. Knowledge includes information embodied in people's minds or exemplified in products, as well as documented information. The term *transfer* means the effective communication of such knowledge from one person or source to a recipient who accepts it and applies it or implements it. Transfer is particularly concerned with the movement of knowledge from one stage in the developmental process to another, e.g., vertically, from phenomenon-oriented research to applied research to development; or horizontally, in movement from one sector of the economy to another. Technology transfer is, therefore, a process involving the generation, the *effective* communication and the application of technical knowledge.

about the new technology is widely and efficiently disseminated, there is no assurance that it will reach the attention of the potential user. He may have no motivation to seek or respond to the stimulus of the information. It may reach him at the wrong time (i.e., when he is preoccupied or otherwise not searching for new technology). He may not fully understand the potential of the new technology in helping him solve a problem he faces.

Thus, because direct transfer links seem relatively rare, the diffusion of new ideas normally takes place in many random steps, over a substantial span of time. One source defines five stages of the process of adopting an innovation for use: 1) awareness, 2) interest, 3) evaluation, 4) trial, and 5) adoption.[1] And at each stage, different types of technical knowledge may be required to assure that the process continues to the next stage rather than ending before adoption occurs.

Figure 16 portrays schematically the process of technology transfer, which can begin either with the generation of new technology (upper left) or with the user awareness of an unfilled need (lower left). If there is a direct communication link (top arrows) to one of the early stages of the transfer process, transfer is significantly speeded and made more likely. If transfer begins with awareness of an unfilled need which starts a problem-solving search (bottom arrow), the process moves more readily to Stage II. With this incentive, the transfer process need not depend on a random diffusion process (wavy arrows) through the many barriers which sometimes block the arrows of the transfer path and which delay or stop the application of the new technology. The factors which affect the strength of the barriers are a complex mixture of characteristics--the nature of the new technology itself, and of its potential applicability; the nature of the information which describes it; the natures (including motivation and technical sophistication) of both the generator and the potential user of the innovation; the existence of a "change agent" or "product champion" (the person who serves as catalyst in creating awareness, and later in promoting trial, of the innovation); and the existing environment in which the transfer occurs (or fails).

The arrows of Figure 16 are one representation of the complex network of channels through which the technology is diffused. Earlier research

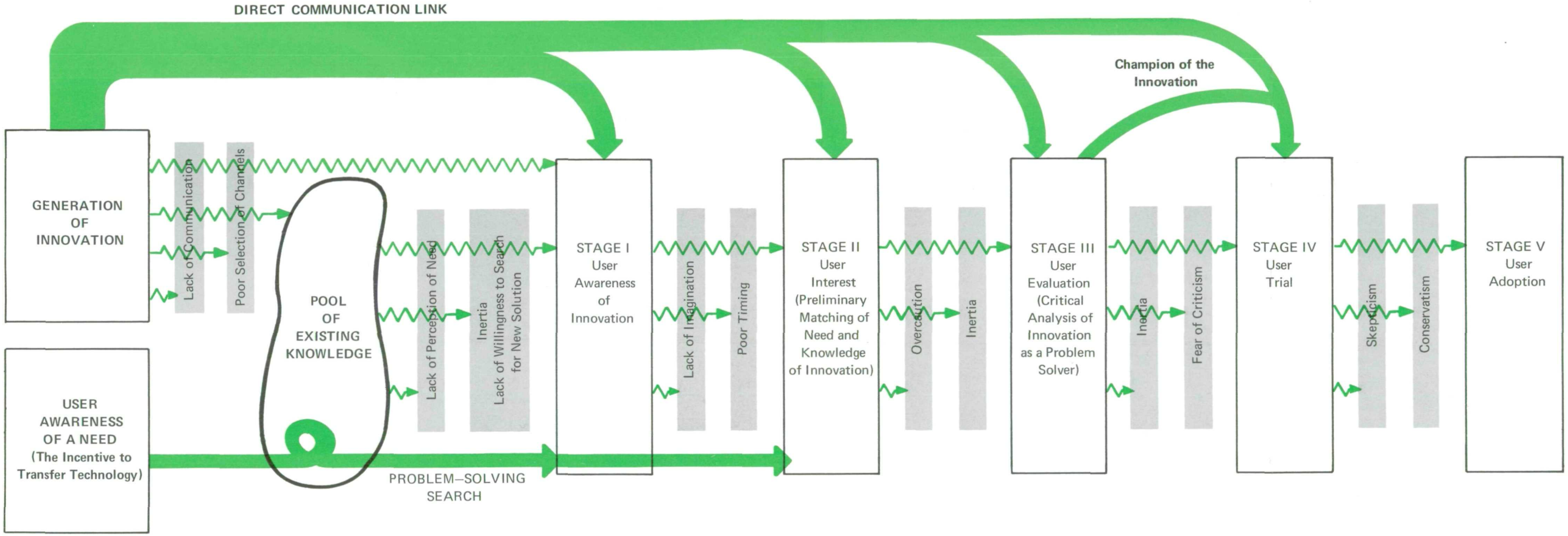


Figure 16 - The Technology Transfer Process

concerned with the process of transfer of hardware technology assessed the relative importance of various classes of channels (both personal and written) of technology acquisition, including commercial channels, professional channels, educational channels, and government R & D information sources.[2] It was found that with hardware technology at least, channel choice varies with the needs of the acquirer. Different channels are used, depending on whether the acquirer is trying to solve a specific problem (the lower arrow of Figure 16) or merely is maintaining current awareness of his field (either a straight or wavy arrow from the generator to Stage I). Channel use also varies with: the role of the acquirer in his organization; the nature of the organization; the acquirer's past experience; and, possibly, his individual personality.

Transferring Management Technology

The transfer of management technology, as compared to engineering or scientific technology, appears to rely more heavily on the face-to-face contact of managers and staff personnel coming from different sectors of the economy. Part of the reason may be that management differs from other technology in the degree of personal involvement of the person performing it. A chemist who tries an experiment which fails considers himself a scientist who has expanded chemical knowledge. A manager who tries a new management technique which fails considers himself a failure. His colleagues frequently agree.

Certain successful innovations in technology transfer which have been made by NASA's Technology Utilization Office (TUO) reflect an awareness of the need for personal interaction. For example, the Biomedical Applications Team concept uses a multidisciplinary team actively searching NASA scientific and engineering expertise for solutions to important biomedical problems. One secret of the teams' success evidently is their close personal interaction with the medical practitioners; the teams do not merely provide a detached literature searching activity. Another example is the informal working relationship encouraged between the industrial client and the professional staff of a NASA-sponsored regional dissemination center. At ARAC, the center operated by Indiana University, an industrial client's technical staff is urged to form a close working relationship with an ARAC staff member, to advise him of specific technical problems or to identify a custom interest profile, and to evaluate the results of his problem solving search. All of these actions guide the ARAC staffer to become more effective in transferring aerospace technology to the client's needs. The evidence seems clear that the more intimately managers work together on a problem solution, the more effective the management transfer seems to be. Perhaps because of the impersonal nature of their communication, publications appear to be of limited value in promoting management technology transfer (a matter of some concern to the authors of this document). Yet certain types of publications evidently have far more influence than others. Particularly valuable are those designed to explain the practical effectiveness of management techniques, based on actual managerial experience.

## Conditions for the Transfer of Management Technology

Can the aerospace management concepts and techniques be transferred and used in industry, or in government outside aerospace activities? Yes, *if* the conditions are favorable for adopting the new management methods and making them work.

The ideal situation for the transfer and application of aerospace management technology would closely parallel the conditions which lead to its generation. That is, the problems that pushed aerospace firms and agencies into these methods may also exist elsewhere. If they do, the problems may also create opportunities for management innovation. In aerospace, for instance:

*Example*: Major programs did not fit within existing organizational or jurisdictional boundaries. Project or task force organization was substituted for the traditional functional or product-line structures.

*Example*: Project-type organization fostered a more mobile work force, so the firm could accommodate to the completion of a project. This mobility generated constant transfusions of different expertise and viewpoints from one firm or organization to another. It was made possible by a reward system which encouraged mobility, and it depended on a practice of hiring people directly for responsible jobs rather than exclusively emphasizing promotion from within.

*Example*: Evaluation of goods and services for which there is no conventional market (and thus no feedback on the relative value or usefulness of such services), e.g., national defense services, was very difficult. Yet without such output measurement, sound choices among different demands for funds and human resources were almost impossible to make. Cost-effectiveness analysis and related means of comparing alternatives were developed as a necessary part of systems analysis--an approach to designing total governmental responses (hardware, manpower, and all) to threats or problems.

*Example*: Similarly, systems management was developed to control and coordinate many simultaneous research, production, training, and test operations--all bent toward rapid solution of a problem. These tasks required effective techniques for identifying suppliers of essential goods and services, choosing which ones would be the best suppliers, and then monitoring their production. All of this demanded effective contract and procurement management. The entire package adds up to systems management.

Two points relating development and adoption of these and other managerial approaches in nonaerospace fields should be noted:

1) These management concepts and techniques were applied to aerospace problems which may not have counterparts in industry, or in nonaerospace government.

2) These management concepts and techniques were not always adopted automatically or easily in aerospace. They were put to use because of urgent needs to deal with serious problems, and because managerial (and political) leadership was available to implement them in the face of organizational inertia and other obstacles. Furthermore, the urgent needs often justified giving a great deal of authority to the system managers.

Since the aerospace environment is not often duplicated in other sectors, some modification of the methods may be required. If certain conditions for transfer are critically important, efforts should be directed toward bringing these conditions into being. If that can't be done, it may be desirable to prepare for a specific managerial innovation, and then wait until it is timely, until conditions favor its adoption. This is often a matter of managerial or political intuition.

In any case, the crucial conditions for adoption of many aerospace management methods may be combined and simplified down to five: *Motivation, Match, Men, Money,* and *Monitoring*.

*Motivation* to innovate, to adopt a new management concept or technique, may result from a crisis or a threat (competitive or internal). It may result from a change in leadership, with an accompanying injection of new energy or ambition. Or it may come from a newly perceived opportunity to accomplish personal or organizational ambitions--political advantage or public service, profit or cost saving, personal advancement or recognition.

*Example*: The aerospace and defense community has put increasing emphasis on technological forecasting in the last fifteen years. This was motivated by their need to estimate what threats "the other side" might face us with X years in the future, what might be expected of our technologies to counter those threats, and which technologies might be lagging these goals and therefore needing more research support.

More recently, manufacturing firms (like TRW) began adopting technological forecasting methods. They are motivated by the desire to anticipate their future operating and marketing environments, to identify product opportunities, and--as in aerospace--to plan research programs for best exploitation of future opportunities.

*Match* is required between need or opportunity and an applicable aerospace management concept or technique. Ideally, the match is a close one and the method can be directly applied. Otherwise, the management approach must be adapted to the need. This report is one possible means for identifying a *Match*. Other means include consultants, experience of colleagues, or demands from outside an organization.

*Men* who can apply and carry out the new management tools also are crucial. Many of the concepts and techniques described in Chapters VI-IX depend on mathematical competence and some on computer capabilities. Others require skills in particular disciplines such as economics or management sciences. Several depend on creative imagination. If the necessary talents are not already present, the organization must be able to recognize this and be willing to acquire them. If in-service training or new hiring cannot furnish what is needed, consultants may be appropriate. Combinations of all of these may be most helpful--people-oriented or face-to-face transfer of management technology is commonly considered the most effective means.

*Examples*: The Office of the Secretary of Defense sought to develop a strong, in-house, systems analysis team, in the face of personnel policies resistant to any idea of recruiting an elite group. Defense officials succeeded by bending civil service grades as far upward as possible, by building up salaries with authorized overtime pay, and by furnishing substantial psychic income to the analysts by giving them exciting work close to the seat of power, the place where decisions and policies were being made.

New York City decided to develop a program and policy analysis capability. It did so by contracting with the RAND Corporation for analytical services, and then developing a close working relationship between the RAND analysts and the City people, institutionalized through a new joint organization, The New York City-RAND Institute. Here again, the analysis group was close to power.

*Money* to implement the new management technology is usually necessary. New managerial approaches often offer long-run savings, but they usually involve start-up costs in equipment, new personnel training, and data gathering. The disruption of the status quo sometimes damages morale, quality of service, or public confidence; all of these possibilities should be guarded against.

*Monitoring* of performance is essential to assure that the new management technique is being successfully implemented. Few managers would hire a new employee without checking back on his performance during his first weeks on the job. Prudent managers also evaluate new equipment installations to determine if they mesh smoothly with existing operations, and if their promised savings have been realized. Certainly there is at least as great a need to monitor a new management technique, implanted in a strange environment, to assure that it doesn't fail.

If all five *M*'s are present, the conditions for adoption of new management technology appear auspicious. Successful implementation is the next concern.

The practical details of insuring success vary with both the new management method and the environment into which it is being introduced. Some examples of such practical details can be drawn from the experience of those applying one of the techniques--systems analysis--to the state and local services sector, as described in Chapter IV. In these examples based on successful applications, the analysts, with their relatively expensive talents, invariably came from outside the existing organization as new employees or as consultants.*

The innovators--the analysts--must have support from the head of the entire organization. As one said in an interview, "It must be known that the analysts are close to power." At the same time, the analysts must understand the uses and limits of authority if they are to relate their analysis to what can be achieved. They must be willing to introduce political feasibility and political timing into their analyses.

Protective support from the top of the organization is not adequate for long, however. The analysis group must quickly develop its own prestige if people in the organization are to take it seriously. This may be done by successfully handling specific practical "nuts and bolts" problems, but this can also be dangerous if it is done without the overview of wide-ranging analysis which puts the various nuts and bolts jobs in perspective. The best approach to prestige may have been voiced by a successful analyst, saying, "You need an early success, blowing the conventional wisdom clear out of the water in a sound and understandable analysis." Imagination and creativity are vital in developing alternatives and in measuring outputs of services.

Participation between the analysts and the users of their work is important. Others, the non-analysts who know the problems and the bureaucratic system, must be involved in analysis. A close relationship lets the analysts bring the operators' and users' understanding along as work progresses. Obviously, this relationship depends substantially on

* These specifics are drawn from the experiences of several analysts, operating as consultants or as in-house staff to cities, state agencies, and universities.

the analysts' personalities--an important part of their competence. Jargon, elitism and snobbery, over-rigorous and time-consuming analyses, are all obstacles to a good relationship.

The antithesis of participation is retreat into the ivory tower, possibly the greatest source of failure. Instead, the analysts must be willing and able to help define and clarify objectives at the beginning and to consult on implementation at the end.

Finally, the analyst working with government must deal with split goals. The elected official seeks short-term successes; he has only two or four years in which to justify his decisions. Administrative personnel, on the other hand, are relatively permanent in their tenure. Both are users of the analyst's work, and he must serve both.

## Other Suggestions for Improving Transferability of Management Technology

1. *Don't be intimidated by strangeness*. It is very easy for administrators and managers to be confused and frightened off by the strangeness of the terms used in some aerospace management techniques. The trade jargon of aerospace and the cultivated mystique of technical programs add to the exotic flavor surrounding some of the management techniques described.

Look beyond this strangeness. Look at the basic *function* which the management technique accomplishes and look for analogies in your own management problems.

2. *Analyze your needs and seek ways to manage better*. During an April 1970 interview, James Webb, former NASA Administrator, explained one reason for NASA's success in management of the space program--a conscious, continual effort to innovate and adapt new management ideas. Webb said:

> We had to be outstanding in every scientific and engineering discipline to succeed. I decided on a conscious attempt to make whatever NASA did a show window of the best in our society. The need for innovative management was implicit in this decision.

Webb went on to describe the process by which he and his top associates, Robert Seamans and Hugh Dryden, sought out outstanding competence in many management areas. "We knew the space industry extremely well and knew who the outstanding people were. This was a key feature in our success. The transfer of people is the most important way of transferring management technology." Mr. Webb observed that, on any new program, it first appears that the operational requirements are all that must be met. However, the really important problems are those caused by the external, non-operational requirements which the environment places on the organization. "Good internal management makes it much easier to respond to these non-operational problems," he added.

An analysis of needs, present and potential, usually will stimulate a search for new management tools. The search, even if a difficult one, still may be easier than overcoming the inertial barrier to the analysis. Most organizations have some inertia which blocks self-analysis. The inertia may relate to departmental insularity (a criticism sometimes directed at the Federal government) or to a "not invented here" barrier against adoption of others' ideas.

3. *Don't expect easy success.* The common experience of innovators who have adopted new management techniques is a degree of disenchantment, judging by study interviews. Based on the experience of those who have tried, it is wrong to expect too much at first from a management innovation. It is equally unwise to expect a technique to be usable without adaptation to the different environment of the innovator's organization. The more peculiar the technique is to the unique aerospace environment, the more effort is required to adapt it.

Organizations should be wary of adopting a management technique that requires more resources than they have and are willing to commit during the period of technique adaptation. The same caution should be used as when contracting for a new digital computer. A common problem with some management techniques (e.g., management information systems), as with computers, is that original estimates of cost often are too low. The adopter is warned that most systems seem to cost more than first expected. The management consultant is warned against a human tendency to oversell. Often the advantage of a new management technique lies in permitting new, or more extensive, or higher quality, performance rather than in the area of cutting costs.

Public administrators may improve their chances of successful transfer of aerospace management techniques by using such technology in areas which are related to equipment or facilities (e.g., fire protection, transportation) rather than in areas related to social programs or services. It is clearly easier to construct a computer model of the tides in Jamaica Bay than a model of public response to programs that reduce bay pollution.

4. *Promote change and change mechanisms.* An organization should analyze its own ways of bringing about change, and should promote ways to stimulate the change-making process.

One way to promote change is to revise management policies (usually unwritten policies) which reward the standpatter and which penalize the risk-taker when he fails. Innovation should be rewarded, as should reasonable risk-taking.

Other ways to promote management change include more use of consultants and contracted research studies, planned managerial rotation, hiring persons with different training from the present managers, and developing programs of management training in new techniques.

Public administrators can use consultants (such as RAND) to accomplish change constructively and avoid some of the intensive public scrutiny which could occur if the work were done in the city planning office. To promote useful urban change there may be a need for efforts to develop a community or regional commitment to long-range goals (e.g., public relations efforts to promote a commitment to realistic air pollution control in the Northeast corridor of the nation).

University professors should not need to be reminded of their heavy responsibilities as change agents to: generate interest in innovation; further refine management techniques and translate theory into practical form for application; and continue to turn out students who actively seek better methods.

The most difficult type of managerial innovation is the introduction of a major new concept into an existing organization, particularly a concept such as systems analysis which constantly questions and threatens the organizational status quo. The exact role of systems analysis is still being fought out in the Defense Department, nearly ten years after its extensive adoption. But under one name or another, it is there for some time to come. Other concepts, and changes at the technique level, are usually less abrasive.

Nonetheless, change and innovation are inevitably disturbing to some, and the chances for successful innovation are increased if the conditions are favorable. "Favorable," in this case, means that *Motivation, Match, Men, Money,* and *Monitoring* are all present; with them, with attention to details of implementation, and with some luck, aerospace management methods can be selectively transferred into the other sectors.

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## APPENDIX A

## PERSONS CONTACTED DURING STUDY

FEDERAL GOVERNMENT CONTACTS
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### National Aeronautics and Space Administration

#### Administrator's Office

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#### Apollo Program Office

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#### Office of Organization and Management

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#### Office of Reliability and Quality Assurance

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## PERSONS CONTACTED DURING STUDY

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## PERSONS CONTACTED DURING STUDY

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## PERSONS CONTACTED DURING STUDY

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### U. S. Department of State

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### U. S. Department of Transportation

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### U. S. Treasury Department

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### U. S. General Services Administration

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### U. S. Office of Economic Opportunity

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## PERSONS CONTACTED DURING STUDY

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## PERSONS CONTACTED DURING STUDY

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## PERSONS CONTACTED DURING STUDY

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## PERSONS CONTACTED DURING STUDY

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## PERSONS CONTACTED DURING STUDY

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## PERSONS CONTACTED DURING STUDY

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## PERSONS CONTACTED DURING STUDY

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