The Space Congress® Proceedings

1969 (6th) Vol. 1 Space, Technology, and Society

Apr 1st, 8:00 AM

Management Contributions of Space Technology; An Analytical Report

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MANAGEMENT CONTRIBUTIONS OF SPACE TECHNOLOGY; AN ANALYTICAL REPORT

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Summary

The Denver Research Institute (DRI) currently is engaged in a major research-on-research effort to improve understanding of the technology transfer process, transfer barriers, and methodology successful in promoting transfer. The research is sponsored by NASA. All aspects of technology are under study, including the broadly applicable area of management. The paper describes and analyzes several recent cases of transfer of space-related management technology found during this research program, as well as certain cases from the literature.

The transferred management techniques are widely diverse in subject matter. To aid analysis and understanding, they have been subdivided into four subject categories: conceptual contributions; planning contributions; administrative methods; and evaluation methods. The paper evaluates the progress made to date in transferring aerospace management techniques, and discusses the prospects for future transfer.

Introduction

Within recent years, the field of management has made rapid and significant progress in advancing from an art, based on instinct, to a recognized science, based on testable and proven principles. During this advance, management theory has relied heavily on the innovative experiences of large-scale aerospace enterprises, responding to the challenges of the space program.

In this context, the term "aerospace" is broadly defined. It is used to describe the large, interrelated system of public agencies, private firms, and other organizations involved together in aerospace activities. The system includes aeronautics (military and commercial), advanced weaponry and space systems, and the many phases of these activities, such as research and development, production, operation, and regulation.

This paper does not, of course, purport to be a complete treatment of aerospace contributions to management technology, but rather an early-stage report of exploration of the subject.*

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* Recently, a substantially more thorough study has begun, under NASA sponsorship, seeking to determine the extent to which aerospace management innovations may be useful to other sectors of economic and governmental activity. The Denver Research Institute and the author would, therefore, appreciate comments and communications from readers concerning experiences in transfer of aerospace management technology.

As was the case with an earlier paper discussing this subject,[1] a caution for the reader is appropriate. Several of the examples of management technology transfer discussed in this paper still must be classified as suspected transfers. There is evidence of an aerospace use which preceded the use of the technology in other sectors but the connection has not yet been traced to prove causality.

The Technology Transfer Process

Although no accepted, standardized definition of "technology transfer" exists, we find it useful to use the following:

"Technology is here considered to be technical information, including scientific knowledge, making possible the conception, development, design, production, and distribution of goods and services. The term transfer means . . . the effective communication of such information from one person or source to a recipient who accepts it for consideration and possible application. Transfer is particularly concerned with the movement of information from one stage in the developmental process to another, e.g., vertically, from phenomena-oriented research to applied research to development; or horizontally, in movement from one sector of the economy to another."[2]

Technology transfer is inseparable from the functions of universities and of industrial research laboratories. Much of the $25 billion spent in 1968 for research and development probably was for application and verification of knowledge gained elsewhere. Possibly a substantial amount of this expenditure could have been avoided, or better used, if the technology transfer process were better understood and more effectively utilized.

The massive generation of new technological concepts in government-related programs is due largely to the heavy concentration of R & D spending required by the complexity of these programs. Some 60 percent of U. S. personnel who are trained in research, development, and engineering are now engaged in aspects of large-scale government-related (e.g., aerospace) activities. Because of this heavy concentration of scarce talent, it is more and more essential to effectively transfer technological knowledge from the governmental sector where much of it is generated, and to supply it to the industrial and commercial sectors which can apply it to products, services, and processes.

Unfortunately, commercial industry (except for some sophisticated segments related to aerospace programs) does not make adequate use of the results of government-sponsored R & D. In earlier research concerning the process of transfer of hardware technology,[2] DRI 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. 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 or merely is maintaining current awareness of his field. 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.

Relatively little research yet has been done in establishing the relative value of the classes of channels in transferring management contributions. Because of the evident limited success of aerospace firms in marketing their systems capabilities in other sectors,[3] it can be hypothesized that the commercial channels, which are significant in moving hardware technology, are less useful in transferring management methods.

As will be shown by examples later in the paper, both horizontal and vertical modes of technology transfer have been observed in the transfer of management techniques. Certain operations research techniques, specifically linear programming, involved vertical transfer from basic inquiry to specific application. Most examples of management technology transfer, however, involve horizontal transfer--the direct application of a technique from the defense-aerospace sector to the private, commercial industry sector. Occasionally, an instance can be identified where sector-to-sector "people movement" has been a successful transfer mechanism.

Much work still is needed in the analysis of the technology transfer process itself. A current major activity in the field is the NASA-sponsored Project for the Analysis of Technology Transfer (PATT), which recently has reported its first year's findings.[4] This research effort, begun in November 1967, is intended to provide a better understanding of the technology transfer process, transfer barriers, and methodology successful in promoting transfer. Its principal application is expected to be the enhancement of effectiveness of NASA's Technology Utilization Program, although the findings will have a substantially broader potential utility.

Aerospace Management Innovation

Employees and executives at all levels in aerospace-related organizations are known to express their frustrations periodically by deriding the management failures (real or imaginary) of the aerospace industry. Even though aerospace technological advances--the space exploration programs, advanced weapons systems, reliable air transportation systems--have been acclaimed widely, they are recognized primarily as physical science and engineering achievements. A mental set, sometimes shared even by aerospace managers, causes these achievements to be viewed mistakenly as occurring despite mediocre management, rather than as management achievements themselves.

Perhaps partially for this reason, there is inadequate popular and professional recognition of the impact which aerospace has made during the past 20 years in the theory and practice of management. To a significant degree, modern management thought appears to have been molded by aerospace experience in evolving and innovating advanced methods of conceiving, planning, administering and evaluating large-scale enterprises.

Professor James Bright has described the technological change resulting from the 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."[5]

Examples of specific management innovations inspired by aerospace-related programs 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 a powerful tool of management decision technique, the Simplex method for solving multi-dimensional linear programming problems, which was developed by a university scientist (George B. Dantzig) working on an aerospace planning problem. 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.

These substantial contributions to management thought raise questions as to the reason for the predominance of the aerospace sector, rather than other complex fields of endeavor, in stimulating management innovation. A clue appears to lie in the pressures to save time which have characterized aerospace programs in recent years--pressures which have led to much monetary waste (and thus indirectly to allegations of aerospace management deficiencies). The intense concentration on speed can be seen in the otherwise illogical concept of concurrent design, development and production which typifies aerospace but few other sectors.

The stimulus to management innovation in aerospace is believed to be its continual and critical time pressure. The constant urgency of the program has led to an intensive cultivation of one economic factor--time--with less emphasis given to such other factors as cost or conservation of resources (personnel or facilities). Aerospace management technology is in fact built around a framework of economizing decisions designed to minimize time expenditure. It is this concentration on economizing decisions that promotes the rapid advancement of the state of knowledge in the field of management technology. One theorist points out that the potential state of knowledge in technological fields "and therefore the inventive potentials of those fields, are economic variables, for the rate at which each such field is cultivated is primarily determined by the promise it holds of yielding useful knowledge. The selection of the means for achieving an economic end is itself an economic process. Hence, the present state of [a technological] field is largely the end product of a history of economizing decisions made in the process of achieving economic ends."[6]

In contrast with aerospace activity, some other highly complex fields of human endeavor (e.g., urban transportation, diplomacy) seem stagnant in methodological innovation. In these, the pressures for economizing decisions appear to have been insufficient to cause intensive cultivation of productive factors and the use of scientific principles for experiments in innovation.

Illustrations of Transferable Aerospace Management Technology

There is a wide diversity, in subject matter and in relative importance, among aerospace contributions to management thought. Several examples of actual or potential transfers of aerospace management technology to other fields are given next. They have been chosen to illustrate the diversity of subject. The examples have been subdivided into four subject categories which lend themselves to summary discussion: conceptual contributions; planning contributions; administrative methods; and evaluation methods. In some cases, an estimate of the degree of promise of future transfer is included.

Conceptual Contributions

The aerospace management conceptual contributions are considered to include:

- technological forecasting
- environmental forecasting
- Delphi technique of analytical prediction
- mission analysis
- systems analysis
- reliability analysis
- maintainability analysis

Technological forecasting, the forecasting of technological change through invention and its diffusion, was developed largely within the military services, aerospace firms (Lockheed, G.E., TRW, and RAND), and the National Research Council. A recent compilation of technological forecasting applications by Bright[7] shows that such forecasting is being transferred to other sectors of activity to a significant degree, "to help set product line performance goals, establish research goals and budgets, . . . to aid in long-range corporate planning, and for communications between technologists and managers" [p. 343]. Transfer examples in Bright's volume included the use of technological forecasting to plan R & D efforts for the Air Force and Navy (an application readily transferable to other R & D efforts); its use in product planning, both for next-stage and highly advanced products; its use to forecast market and economic trends in the Canadian pulp and paper industry; and its use in strategic planning for the U. S. bituminous coal industry. Evidently, technological forecasting as a transferable management method has unusually wide applicability and strong promise of benefit.

The Delphi technique of analytical prediction, developed by Helmer and Dalkey of RAND, is not widely known outside the U. S. Air Force and closely-related aerospace organizations. Briefly summarized, the Delphi technique uses the informed intuitive judgment of a panel of expert persons by asking their forecasts of future events. In a series of feedback cycles, each expert is advised of the range of panel responses and must either modify his forecast or justify its deviation from the consensus. The Delphi method still is largely used in the U. S. Air Force and by aerospace organizations (e.g., TRW) for direct mission applications. However, it has been undergoing tests by these organizations for applicability to social areas as well. The technique shows promise in its potential application to business and economic forecasts and to cost-benefit analysis.[8]

The aerospace approach to systems analysis which was tested successfully in major national space and weapons programs, also has been introduced to management of civil government enterprises, including the frequently-cited California studies of 1965. Lockheed has extended the systems approach to develop an overall medical services system for the Mayo Clinic, and to conduct systems analysis for local and state agencies in Alaska, Massachusetts, Texas, and California. Many other aerospace firms are similarly probing these areas; a 1967 report lists 80 recent civil systems projects undertaken by aerospace-related firms.[2]

Certain concepts developed (if not originated) within the aerospace systems analysis process have potential application to planning and control techniques in other fields even if the entire aerospace process is not transferred. Examples are the program package concept, relating plans and budgets to mission objectives; the concept of concurrency, applicable to any time-critical operation; the concept of a system life cycle, with stages from conceptual formulation to operation;[9] and the concept of interrelationships and interfaces of systems and subsystems, leading to a rationality of decentralization of effort in highly complex enterprises.[10,11]

Reliability analysis and maintainability analysis are additional examples of aerospace management concepts whose wide applicability is evident. These concepts preceded aerospace, although in very crude form. What aerospace contributed was a high degree of sophistication--statistical validity, probabilistic measurements, and above all a recognition that they must be considered in the early conceptual stages rather than during late development or production stages of a program.

Planning Contributions

The contributions of aerospace to management planning include:

- systems design
- computer-aided design
- systems engineering
- PPBS (Planning/Programming/Budgeting System)
- simulation and modeling
- heuristics in decision theory
- synectics

Systems design and engineering, which are philosophic extensions of the systems analysis concept, are technically as applicable as is systems analysis to the design and engineering of complex systems in other sectors. However, there are important practical barriers, largely economic, to the transferability of these techniques. Systems design and engineering require the dedication of specially-trained personnel and an elaborately sophisticated technology of management. Prodigious and costly efforts are required to maintain a true project management system (an essential prerequisite), to assure subsystem combinations that balance and mesh, and to accomplish physical system integration. Such achievements are not routine, nor should they be attempted for development and production of products of only moderate complexity. Systems design and engineering are essential for such complex efforts as a major innovation in urban transportation systems, for the next-stage communications instrument, or for advances in medical electronics. However, it would seem to be an unwise allocation of resources to apply our scarce systems design/engineering talent to modifying or optimizing a typical consumer product, even if it could be afforded.

There are several less-complex aerospace planning contributions that have wider applicability. One example is computer-aided design. On its face a technical rather than a management contribution, nevertheless it has potentially great impact on management planning of R & D. This innovation also causes changes in the behavioral response of traditionally-trained design engineers, requiring modification of the supervisory patterns of engineering managers.

Simulation or model-building, and specifically computer simulation, have reached their current state of development in large part because of the challenge of aerospace programs. Work has proceeded in other sectors, of course, and in universities (here often supported by an aerospace relationship), but the participation of aerospace has been significant. Many examples could be cited of the current transfer of computer simulation technology to other sectors, such as business.

In recent analyses of technology transfer, the Denver Research Institute traced examples of cross-sector transfer of a NASA-supported statistical technique involving a mathematical model for long-range planning of manpower requirements.[12] Thus far, examples have been found of direct application of this technique by a leading midwest chemical manufacturer and by a large, integrated petroleum company's corporate R & D laboratory.

Few aerospace-related management contributions have greater potential applicability than computer simulation technology. In a single area of current interest, urban research, a RAND staff member recently identified the following applications: simulating voter behavior to determine successful campaign strategies in national elections and local policy referendums; simulating actual governmental decision processes in allocating resources and balancing budgets; simulating urban development and planning of activities and land uses; forecasting and conducting experiments on metropolitan transportation and traffic problems; and forecasting changes in shares of various economic activities within a territorial subdivision, to plan growth trends in employment, population and economic markets.[13]

Certain identified aerospace management technology transfers are purely imitative, although a considerable degree of imagination sometimes is necessary to recognize their applicability. The Planning/Programming/Budgeting System (PPBS) is being extended by direct imitation from the aerospace-related to the more traditional departments of the Federal Government, as a method for planning and control of operations. However, despite the recognized great promise of PPBS as a tool for allocating limited resources among less-limited demands, there has not been widespread transfer of the concept. A recent study[3] found that PPBS transfer has been very slow into state and local governments. Except for the Federal Government's interest and that of the State of New York, which began PPBS implementation in 1965, only a limited demonstration effort has been initiated by the Ford Foundation. Unexpectedly, considering the aerospace contributions to PPBS, evidently no defense firms have participated in any PPBS work in civil government. Hypothetically, some institutional barriers may exist to the transfer of such a sophisticated system as PPBS to a less complex environment than that of the Federal Government, despite the theoretical promise of PPBS to others. Alternatively, typical aerospace firms may not have developed the marketing capability to profitably exploit such prospects.

Several techniques that are heavily utilized for planning and decision making in complex enterprises (notably aerospace) have potential for transfer. One of these is heuristics, the use of instinctive judgments or rules of thumb to reduce problem-solving complexity, which has been developed to simplify complex management decision-making techniques. Heuristics often is used in combination with computer programs, in an approach to artificial intelligence. Already proven in some industrial applications (e.g., balancing assembly lines, production scheduling of large projects), heuristic techniques appear suitable for solving certain engineering design problems and even for selecting stock portfolios.[14]

Administrative Methods

The category of administrative methods includes the greatest number and variety of aerospace contributions to management. The category involves an extensive list of techniques, including:

- the use of government/private corporations (e.g., Comsat) as a management device
- project management and subcontract management techniques
- systems integration
- matrix organization structure
- configuration management
- logistics management
- activation of remote operational/facility systems
- retrofit and modification activities
- value engineering
- information acquisition and retrieval
- management reporting and display techniques
- incentive contracting
- contract negotiation, renegotiation and administration
- PERT/Time, PERT/Cost, CPM, network analysis

Probably the most widespread management transfer has occurred with project scheduling techniques based on PERT or Critical Path Method (CPM). The General Electric Company, which was introduced to PERT on the Polaris Program, adopted either PERT or CPM in all of its divisions several years ago.[15] Improvements and extensions of PERT and CPM still are being developed, as the technique is being cultivated more intensively through transfer to new industrial sectors.

One example of transfer of a PERT-related technique is both timely and of local interest. It involves the Vis-a-Plan technique developed at the Kennedy Space Center by Nathan Ranck of Trans World Airlines.[16] This technique supplements a PERT logic diagram by graphically portraying status in a series of horizontal bars representing true time scales, as readily understandable as a Gantt chart. Since the announcement of Vis-a-Plan in 1967, it has been fully implemented as a control tool at the Owens-Illinois Consumer and Technical Products Division, Toledo, Ohio, and at the Aero/Hydrospace Division of Scott Aviation, Lancaster, New York. The technique, in modified form, currently is being used to control an extensive interdisciplinary research program at the University of Denver.

Another computer-related PERT technique, developed at NASA's Lewis Research Center to monitor actual costs versus allocated costs,[17] similarly has been traced to use in planning programs of the University of Indiana, as well as at a major aerospace manufacturer.

As still another example of follow-on improvement of PERT, NASA's COSMIC Computer Center at the University of Georgia last summer announced a computer program used with a PERT-oriented system which calculates an index of overall schedule effectiveness as a measure of organizational performance and allegedly develops a statistically reliable prediction of future schedule performance.[18]

It is evident that several new methodological techniques developed by aerospace to manage large-scale enterprises appear to have potentially useful applications in the management of other massively complex enterprises, in both public and private sectors. For example, advanced elements of the U. S. shipbuilding industry have abandoned the traditional fixed-position production layout and have substituted a method using assembly stations, similar to that of an airframe/missile manufacturer, to maximize integration of production and design. Standardization and simplification are combined with transferred aerospace techniques in an effort to improve U. S. shipbuilding productivity.[19] An executive of a leading U. S. shipbuilding firm (a division of Litton Industries) recently wrote: "The new shipyard, which we call a ship-manufacturing facility, . . . is designed and structured around the systems engineering approach. What we are in fact doing is transplanting known technology from other American industry, such as Aerospace. . . , to the shipbuilding industry."[20]

Configuration control, whose intricate techniques were pioneered in aerospace, is the basis for the expected next revolution in production management: modular production. This concept will utilize advanced production controls for scheduling, inventory management, and quality control to permit adaptive automation capable of producing unique consumer products at no sacrifice of volume or interest in cost.[21]

Another, substantially different, application of configuration control concepts was described at this Congress two years ago. This is the extension of hardware configuration control procedures to use in the production of computer programs. This analogous transfer promotes more effective management control over changes to the program specification and the program itself, and over maintenance of the program's supporting documents.[22]

Even organizational theory has been affected by aerospace innovation. The matrix organization concept, which evidently was developed several years ago in the aerospace sector,[23] is now widely used by complex R & D establishments such as the Lawrence Radiation Laboratory of the University of California, Livermore. The matrix is an organizational form which combines direction from two lines of authority: a project line and a functional line. This form of organization provides a focus of attention on program objectives by creating a project director, yet assures that functional authority is maintained over the work standards. The matrix also provides organizational flexibility in adjusting to new situations and program demands, and is considered especially appropriate to training, development, and research activities.[24]

Evaluation Methods

The category of aerospace-related evaluation methods is considered to include:

technical evaluation
environmental impact analysis
quality assurance
evaluation of facility locations

The problem of selecting locations for industrial plants or research facilities is a problem applicable to a wide variety of organizations, yet it is one that few organizations engage in often enough to gain expertise. Frequently, site selection depends on subjective assessment of competitive promotional proposals prepared by chambers of commerce or utility suppliers. However, last year an aerospace firm developed an unusual methodological technique for objective site selection of a technologically-specialized facility.[25] This technique involved a methodical search of all potential sites, each graded numerically according to preselected criteria. The result was an identification of a relatively few top-ranking candidate sites which could be separately evaluated as to final preference. This method shows promise as a basis for a quantitative evaluation technique for general site selection.

Probably the least widely understood of the evaluation methods is environmental impact analysis. This analytical technique is used to measure the social and ecological impact of technical change on environment. It can be extended broadly to encompass many physical-science aspects of change, can be limited to a single aspect, or can be used in analogy (the most common being economic impact analysis). For example, environmental impact analysis can be used to measure the effect of the supersonic transport on the balance of payments, on the fishery catch (from shock wave disturbance), on land values along air routes and near air terminals, and a host of other impacted areas of the environment.

Economic impact analysis is believed to have its origin in Leontief's input-output research, sponsored in part by the U. S. Air Force.[26,27] In 1963, the President formed an interdepartmental committee to study economic impact of defense and disarmament, and in 1964, the Office of the Secretary of Defense initiated a series of studies of the impact of defense programs on various industries and geographic areas.[28] As a result of this program, economic impact analysis received a significant stimulus. A considerable expertise has grown within aerospace to conduct such studies, involving such firms as Research Analysis Corporation and C-E-I-R, Inc. Certain other studies have been contracted outside aerospace, thus accelerating a technological transfer. For example, the Navy Bureau of Yards and Docks contracted with Princeton University,[29] and ACDA with the State of Washington Employment Security Department.[30]

Such technological skill dissemination already has shown results--the application of economic impact analysis to complex technological interrelationships of non-aerospace sectors. A 1965 study described several such applications: the geographical impact of Bureau of Reclamation expenditures throughout the U. S.; the impact of farm price support subsidy programs; and the impact of veterans' compensation payments on economic regions.[31] It seems certain that economic and environmental impact analysis techniques will become substantially more common in years ahead, as it is shown that impacts of foreseeable technological developments on personal and business life can be predicted with accuracy.

Conclusions

The continual and critical time pressure that pervades aerospace activity and requires frequent time-economizing decisions appears to be the significant stimulus which causes aerospace influence in management innovation, quite disproportionate to its relative size as an economic sector. The innovative management contributions of aerospace are less widely recognized than physical science contributions. Nevertheless, these management contributions are widespread and have helped promote a trend in management theory and practice away from the traditional management-as-an-art toward the quantitative management-as-a-science.

For analytical purposes, aerospace management contributions can be arbitrarily classified into four categories: conceptual, planning-oriented, administrative methodology and evaluation methodology. Of these, some contributions appear to have been oversold and overpublicized. For example, systems design and engineering (which are indispensable to the success of complex, large-scale programs) appear to have been mislabeled as readily-transferable techniques suitable for a variety of commercial production items. In truth (if the terms are used accurately), systems design and engineering skills are quite expensive, in short supply, and applicable only to complex and significant areas of national interest rather than to prosaic consumer products.

Certain other aerospace management methods must be considered of questionable transferability. Although they appear promising, their transfer has been unexpectedly slow. Examples of these methods are PPBS and the use of heuristics in decision-making. Quite possibly, institutional or disciplinary barriers to transfer may exist. The aerospace-defense environment is in some ways a different way of life--a different culture--from either commercial industry or many parts of non-defense governmental operations (Federal, state, and local). This difference appears to introduce institutional factors affecting the adoption of some aerospace management methods. These factors require more examination if purposeful efforts are planned to enhance the flow of aerospace management contributions to other economic sectors.

Still another category of aerospace-related management methods can be identified--those methods which have been relatively overlooked but have great promise of transferability and potentially great impact on other sectors of national activity. Examples of these are technological forecasting, systems analysis (in contrast to systems design and engineering which are outgrowths of it), computer simulation, configuration control, and environmental impact analysis.

The process of technology transfer has major significance to the economic and social aspects of national life. Research now in progress concerning the transfer of technology already has indicated that aerospace contributions to management science have been substantial.

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